INDUSTRIAL CHOCOLATE MANUFACTURE AND USE

FOURTH EDITION

EDITED BY S. T. BECKETT

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INDUSTRIAL CHOCOLATE MANUFACTURE AND USE

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INDUSTRIAL CHOCOLATE MANUFACTURE AND USE

Fourth Edition

Edited by

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CONTENTS

7 Particle Size Reduction 142

G.R. Ziegler and R. Hogg

8 Flavour Development in Cocoa and Chocolate 169

G. Ziegleder

Colour plates appear between pages 368 and 369

PREFACE

It is now nineteen years since the first edition of *Industrial Chocolate Manufacture and Use* was published and nine years since the third was written. It is therefore very gratifying to have been asked to revise it once again and I am very grateful to those authors who have once again updated their chapters. Only one of these in fact contributed to the first edition. As with every other industry, however, both people and technology change and this new edition has had ten of the chapters completely rewritten. The book has also been increased in size, by four chapters (five new topics), to give a total of twenty-nine.

One of these new ones concerns chocolate crumb, which although widely used in some markets is not often described in the literature. Cold forming technologies had previously been reviewed as a 'non-conventional' process. Over the years it has become more widely used and now merits its own chapter. With the increase in the size of production plants process control has become more important and this too is reviewed in this edition. Another new topic concerns intellectual property. A basic understanding of this can be very important for example before launching a new product to ensure that you are not infringing a process or product patent. Also how do you make sure that no one copies your packaging design? Finally, although the industry is under attack in some media as providing 'junk food' and causing obesity, the new chapter on nutrition shows that this is far from the case and chocolate is good for you!

Many of the other chapters have had a significant update. Nineteen years ago most companies used a few basic recipes, but now the choice is endless and a rewrite of the chapter on this topic shows some of the possibilities. Failure to make a product safely can have a serious effect not only upon the consumer, but also upon the industry itself. The chapter on microbiology has therefore been rewritten and widened to include a lot of other aspects of food safety.

It is hoped that the book will continue to provide an up-to-date scientific and technical approach to the principles of chocolate manufacture, from the growing of the cocoa beans to the packaging and marketing of the final product. As the processes become larger and more complex, the aim is to give the reader the principles behind them in a practical and readable form. As with any multi-author book there are some repetitions, and indeed some apparent contradictions are present. These have been deliberately left as each author has written according to his or her own experience. They are also an indication that our knowledge remains incomplete and that there is still a lot for researchers into cocoa and its products to do. Mistakes still occur however and I would welcome readers informing me of them. Two letters in fact resulted in entries in the new edition. Some time ago I was told that I was incorrect in saying that Daniel Peter invented milk chocolate. This resulted in me going to the Nestlé archives in Switzerland and finding his original notebook, a page from which is reproduced in Chapter 1. Secondly a competitor complained that the measurement of thermal conductivity was incorrect. The source of the original entry was traced and admitted that he hadn't measured it himself. In the end the measurements were made by Leatherhead Food International (UK) and have been included in the table of physical constants.

I would once again like to thank all the authors who have contributed to the book for the care they have taken and the time they have spent in producing their chapters. Even revising an original chapter can take a considerable effort in confirming new information, updating references, etc. There cannot be many industries where people from competing companies and different continents come together to produce a book. The wide range of knowledge and experience of the different authors has greatly added to its usefulness to people within chocolate making and has resulted in the first three editions being present in factories in Asia, Africa and South America, as well as in those countries in which it was written.

It is sometimes said that the worldwide web will remove the necessity for books. I certainly hope that this is not the case and have not always found the web to be as reliable as you might expect. The website of one major international company proudly announced that its chocolate was processed in a sea shell, which I very much doubt and suspect the author's miss-use of a thesaurus on the word conche. An on-line encyclopaedia on the other hand informed me that most cocoa butter is made by hanging up sacks of nibs in a warm room, so that the fat runs out. I hope that readers will find this book to be much more reliable.

I would also like to thank my family for their help with the figures and indexing and for putting up with me spending most of my free time on it, and the publisher for giving me the opportunity and encouragement to produce a new edition.

My sincere gratitude to Maxine Keeping of Nestlé PTC, York for her help and advice in preparing the references for several authors.

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STB

CONTRIBUTORS

Stephen T. Beckett, B.Sc. (Durham), D.Phil. (York, UK) in physics, worked for 8 years on research into asbestosis. The interest gained here in particle size distribution measurement, together with its effect on flow properties, continued into the confectionery industry. Here he worked for more than 27 years, initially for Rowntree Mackintosh and subsequently with Nestlé. The work has primarily been concerned with research and development, but also included a period as Process Development Manager. He has given several lectures on different aspects of chocolate making at Leatherhead Food International in the UK and the German Confectionery College (ZDS), Solingen, as well as two presentations at both the PMCA conference in the USA and the CMA conference in Australia. He has written a book on the science of chocolate and has several published papers on this topic and is the named inventor on more than six confectionery patents. Currently he is chairman of the ZDS Chocolate Technology Conference Committee.

Marcel Aebi is a classically trained confectioner – patissiere from Switzerland. After several years travelling around the world working in the confectionery industry, he joined Nestlé in 1978. For the last 20 years he has worked in the area of New Product Development and Process Application in panning, both in Europe and America. He is currently based at Nestlé R&D in Marysville, Ohio, USA.

Faith Burndred has a B.Sc. in chemistry from The University of York, UK. She joined Nestlé in 1992 and since then has held a variety of technical roles supporting the confectionery business, including factory quality management. She is currently a QA specialist in the Nestlé Product Technology Centre in York, supporting confectionery factories worldwide in food safety matters.

Patrick J. Couzens joined Nestlé's confectionery business in 1991 after obtaining a D.Phil. in physical chemistry from the University of York. For the first few years he worked as a research scientist and has published studies of lipid migration in confectionery products. He then moved into product development, specializing in panned confectionery. In 2005 he presented a lecture on the science of chocolate at the Royal Institution in London. Since

2002 he has worked in the field of intellectual asset management and is currently Technical Intellectual Property Manager for Nestlé Confectionery.

Tracey M. Dodds has a degree in food technology from Massey University in New Zealand. She has worked for Fonterra and legacy companies for 20 years. She has been involved in both strategic research and product development of dairy ingredients for confectionery and cheese applications. She is currently a project manager at Fonterra's innovation site in Palmerston North.

Mark S. Fowler studied at the University of Oxford where he obtained a degree in zoology. He joined Rowntree in 1977 and spent several years forecasting the size of the West African cocoa crop. He participated in a cocoa quality improvement project working directly with cocoa farmers in Côte d'Ivoire. After a period of time spent in technical management in confectionery factories, he joined Nestlé's Product Technology Centre in York, UK. Here he has been responsible for the Cocoa & Chocolate research & development programme and he now heads the Applied Science department.

Mike P. Gray graduated as an industrial chemist from Loughborough in 1970, followed by an M.Sc. in microbial biochemistry from Imperial College, London. He started with Cadbury Schweppes R&D in 1972 working on milk powders, and moved to Rowntree Mackintosh in 1979, spending 15 years in a general confectionery factory, both troubleshooting and seeking ways of making chocolate more efficiently. He joined Nestlé's central R&D in York in 1988 following 3 years in France working on ice creams and ice cream coatings. He is now mainly involved with technical assistance concerning chocolate making and use.

Steve J. Haylock has a Ph.D. in chemistry from Massey University. He has worked for Fonterra and legacy companies for 25 years. He has worked in a variety of applied research areas targeting the utilization of dairy ingredients in food products and more recently the development of new consumer products. He currently manages the Food Processing Team for Fonterra Brands in Palmerston North, New Zealand.

Richard Hogg is chairman of the GeoEnvironmental Engineering Programme at Pennsylvania State University in the USA and is a member of the Society for Mining, Metallurgy and Exploration, the American Filtration Society and the Fine Particle Society. He has contributed articles on particle technology, particle characterization and colloid science in *The International Journal of Mineral Processing, Minerals and Metallurgical Processing* and in *Powder Technology.*

Carl E. Jones joined Nestlé Research & Development in 1987 where he was trained as a food technologist before completing the Institute of Packaging diploma in 1990. Since joining Nestlé he has worked on packaging projects in the UK for culinary R&D, in Sweden for frozen food R&D, in Hungary on beverage, culinary and confectionery projects. Carl has worked in the Nestlé Product Technology Centre in York since 1992 working on confectionery packaging for R&D projects in addition to providing packaging technical assistance to many Nestlé confectionery markets around the world. Since 2002 he has travelled the Nestlé confectionery world as part of a multi-disciplined team identifying optimization and efficiency opportunities in confectionery manufacturing sites including packaging materials and wrapping operations.

Henri J. Kamphuis (M.Sc. and Ph.D.) studied food technology at Wageningen Agricultural University, Wageningen (The Netherlands). Having obtained a doctorate he joined Gerkens Cacao BV, a Cargill Foods company in 1992 and worked for 15 years within the quality and application department. Currently he is director quality, food safety and technical service within Cargill Cocoa.

Christof Krüger studied chemistry and sugar technology at the Braunschweig Institute of Technology. After his graduation as 'Diplom-Chemiker' (M.Sc.), he worked in German sugar companies and was the first applications manager in the German sugar industry. Concurrently with this function he was also senior manager of a company producing caramel colours and sugar syrups and was involved in the commercial and technical planning of a new liquid sugar plant. For seven years, he was chief chemist at Rowntree Mackintosh, Hamburg, where his responsibilities included management of the laboratories, quality control, product development and the sensory department. He also worked actively on the committee for food law and on the scientific committee of the Association of the German Confectionery and Chocolate Industry, by which association he was commissioned to serve as research representative on the confectionery section.

Since 1986, Christof Krüger has worked for the Finnish Cultor group, formerly Finnish Sugar Corporation. He began as technical applications manager at Finnsugar Xyrofin, became technical director of Xyrofin GmbH and since 1996 has been vice president for Technical Applications of Cultor Food Science GmbH in Hamburg. In this capacity, he advises customers in the food industry, and especially in the confectionery and chocolate industry worldwide, in the use of various bulk sweeteners. He frequently presents papers and acts as moderator at international symposia at the Central College of the German Confectionery Trade (ZDS) at Solingen.

Janet P. Lambert (Ph.D.) graduated in nutrition, with dietetics, at the University of Surrey, UK and spent over 15 years working as a dietitian and nutritionist in the health service and higher education before joining the food industry. She was the senior nutrition adviser for the Meat and Livestock Commission in the UK and, in 1992, joined Masterfoods as their nutrition manager for Europe. Since 2001, she has been an independent consultant and is the director of Lambert Nutrition Consultancy Ltd. She is currently a nutrition consultant to the UK Biscuit, Cake, Chocolate and Confectionery Association. She is a registered public health nutritionist, registered dietitian and an accredited sports dietitian.

Ulrich Löser was awarded a Ph.D. degree in food engineering at Dresden University of Technology and is currently principal scientist WW Chocolate Process Development at Kraft Foods R&D Inc. in Munich, Germany. In 1976, during his last year of study in chemical engineering for food material, he worked on a number of aspects of chocolate technology. In 1990, after seven years at the Plant Engineering and Construction Department of Maschinenfabrik Heidenau (a machine manufacturer), he joined Jacobs Suchard, Operations Plant Loerrach, Germany. While with Kraft, his career has moved from plant management and ISO systems implementation to technical engineering support, developing novel analytical methods and processes. Ulrich transferred into the R&D team in 1996 and has championed the use of digital analysis/process control at human–machine interface. He has co-authored two chapters in *Grundzüge der Lebensmitteltechnik*, 3rd edition, published by BEHR's Verlag, 2004, and is a member of the Solingen Confectionery School's (ZDS) steering committee for the international congress 'Chocolate Technology'.

Andrea Martinez-Inchausti joined the British Retail Consortium, the trade association representing retailers, in November 2005 as assistant director of the Food Policy team. Andrea's areas of responsibility include: Allergens, ambient stable foods, compositional standards, dairy, food surveillance, hygiene, microbiology, labelling and nutrition. She previously worked at Leatherhead Food International, where she was responsible for assessing technical regulatory issues in number of markets across the globe. Prior to this Andrea trained as a veterinarian has worked in gaining regulatory approvals for food, healthcare and cosmetic products.

Edward Minson is currently flavours sales manager with Eskimo Pie Corporation in New Berlin, Wisconsin, USA. He has held various research and development management positions with Grace Cocoa/Ambrosia Chocolate and was a research chemist at Ralston Purina Company. He holds an M.S. in food science from the University of Wisconsin, a B.S. in food science from the University of Massachusetts and an M.B.A. from Marquette University.

Geoff Talbot (B.Sc., MRSC, C. Chem) spent more than 20 years with Unilever Research in Welwyn and Colworth House studying the use of speciality fats in confectionery applications. Much of this research was directed at the use of cocoa butter equivalents and covered processing, mathematical blend optimization techniques and application in chocolate and coatings.

He then joined Loders Croklaan as senior applications and technical service manager responsible for customer development work in the UK, Ireland, South Korea, Turkey and Nordic countries. During this time he was also responsible for research and development into fat bloom inhibitors and moisture migration barriers which resulted in the products Prestine™ and Cotebar™ winning the titles of 'Most Innovative Food Ingredient'. In 2003 he formed his own consultancy, The Fat Consultant and he now trains and advises clients on the best choice and application of fats in a wide variety of food products. A significant proportion of this is in the areas of replacement of hydrogenated and saturated fats in foods. He writes and lectures widely and is the author of *Application of Fats in Confectionery*, published by Kennedy's Publications (2006).

John H. Walker has over 30 years experience in the confectionery industry. He began work as a drawing office apprenticeship with the packaging machinery manufacturer Rose Forgrove Ltd in 1967 and moved to Rowntree Mackintosh in 1977. Between 1977 and 1986 he worked on the design of a variety of special purpose machines used in the company's confectionery and grocery businesses. In 1986 he moved to the Castleford (UK) factory to take the position of project engineer where he was involved in the manufacture of an international brand of boxed mint chocolates. Since 1992 he has worked in the Nestlé Product Technology Centre in York (UK) where he is currently the head of the Engineering Department. He is the inventor on several patents for the design of equipment now being used for the manufacture of confectionery throughout the world.

Mike J. Webber graduated from Birmingham University (UK) and joined Cadbury Brothers Ltd (as it then was) where he worked for four years in the work study department at the Somerdale factory. After leaving Cadbury, Mike worked in the paper industry and then for eleven years in the handmade glass industry as a production manager and as a training manager. This was followed by two years personnel and training management for a department store group. In 1982 Mike joined the Cocoa Chocolate & Confectionery Alliance (now the Biscuit Cake Chocolate & Confectionery Association) as national training manager. Subsequent roles included scientific & regulatory manager and, for the final four years of his career, director general of the Association.

Martin A. Wells, M.A. (Oxon) in chemistry worked for 17 years in Unilever Research, Port Sunlight, most of that time on the development and understanding of fabric conditioners. The experience gained there on colloid science and rheology developed further when he moved to Cadbury Ltd, Bournville in 1985. He was initially involved in the development of novel chocolate making processes and was later responsible for scientific services to the company. He has given lectures on chocolate rheology and crumb making at Leatherhead Food International in the UK and for ZDS Soligen in Germany. Following retirement in 2004 he has acted as a chocolate consultant.

Erich J. Windhab (Prof. Dr.-Ing.) graduated in chemical engineering at the University of Karlsruhe and then obtained a Ph.D. at the Institute of Mechanical Engineering and Applied Mechanics (TU Karlsruhe). Following research at Berkeley University (CA, USA) and TU Munich (D) he joined The German Institute of Food Engineering DIL (Quakenbrück/Osnabrück), becoming the vice director in 1985. During this period he built his own engineering company (LTG Karlsruhe; process plant design/optimization) and also lectured in fluid dynamics/rheology at the University of Munich. Since 1992 he has been professor for food process engineering at The Swiss Federal Institute of Technology, Zürich (ETH) and head of Laboratory of Food Process Engineering. He has published about 200 reviewed papers and more than 60 patents and is a member of many committees including: President of Swiss Rheology Group/Polymer Society, Chairman of Codex Alimentarius CCPC (WHO/FAO), Director of Swiss Competence Centre of Rheology (SRC), Member of European Academy of Sciences, Member of Steering Board of the Material Research Center, ETHZ (Switzerland) and Member of Expert Commission of Swiss Commission for Innovation and Technology (CTI, Bern). Recently he had received the 2003 European Food Technology Award, the 2004 Blaise Pascal Medal (European Academy of Sciences) and the 2005 International Nestlé Innovation Award.

Edward G. Wohlmuth was born and educated in Austria and moved to London in 1952 where he became a pastry chef (French/Austrian style) with training in England, Germany and Austria. In 1972 he moved to Caxton London Chocolate company where he was production manager and then the technical services application manager. He maintained this position with Steward & Arnold Chocolate Company, High Wycombe, then Lesme and Barry Callebaut UK, making technical visits to Europe, Middle East, China, Asia Pacific, including Japan, Australia, NZ, India, Pakistan, Bangladesh, Canada and the USA. After retiring from this company he started Wohlmuth Chocolate Consultancy, based in London, UK.

Gottfried Ziegleder ((Dr. Dr.-Ing.)), chemist (University Munich, Germany) and engineer in food technology (Technical University Munich), has 30 years of experience in chocolate technology. Since 1977 he has worked at the Fraunhofer Institute of Processing and Packaging (Fraunhofer IVV, Freising, Germany, the former Fraunhofer ILV, Munich), from 1990 as head of the Food Technology Department, and currently as deputy director. The main fields of his R&D activities are in general food sciences, specializing in cocoa and chocolate flavour and flavour precursors, roasting and conching, tempering and crystallization of chocolate, rheology and new forming techniques, milk chocolates and amorphous lactose, oil migration and bloom development, the shelf life of chocolates and pralines, the influence of light on packaged food and the application of innovative concepts for food packaging. He has published more than 120 scientific papers in these areas, and has developed several analytical methods for the evaluation of raw materials and for the rapid control of production processes. A central part of his work is the close cooperation with the industrial working group 'Chocolate Technology' of the Industrial Organization of Food Technology and Packaging (IVLV), Munich (Germany), which internationally carries out pre-competitive and applied research for the chocolate industry and machinery manufacturers. In addition, he teaches students at the Technical University Munich and the University of Applied Sciences Weihenstephan. For many years he has been a member of the organization committee and invited lecturer at the international seminar on chocolate technology in Cologne, organized by the Central College of the German Confectionery Industry (ZDS) Solingen.

Gregory R. Ziegler obtained his B.S. in food science from Pennsylvania State University (USA) (1980), an M.S. in food science from Clemson University (1982) and a Ph.D. in food engineering from Cornell University (1988). He joined the faculty in the Department of Food Science at Pennsylvania State University in 1988 and currently holds the rank of professor. He has industrial experience in product and process R&D with H.J. Heinz. His current research focuses on the physical properties of polymeric and particulate foods, with an emphasis on chocolate and confectionery products. He has numerous publications related to confectionery and has presented his papers at Schoko-Technik (Germany) and the PMCA Production Conference.

Plate 1 The small pods or cherelles grow directly from the trunk and main branches.

Plate 2 Open cocoa pods showing beans covered in pulp.

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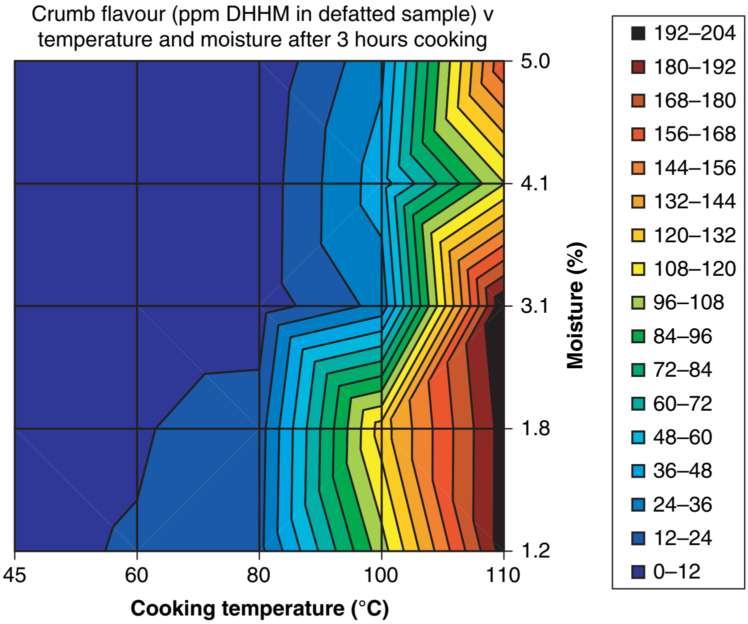


Plate 3 DHHM formation during crumb manufacture after 3 hours cooking.

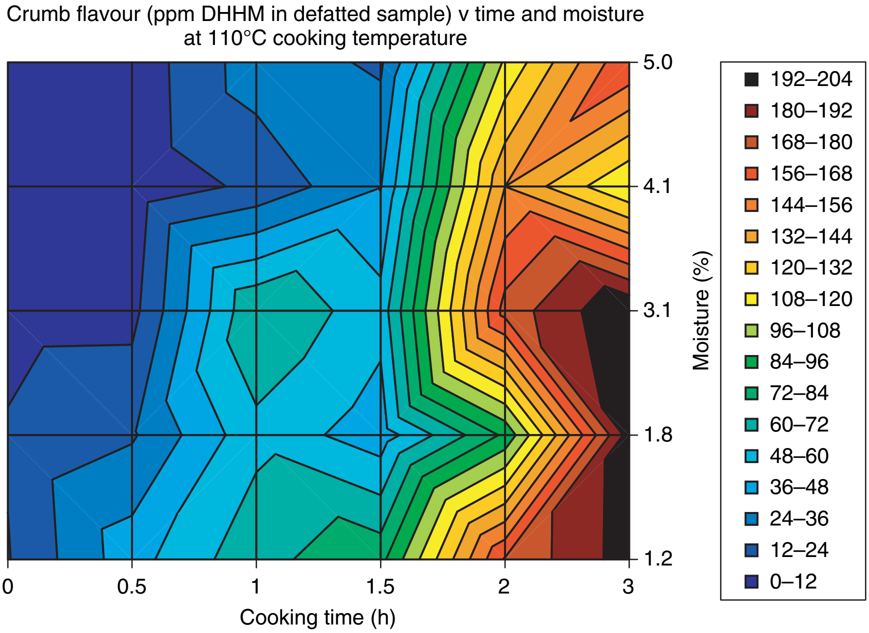


Plate 4 Effect of cooking time and temperature on the production of the flavour volatile DHHM.

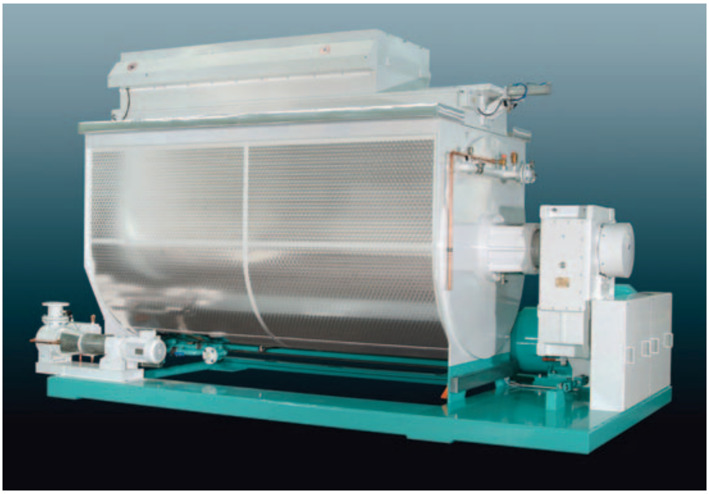
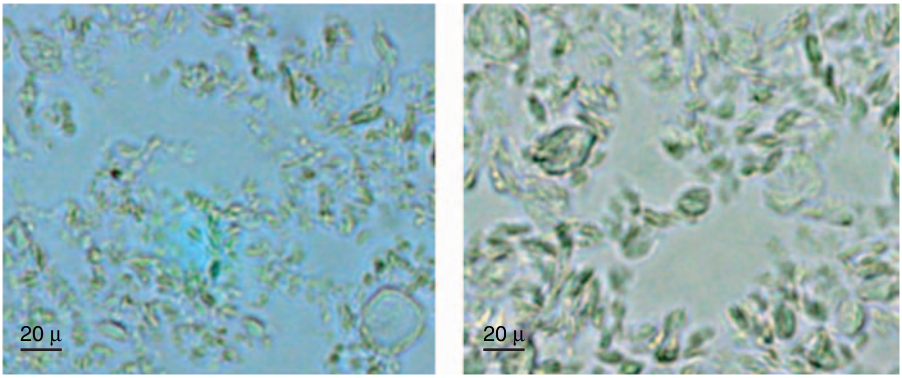


Plate 5 Frisse ELK conche.

Plate 6 Chocolate with ‘foot’ due to incorrect viscosity (reproduced from Beckett, 2000).



SeedMaster compact B

SeedMaster cryst/Mix A

Plate 7 Cocoa butter seed crystals in seed suspensions produced with set-up B (SeedMaster Compact (®Bühler AG)) and set-up A (SeedMaster Cryst/Mix (®Bühler AG)).

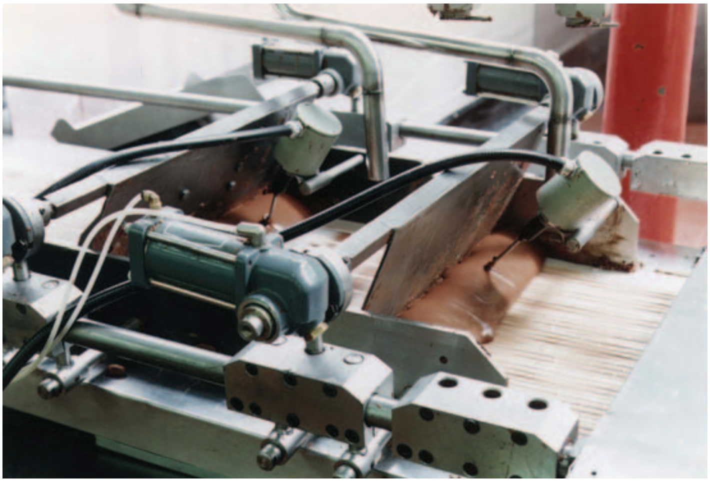


Plate 8 Flood backing off.

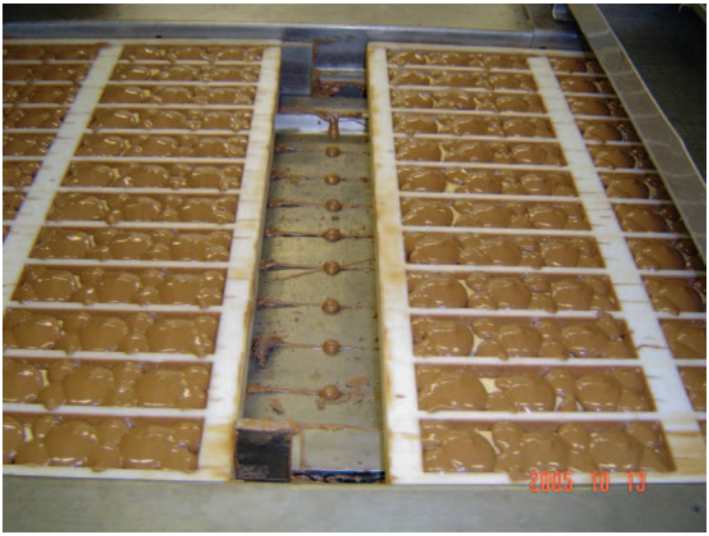


Plate 9 Deposit backing off.

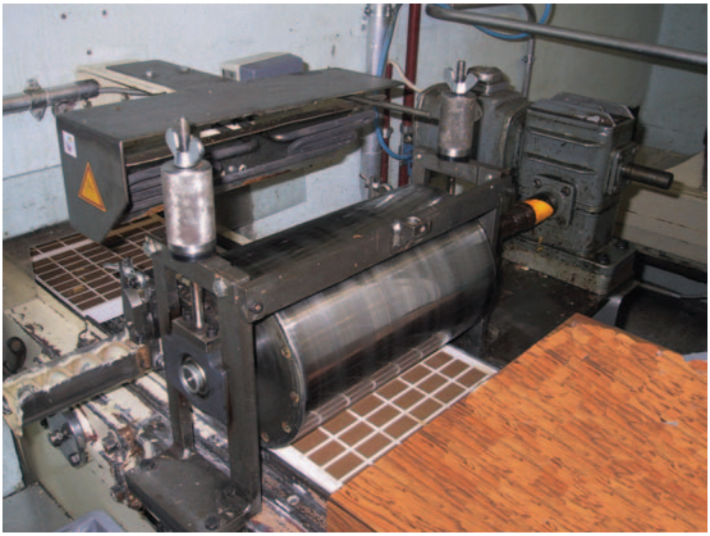


Plate 10 Licking roller.

Plate 11 Drop moulding production plant.

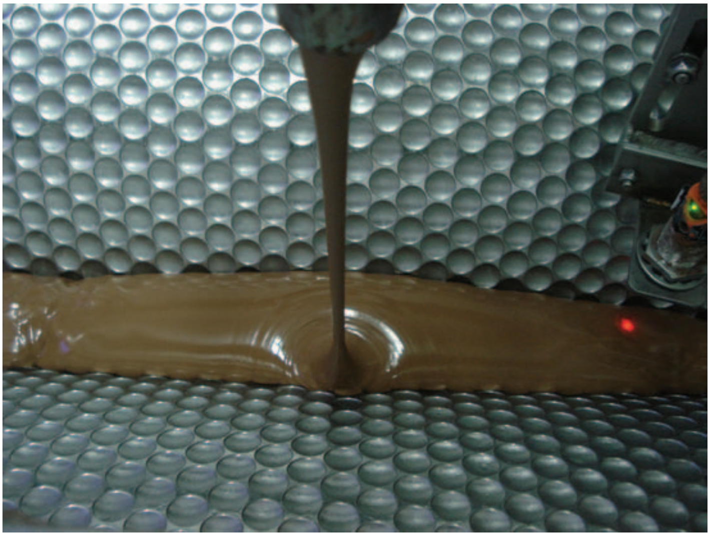


Plate 12 Dragee moulding plant.

Plate 13 Meniscus on a chocolate bar.

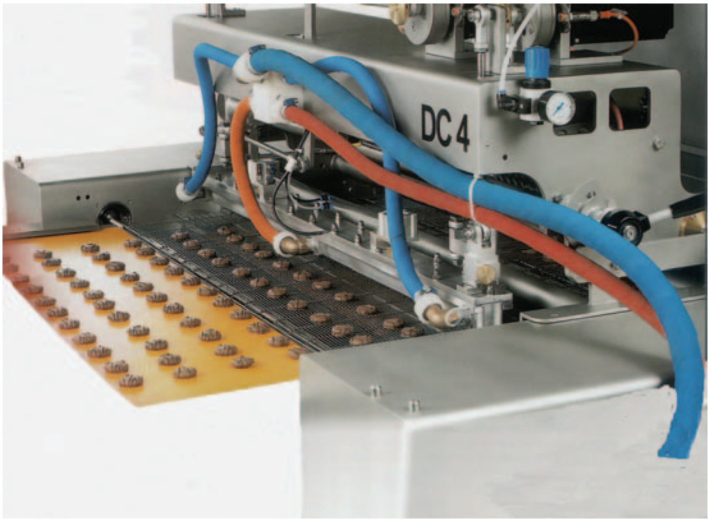


Plate 14 Decorating machine.

Plate 15 Chocolates with different shapes and colours made with single deposit (Aasted-Mikroverk, Denmark).

Plate 16 Robot loading complete boxes using the ChocoAssort™ system (Aasted-Mikroverk, Denmark).

Plate 17 Chocolate products with two components in the centre and shell. Reproduced with permission of Awema A.G., Switzerland.

Plate 18 Different sizes of bubbles in aerated chocolate.

Plate 19 Some examples of foreign materials. Reproduced with permission of Paul Davies

Plate 20 Typical foil and band tablet packaging.

Plate 21 Flow-wrapped countlines.

Plate 22 Display box.

Plate 23 Rigid plastic containers.

Plate 24 Double-ended twist wrapped sweets.

Plate 25 Single-ended twist wrapped sweets.

Plate 26 Seasonal chocolate novelties.

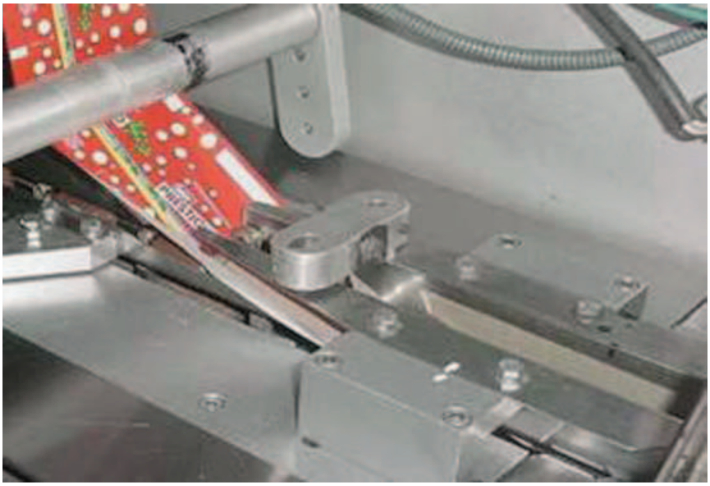


Plate 27 Folding box to produce the tube for horizontal flow wrapping.

Plate 28 Labelling on typical countline product.

Plate 29 Packaging on aerated chocolate bars (UK).

Plate 30 Wrapper of chocolate bar from Mexico.

Chapter 1

TRADITIONAL CHOCOLATE MAKING

S.T. Beckett

1.1 History

Cacao trees were cultivated by the Aztecs of Mexico long before the arrival of the Europeans. The beans were prized both for their use as a currency and for the production of a spiced drink called 'Chocolatl'. The Aztec Emperor Montezeuma is said to have drunk 50 jars or pitchers per day of this beverage, which was considered to have aphrodisiac properties, a belief still held as late as 1712, when The Spectator newspaper advised its readers to be careful how they meddled with 'romances, chocolate, novels and the like inflamers …'. The chocolate was prepared by roasting the cocoa beans in earthenware pots, before grinding them between stones. The mixture was added to cold water, often with other ingredients such as spice or honey, and whipped to a frothy consistency (Whymper, 1912).

The first cocoa beans were brought to Europe by Columbus as a curiosity, but were later exploited commercially by Don Cortez as a new drink (Minifie, 1980). The Spaniards preferred their drink sweetened, and in this form its popularity spread to Central and Northern Europe. In 1664 it was mentioned in England in Pepys' Diary, but was essentially still restricted to the wealthy. The introduction of milk into this chocolate drink was first recorded in the UK in 1727, by Nicholas Sanders (Cook, 1984), although his reasons for doing so are uncertain.

A mixture of the ground cocoa beans and sugar would not by itself produce the solid chocolate so familiar to the modern consumer. Instead it would give a very hard substance which would not be pleasant in the mouth. In order to enable it to melt easily, it is necessary to add extra fat. This can be obtained by pressing the cocoa beans and removing some of the fat content, known as cocoa butter. The ability to extract this fat was developed in 1828 by Van Houten of Holland, and had a double advantage: the expressed fat was used to make the solid chocolate bars, while the remaining lower-fat cocoa powder could still be incorporated into a drink. This 'drinking chocolate' was in fact usually preferred, as it was less rich than the original high fat mixture.

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Van Houten's development is even more remarkable when one considers that his factory and presses were entirely operated by manpower. In 1847, however, Fry, in Bristol in England, used recently developed steam engines to power the first factory to produce tablets of plain chocolate.

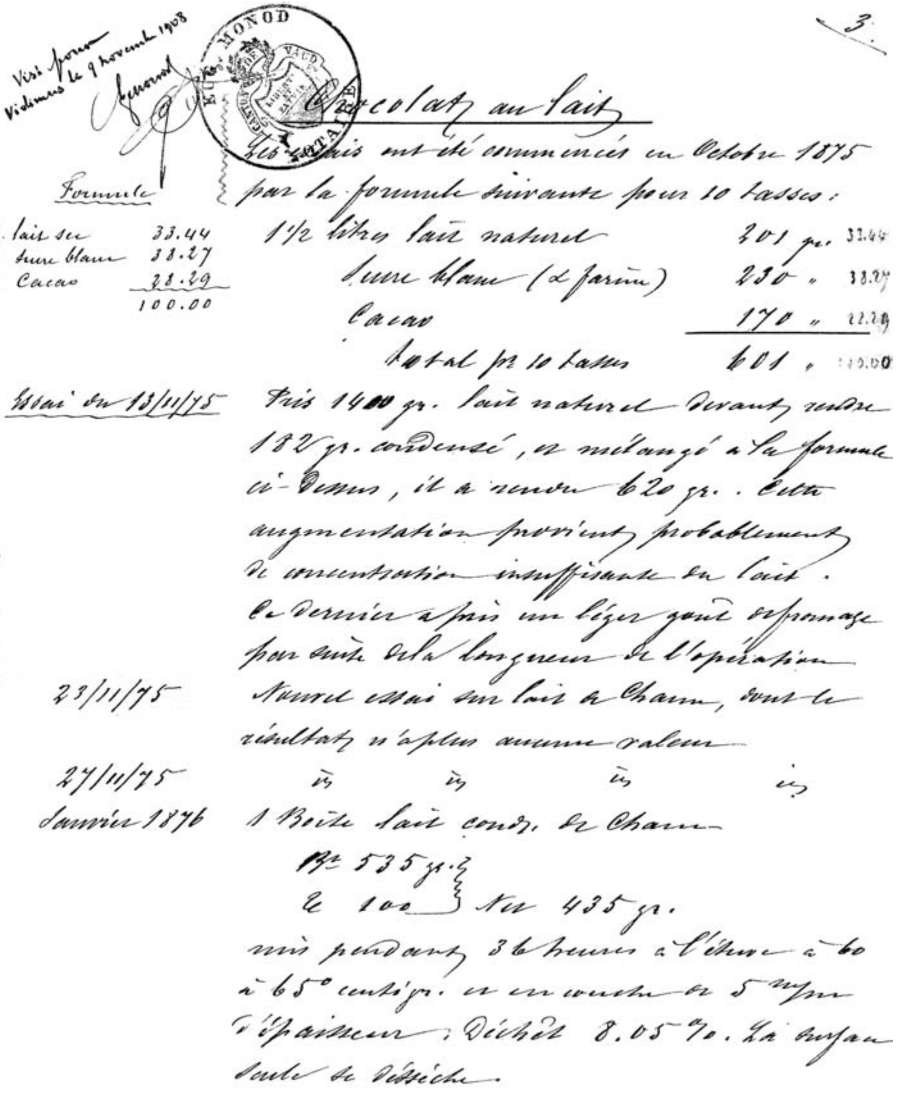
The solid form of milk chocolate is normally attributed to Daniel Peter of Vevey, Geneva, in 1875. In Switzerland, water-powered machines were able to operate for long periods at an economic rate. This enabled the extra water from the milk to be driven out of the chocolate without incurring a large extra cost. Chocolates with moisture contents roughly above 2% are normally unacceptable as they have poor keeping qualities, as well as a poor texture. The page of the notebook where he wrote his original recipe is shown in Figure 1.1. In 1908 his invention of milk chocolate was disputed, so this notebook was taken to a lawyer, who placed his stamp at the top of the page.

Over the years many different flavours of both milk and plain (dark) chocolate have been developed. Sometimes there has been a definite policy to develop a 'house' flavour within a company, for example in Cadbury's Dairy Milk, or the Hershey Bar. At other times the flavour is adjusted to complement the centre of the sweet, which is to be coated with chocolate. A very sweet centre such as a sugar fondant may be best complemented by a relatively bitter chocolate and vice versa. For milk chocolate, one of the biggest flavour differences is between the chocolates made from milk powder which are predominantly found in Continental Europe, and the 'milk crumb' ones of the UK and parts of America. Milk crumb (see Chapter 5) is obtained by dehydrating condensed milk and cocoa mass. This was developed where milk production was very seasonal. As cocoa is a natural antioxidant, it was possible to improve the keeping properties of the dehydrated form of milk over extended periods without refrigeration. The drying process also produced a distinct cooked flavour, not normally present when the milk is dried separately.

Table 1.1 summarizes some of the important dates connected with the history of cocoa and chocolate.

1.2 Outline of process

Chocolate has two major distinguishing characteristics: its flavour and its texture. Although many different flavours of chocolate exist, all must be free from objectionable tastes and yet incorporate at least some of the pleasant ones, which the consumer will associate with the product. A primary feature of the texture is that it must be solid at a normal room temperature of 20–25°C (70–75°F) and yet melt rapidly in the mouth at 37°C (98.5°F) giving a liquid which appears smooth to the tongue. The processing of chocolate is related to obtaining these two criteria, and is therefore devoted either to developing the flavour of the product – using a raw bean would produce a



Visé pour
vidimus le 9 novembre 1908

E. MONOD

3.

Chocolat au lait

Les essais ont été commencés en Octobre 1875
par la formule suivante pour 10 tasses:

Formule				
lait sec	33.44	1½ litres lait naturel	201 gr.	33.44
Sucre blanc	38.27	Sucre blanc (& farine)	230 "	38.27
Cacao	28.29	Cacao	170 "	28.29
	100.00	Total pr 10 tasses	601 "	100.00

Essai du 13/11/75 Pris 1400 gr. lait naturel devant rendre
182 gr. condensé, et mélangé à la formule
ci-dessus, il a rendu 620 gr. Cette
augmentation provient probablement
de concentration insuffisante du lait.
Ce dernier a pris un léger goût de fromage
par suite de la longueur de l'opération

23/11/75 Nouvel essai sur lait de Cham, dont le
résultat n'a plus aucune valeur

27/11/75 id id id id

Janvier 1876 1 Boîte lait cond. de Cham
Bt 535 gr.
T 100 } Net 435 gr.
mis pendant 36 heures à l'étuve à 60
à 65° centigr. et en couche de 5 mm
d'épaisseur; Déchet 8.05 %. La surface
seule se dessèche.

Figure 1.1 Page from Daniel Peter's notebook showing the original milk chocolate recipe. Reproduced with permission of NESTEC S.A., Nestlé archives, Vevey, Switzerland.

very unpleasant taste – or treating it so that it will flow properly and be free from large gritty material.

Although many different methods of chocolate-making exist, most traditional ones are based on the process outlined in Figure 1.2 and briefly described below. Further details are given in the relevant chapters of the book.

Table 1.1 Some important dates in the history of cocoa and chocolate.

1519	Cortez discovered that cocoa had been cultivated by the Aztecs more than 3000 years
1528	Cortez introduced a chocolate drink to Spain
1606	Chocolate drinking spread to Italy
1615	Chocolate drinking reaches France
1657	First chocolate house established in London
1727	Nicholas Sanders invents a milk chocolate drink
1746	First cocoa planting in Bahia
1765	First chocolate company established in North America
1828	Van Houten patents the cocoa press
1847	Fry's factory established in Bristol to produce eating chocolate
1875	Daniel Peter manufactures milk chocolate
1988	World cocoa grindings exceed 2 million metric tons

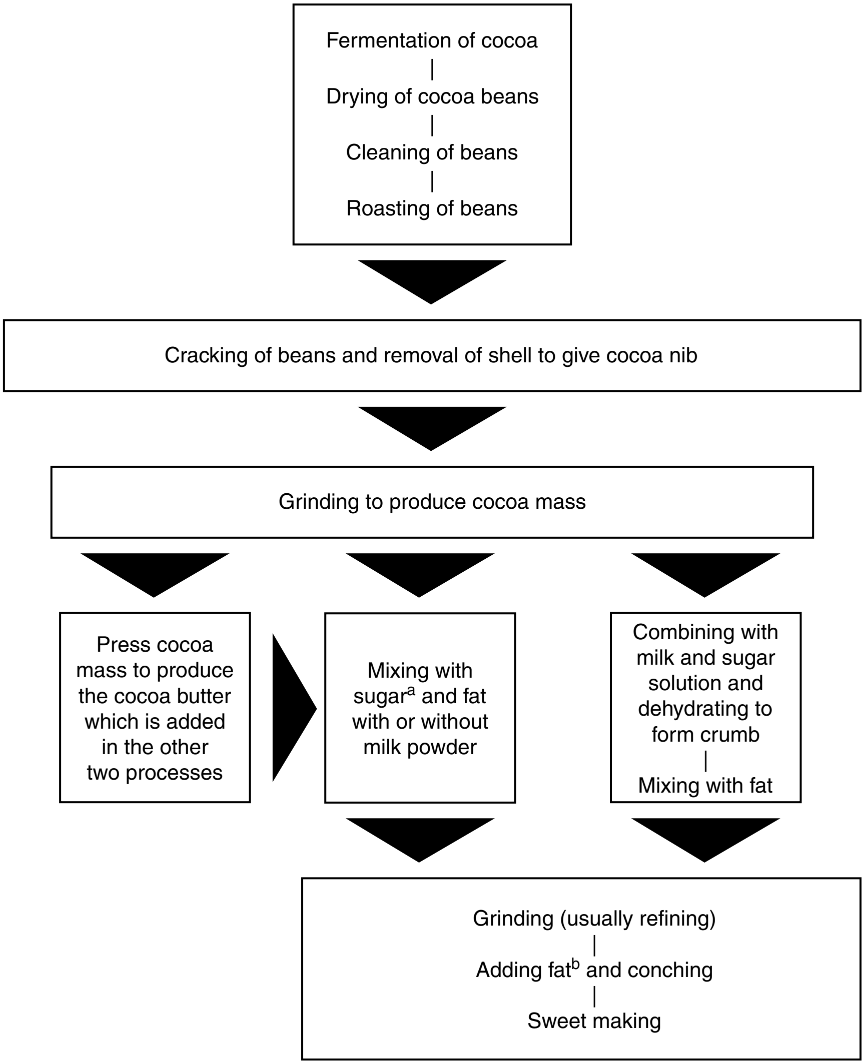
1.2.1 Preparation of cocoa nib – flavour development

The cocoa tree produces pods containing a pulp and the raw beans. The outer pod is removed together with some of the pulp and the beans are fermented. This enables chemical compounds to develop inside the beans, which are the precursors of the flavour in the final chocolate. Failure to carry out this stage properly cannot be rectified by processing at a later date. This is also true of the subsequent stage, when the fermented beans are dried. Poor control here can give rise to moulds, which give a very unpleasant-flavoured product, even if the fermentation has been carried out correctly. Similarly where beans are accidentally contaminated with smoke from a faulty drier, the resulting cocoa will be unusable. In addition, correct transport conditions are required when the beans are moved from the country of growing to that of chocolate manufacture.

On arrival in the processing factory, it is necessary to clean the beans to remove metal and stones and other extraneous material that might contaminate the product. Further flavour development is subsequently obtained by roasting the beans. This also loosens the shell round the outside of the bean, and enables them to break more easily. (Some chocolate manufacturers' prefer to heat the surface of the beans, to facilitate shell removal, and to carry out the full roasting of the cocoa bean centres, either as whole pieces or as a liquid following grinding. This is described more fully in Chapter 6.) The beans are then broken, and the relatively lighter shell particles removed by a winnowing action. The presence of shell in the final chocolate is undesirable as it will impair the flavour, as well as causing excessive wear to the subsequent grinding machine. It should also be noted that the shell content of chocolate is legally restricted in some markets. In some countries the shell itself has found a use in horticulture.

1.2.2 Grinding – particle size reduction

Up to this stage the cocoa is in discrete pieces, several millimetres in diameter. Subsequent processing may take several forms, but all require



[a] Milled or granulated
[b] Cocoa butter and/or lecithin

Figure 1.2 Schematic diagram of traditional chocolate-making process.

the solid cocoa particles, sugar and any milk solids to be broken so that they are small enough not to be detected on the tongue. The actual size depends upon the type of chocolate and the market in which it is sold, but in general the vast majority of particles must be smaller than 40 μm (0.0015 in.). The unground ingredients used to make dark chocolate are shown in Figure 1.3.

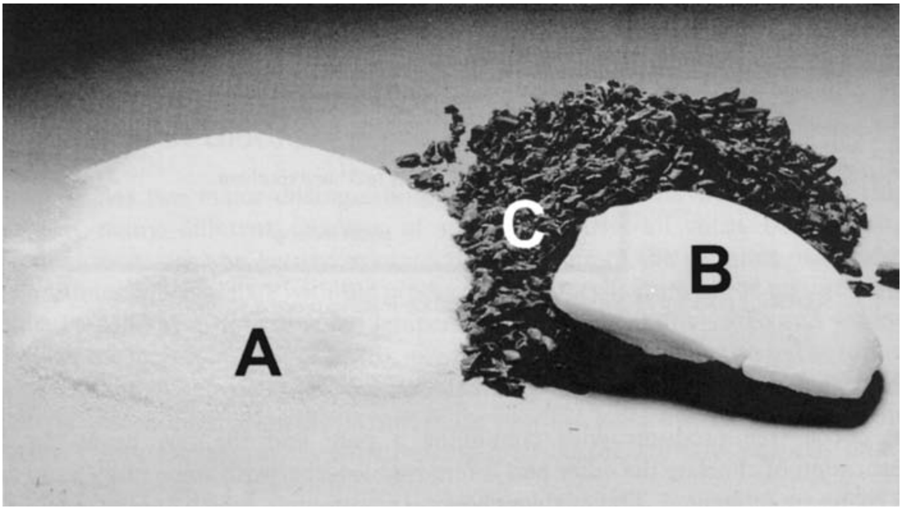


Figure 1.3 A picture of the unmilled ingredients used to make dark chocolate. A is sugar, B is cocoa butter and C cocoa nibs.

The most common method of achieving this is by the use of roll refiners. In order to enable the chocolate ingredients to pass through the refiner, however, it is necessary to get them into a paste form. This may be done in a variety of ways. One of the most common is to grind the nib to form cocoa mass, which is a liquid at temperatures above the melting point of cocoa butter, 35°C (95°F). This usually involves hammer mills, disc mills, ball mills, three-roll refiners or a combination of the four. The sugar can then be added in a granulated or milled form and the two mixed with extra fat (and milk powder if milk chocolate is being manufactured). The mixing may include some grinding, and traditionally a melangeur pan was employed for the purpose. This machine has a rotating pan, often with a granite bed, on which two granite rollers rotate. Scrapers ensure mixing by directing the material under the rollers (Figure 1.4). The modern requirement for continuous higher throughput methods has often led to the mixing and grinding being carried out separately. Probably the most widely used, is to mix the initial ingredients into a paste and then grind this on a two-roll refiner. This gives a sufficient amount of crushing and mixing to provide a particle size and consistency suitable for feeding to the 5-roll refiner (see Chapter 7).

Where chocolate crumb is used, this dehydrated mixture of condensed milk and cocoa mass is normally preground to a maximum size of 2 mm (0.1 in.). This is then crushed and mixed with fat in order to provide a suitable paste for processing in a refiner.

The most widely used alternative method is to mill the solid ingredients (i.e. sugar, milk powder and/or crumb) separately and then mix with the

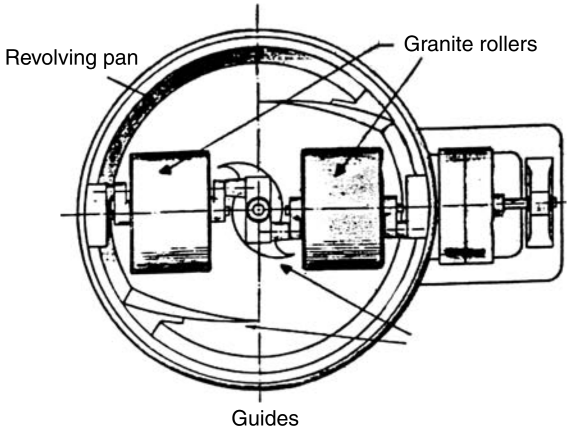


Figure 1.4 Diagram of melangeur pan.

liquid components (cocoa mass, cocoa and cow's butter and lecithin) in the conche. This may result in different flavours from when all the ingredients are processed together. Niediek (1994) attributes this to the fact that when sugar particles are broken, the surface becomes very reactive and is able to pick up any flavour components in the vicinity. These will be different if the cocoa is present, as in the combined milling, than if the ingredients are ground separately.

1.2.3 Conching – flavour and texture development

Although the fermentation, drying and roasting are able to develop the precursors of chocolate flavour, there are also many undesirable chemical compounds present. These give rise to acidic and astringent tastes in the mouth. The object of conching is to remove the undesirable flavours, while developing the pleasant ones. In addition, the previous grinding process will have created many new surfaces, particularly of sugar, which are not yet covered with fat. These uncoated surfaces prevent the chocolate flowing properly when the fat is in a liquid state. Because of this the chocolate cannot yet be used to make sweets, and does not have the normal chocolate texture in the mouth. The conching process, therefore, coats these new surfaces with fat and develops the flow properties, as well as modifying the flavour.

This is normally carried out by agitating the chocolate over an extended period in a large tank, known as a conche. The mixing continuously changes the chocolate surface and this, coupled with some heating and ventilation, enables the volatile components to escape and the flavour to be modified. Some manufacturers prefer to limit the conching time by restricting the conching process to primarily one of liquefying the chocolate. This is made possible by treating the cocoa mass at an earlier stage, in order to remove some of these less desirable volatile chemicals.

1.3 Concept of the book

Chocolate making was, for over one hundred years, a traditional industry governed by craftsmen who developed individual methods of working, as well as ‘house’ flavours for products. With increasing economic demands for higher throughputs and less labour, the industrial manufacture of chocolate has become more and more mechanized. There has also been an increased application of science and technology to control production plants and enable them to operate efficiently. In this situation the equipment manufacturers’ are introducing new machinery, whilst the literature abounds with new methods of manufacture and patents for ‘improved’ techniques. Certain basic principles of chocolate making exist, however, and the aim of this book is to show what these are, and how they can be related to the processes used in its manufacture. It has been intended to avoid making the book a catalogue of a selected number of machines and products. In order to try and achieve this, and give the book as wide a coverage as possible, authors have been chosen from a range of industries and research institutions in Europe, North America and New Zealand. Chapters have deliberately been kept relatively short, and to a certain extent follow the order of processing described in this chapter.

Certain topics have been divided into two, for example the chemical changes involved during conching have been presented separately from the physical and engineering aspects, as most authorities tend to concentrate predominantly on one or other of these aspects of conching. In addition to the technical side, plant hygiene, intellectual property and nutritional values have become increasingly important within the chocolate industry. Chapters have therefore been included to provide an overview of these subjects.

The manufacture of chocolate goods would not exist but for the consumer. What is seen on the market shelves is seldom the chocolate itself, but usually the container. For this reason the packaging, marketing and legal requirements for the product is of considerable importance and chapters on these three topics are included in the book.

Every author has contributed to the book as an individual. Each chapter, therefore, is the author’s responsibility, and may or may not be in agreement with the theories or principles adopted by the company by whom he or she is employed, or by the editor. As the chapters were written concurrently with little contact between the authors, several topics were duplicated. This has been minimized where possible, but retained where authors have given additional or even contradictory information. The latter is bound to occur owing to the present incomplete understanding of the processes involved. Minor differences in machinery or ingredients can produce major changes in the product. Each author, therefore, is merely reflecting his own experience within the wide range of combinations possible in chocolate making. The multinational authorship of the book highlighted the differences in terminology and units found throughout the industry. For example, the term 'refinement' means flavour development in some countries and grinding in others. For this reason, and to aid people unfamiliar with the industry, a glossary of terms has been included (p. 663). The units given are those with which the author is most familiar, but frequently the most widely used alternative is also quoted. In addition, some of the more commonly used physical constants associated with chocolate making have been included in this edition.

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Chapter 2

COCOA BEANS: FROM TREE TO FACTORY

M.S. Fowler

2.1 Introduction

Cocoa is the essential ingredient of chocolate, responsible for its unique flavour and melt-in-the-mouth properties. A manufacturer needs a reliable supply of good quality cocoa at reasonable prices. This chapter examines how growing of cocoa, fermentation and drying, and storage and transport can affect quality prior to arrival at the factory. Also discussed are the operations of the cocoa markets, quality assessment and the use of different types or origins of cocoa for chocolate.

Cocoa has a long supply chain extending from smallholders, often in remote, less well-developed tropical regions of the world, to factories and consumers mainly in developed industrial countries. Like any crop, it is susceptible to changes in the weather, to pests and diseases and to social and economic factors. The supply of cocoa has continued to grow throughout the last 30 years despite historically low prices on the world markets since 1990. At the same time, demand for cocoa has kept pace with supply and is growing steadily. About two thirds of the cocoa crop ends up in chocolate products, with the remainder going mainly into beverage and bakery products (*Source:* ICCO website).

2.2 Growing cocoa

2.2.1 Where cocoa is grown

Cocoa is grown commercially between 20° north and south of the Equator, in areas with a suitable environment for cocoa. There are three main growing areas: West Africa, South East Asia and South America (see Figure 2.1). The seven largest cocoa-producing countries are Côte d'Ivoire (Ivory Coast), Ghana, Indonesia, Nigeria, Cameroon, Brazil and Ecuador and between them they account for 90% of the world crop (see Figure 2.2). The fortunes of

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Figure 2.1 Main cocoa growing countries.

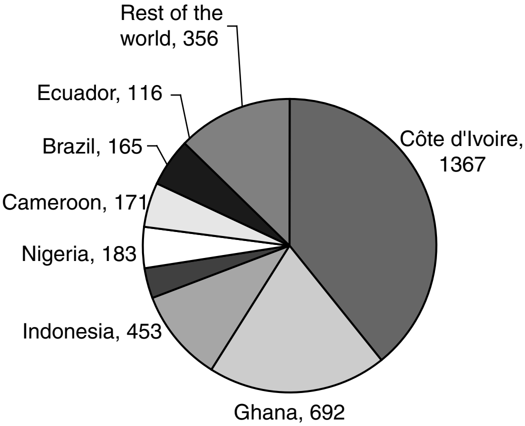


Figure 2.2 Average production of cocoa beans by country (in 1 k tonnes). Data (3 year average, 2003–6) with permission from the International Cocoa Organisation (ICCO), London.

the various countries have changed significantly in recent decades. A main feature of the current pattern of production is the huge concentration (around 70%) within West Africa. Côte d'Ivoire alone produces around 40% of the world crop. This means that future supply is vulnerable to a number of factors, such as the spread of pests and diseases, weather or climatic variations, political or social change. In many areas, cocoa faces competition from other crops such as oil palm, Robusta coffee, rubber and cloves. About 90% of the world's cocoa is grown by smallholders (Smith, 1994), usually on farms with mixed cropping systems.

2.2.2 Varieties of cocoa: Criollo, Forastero, Trinitario and Nacional

The cocoa or cacao tree (*Theobroma cacao*, L.) originates from South and Central America. It is a small tree, 12–15 m height (40–50 ft), (Mossu, 1992), that grows naturally in the lower storey of the evergreen rain forest in the Amazon basin. The leaves are evergreen and are up to about 300 mm (12 in.) long. The flowers, and hence the fruits (cocoa pods) grow from the trunk and thicker branches (see Figure 2.3).

Cocoa has been cultivated since before AD 600 by the Mayan and Aztec peoples. In the sixteenth and seventeenth centuries cocoa was introduced into Asia. These early movements of cocoa were of a type called Criollo. Criollo cocoa beans have white cotyledons and a mild, nutty cocoa flavour. They are susceptible to diseases and produce low yields. This type is now very rare; only found in old plantations in Venezuela, Central America, Madagascar, Sri Lanka and Samoa.

The main type of cocoa is called Forastero and in the eighteenth century, a Forastero variety of cocoa from the Lower Amazon was introduced into Bahia in Brazil. This variety of cocoa is called Amelonado, named after the melon shape of the pods. From Bahia, cocoa cultivation spread to West Africa in the nineteenth century (Wood, 1991). The Amelonado variety was well suited to West African smallholder cultivation.

There have been several wild cocoa collecting expeditions in the twentieth century, usually into the Amazon basin. The most famous was by Pound in 1938, which brought back some Forastero material termed Upper Amazon. There are a few important collections where the different varieties of cocoa are conserved. The Upper Amazon and some other collected material have been incorporated into breeding programmes and these have led to the development of improved varieties. The objectives are usually higher yield, earlier bearing, and resistance to pests and diseases with less emphasis on flavour and other quality attributes. Breeding in a tree crop is a long process and most cultivated varieties of cocoa are only one or two generations away from wild collected material.

The third type of cocoa is called Trinitario. The origin of the Trinitario varieties is usually stated as the result of hybridization between Forastero and Criollo trees. Consequently, some Trinitario varieties produce cocoas with special flavours. The fourth type is Nacional which is only grown in Ecuador and probably originates from the Amazonian area of Ecuador. Nacional cocoa produces beans with 'Arriba' flavour (see Section 2.6.8). Pure Nacional varieties have almost disappeared and the varieties with Arriba flavour in Ecuador are hybrids between Nacional and Trinitario.

Figure 2.3 Amelonado-type cocoa trees growing in West Africa.

The type of planting material originally introduced into an area has strongly influenced the type of cocoa grown today and hence the quality and uses of the cocoa beans (see Section 2.6).

2.2.3 Climatic and environmental requirements

Cocoa grows in areas of high rainfall (1000–4000 mm (40–160 in.) per year); but the range is preferably between 1500 and 2500 mm (60–100 in.), evenly distributed throughout the year. If there is a dry season of more than three months with less than 100 mm (4 in.) rainfall, some form of irrigation maybe necessary. Cocoa prefers high humidity, typically 70–80% during the day and up to 100% at night. Strong dry winds can defoliate the tree and very strong winds or hurricanes can cause physical damage.

The temperature requirements are a mean monthly minimum of 18°C (64°F) and a mean monthly maximum of 32°C (90°F). The absolute minimum is about 10°C (50°F).

Quite a wide range of soil is suitable for cocoa, but it grows best where the soil is deep (1.5 m (5 ft) or more), with good drainage and a pH of neutral to slightly acidic (range 5–7.5). Soil influences one important quality aspect of cocoa: the cadmium content. Some soils, especially volcanic ones, can contain high levels of cadmium. If this is in an 'available' form, it can be taken up by the plant and concentrated in the beans (see Section 2.5.4).

2.2.4 Propagation of the planting material

The most common method of propagation is by seed. Good planting material may be obtained from selected parents by using hand pollination. These hybrids may also have hybrid vigour (giving faster growth and earlier bearing). Growing cocoa from seed produces a tree with a straight, single, vertical trunk which branches at around 2 m (6.5 ft) above the ground (this point is called the jorquette). Trees grown from seed tend to be more drought resistant and require less pruning. However, they often exhibit a great deal of variability in their agronomic characteristics which is not desirable. This can be overcome by using one of the techniques of vegetative propagation such as cuttings, grafting or micropropagation systems. Grafting can be onto young seedlings, small plants or even mature trees. Grafted trees tend to have a more open branching structure, usually without the straight single trunk associated with seedling (hybrid) cocoa.

Micropropagation systems are under development: one system involves culturing some cells and growing them into plantlets, which are then transferred to a nursery. Micropropagation enables more rapid propagation of new varieties developed by plant breeders. The trees have a similar structure to seedling grown trees. All the vegetative methods produce trees that are identical genetically to the original tree and therefore perform similarly in respect to yield, disease resistance and quality parameters.

The plants are initially grown in a nursery and, after three to six months, they will be ready to plant out in the field.

2.2.5 Establishment and development of the plants in the field

The selection of a suitable site is very important and needs to take into account local factors such as weather conditions (especially rainfall, temperature and wind), soil fertility and drainage. Prior to planting the site is prepared, which normally involves some land clearance and establishing some form of shade (unless it is already present). Shade protects the trees from excessive sunlight and wind. Initially shade requirements are high for young cocoa trees and it is common practice to plant a temporary shade of bananas or plantains.

Cocoa trees are usually planted to achieve a final density of 600–1200 trees/ha (1500–3000 trees/acre). In the first year, the cocoa is often inter-cropped with food crops. Trees come into bearing when they are two to three years old and full yield is achieved after six to seven years. They have an economic life of 25–30 years or more.

Growth occurs in 'flushes' when each shoot on the tree grows a few fresh new leaves at the same time. The timing and extent of this 'flush' growth depends on recent rainfall and the state of the tree. Maintenance of the tree is mainly pruning (to keep to a canopy height of 3–5 m (10–16.5 ft)) and weed control. Depending on the soils, fertilizer may be applied to correct deficiencies and so increase yields, although this is unusual on small-holdings.

2.2.6 Major pests and diseases

Some 20–30% of the crop is lost to pests and diseases. The main pests and diseases are black pod, witches' broom, frosty pod rot (*Moniliasis*), vascular streak dieback, swollen shoot, capsids and mirids, and the cocoa pod borer. Squirrels, rats and monkeys can consume significant quantities of ripe pods. Further information is given in Table 2.1.

Control of the pests and diseases is achieved by a combination of using appropriate planting material, good growing practices, sanitation and careful application of approved pesticides. In some areas, cocoa growing is not viable because of the effects of pests and diseases. Due to the high costs of pesticides, most small-holders do not use them.

2.2.7 Flowering and pod development

The flowers develop from flower cushions located on the trunk and branches. They are small, about 15 mm (0.6 in.) in diameter. Flowering depends on the environment, the condition of the tree and the variety. Some trees flower almost continuously; whereas others have well-defined periods (generally twice a year). The flowers are pollinated by small insects such as midges. Only small proportions of the flowers are pollinated and develop into pods.

The small pods are known as cherelles (see Figure 2.4). If there are too many for the tree to support through to maturity, the excess stop growing and die (this is known as cherelle wilt).

After 5–6 months the pods are fully developed. They measure between 100 and 350 mm long (4–14 in.) and have a wet weight from 200 g (7 oz) to more than 1 kg (2.2 lb) (Mossu, 1992). There is considerable variation in the shape, surface texture and colour of the pods depending on the variety.

Table 2.1 Major pests and diseases of cocoa.

Name of pest or disease	Distribution[a]	Caused by	Symptoms or damage[b]	Transmission or spread	Control[c]
Black pod disease	World-wide	*Phytophthora* species	Fungal attack of mainly the pods causing them to go brown and rot	By spores in water droplets	Sanitation (removal of infected material) and application of fungicides
Witches' broom disease	South America, Caribbean	*Moniliophthora perniciosa* (formerly *Crinipellis perniciosa*)	Fungal attack causing extra growths or brooms to develop from leaf buds. Can also affect flowers and pods	Wind-borne spores	Pruning and sanitation Application of fungicides
Frosty or watery pod rot – Monilia, Moniliasis, or Moniliosis	Peru, Ecuador, Columbia, Central America including Mexico	*Moniliophthora roreri*	Pod rot	Durable spores are carried by the wind and other vectors	Sanitation (removal of infected pods)
Vascular streak dieback disease (VSD)	South East Asia, Pacific Islands	*Oncobasidium theobromae*	Leaf fall and dying back of stems	Wind dispersed spores	Regular pruning of infected material
Cocoa swollen shoot virus (CSSV)	Ghana, Togo, Nigeria and possibly Côte d'Ivoire	Badnavirus	Swelling or thickening of the shoots. The infected tree frequently dies	The virus is carried by mealybugs	Eradication of infected trees
Capsids or mirids (insects)	World-wide	Various species for example *Distantiella theobroma, Sahlbergella singularis, Helopeltis*	These insects feed by sucking the sap causing direct damage to plant tissue. In addition, this allows entry by fungi that cause stems and pods to rot	Adult insects fly	Application of insecticides
Cocoa pod borer moth	South East Asia and a recent (2006) outbreak in Papua New Guinea	*Conopomorpha cramerella*	Larva bores into the pods and affects the development of the beans	Moth is a weak flyer	Regular frequent harvesting of pods, pruning, application of insecticides

[a] Distribution includes growing areas where the pest or disease causes significant losses.
[b] Symptoms or damage depend on local factors and the type of planting material.
[c] Control methods are not effective or economic in many cases.

Figure 2.4 The small pods or cherelles grow directly from the trunk and main branches. See Plate 1 for the colour image.

2.2.8 Harvesting, pod opening and yields

When they ripen, most pods change colour – usually from green or red to yellow or orange. They are cut by hand from the trunks and branches. This is easily done with a machete (cutlass) for the pods that are low on the trunk, but for the pods on the upper branches it is necessary to use a special knife fixed on a long pole. The crop does not all ripen at the same time so that harvesting has to be carried out over a period of several months. Pods are normally harvested every 2–4 weeks. Frequent harvesting reduces the losses to rats, squirrels, monkeys, cocoa pod borer moth and the various pod rot diseases. In West Africa the main harvest period is from the beginning of October until December. Cocoa purchased from farmers during this period and up to March is termed 'main crop'. This is generally of higher quality than the secondary or intermediate harvest known as the 'mid' or 'light' crop.

The pods are opened (see Figure 2.5) to release the beans, either by cutting with a machete or cracking with a simple wooden club. Pods opened with a machete can result in damaged beans if the machete cut is too deep. There are some 30 to 45 beans or seeds inside the pod attached to a central core or placenta. The beans are oval (or a plump almond shape) and covered in a sweet, white mucilaginous pulp (see Figure 2.6). The beans are separated by hand and the placenta is removed.

Figure 2.5 Opening the ripe pods in a West African cocoa farm.

Figure 2.6 Open cocoa pods showing beans covered in pulp. See Plate 2 for the colour image.

Each bean consists of two cotyledons (the nib) and a small germ or embryo, all enclosed in a skin or testa (the shell). The cotyledons serve both as the storage organs containing the food for the development of the seedling and as the first two leaves of the plant when the seed germinates. Much of the food stored in the cotyledons consists of cocoa butter that amounts to about half the weight of the dry seed. The moisture content of the fresh beans is in the region of 65%.

The yields obtained from cocoa trees vary considerably. Yield depends on the variety of cocoa grown, the growing system (tree density, shade levels), the age of the trees, the local environment (weather, soil fertility), and losses caused by pests and diseases. Yields of dry beans can vary from 150 kg/ha (132 lb/acre) in a poorly maintained small-holding, through typical West African levels of 250–450 kg/ha (220–400 lb/acre) to that achieved on well-run plantations, which can be 2500 kg/ha (2200 lb/acre).

2.2.9 Environmental aspects of cocoa cultivation

In the past, expansion of cocoa production has been from new small-holdings in former areas of primary forest that previously have been logged for timber. This is not a sustainable model for the future. There is potential to increase productivity by better control of pests and diseases, improved higher yielding planting material and better farming practices.

Once an area of primary forest has been logged, then cocoa growing becomes one of the most environmentally beneficial uses of the land. Essentially this is because it is a stable tree crop, often grown as part of a mixed cropping system including shade trees. Cocoa farms support a relatively high biodiversity and have been shown to be an important habitat in Central America for migrating birds. Tropical tree crop systems such as cocoa cultivation are important in providing vegetative continuity with residual areas of primary or secondary tropical forests. The low level of farming inputs means much of the cocoa production is essentially organic. An increasing number of farmers and farmers' co-operatives are going through the process to achieve organic certification.

2.2.10 Labour practices on farms

Cocoa production in West Africa is mainly on small family farms using labour-intensive methods. Following media allegations about forced child labour in Côte d'Ivoire there have been some independent studies into labour practices (e.g. Gockowski, 2006). The vast majority of labour on cocoa farms in West Africa is adult and is in one of three basic categories: full time seasonal, casual labour for a specific task or a share-cropping tenancy (where the share-cropper provides labour on part of the farm in exchange for a share in the crop proceeds). Family children are involved especially during busy harvest periods and can be exposed to hazardous tasks such as using a machete or carrying heavy loads. Gockowski (2006) also reported that less than 1% of cocoa farms employed adolescent workers; child slavery was uncommon and cocoa producing households sent more of their children to school when compared to non-cocoa producing households. There is no doubt that cocoa growing provides significant benefits to many rural economies, but much can be done to improve the conditions and livelihood of cocoa farmers.

2.3 Fermentation and drying

The immediate post-harvest processes of fermentation and drying are normally carried out on the farm. They are essential steps during which the cocoa flavour precursors are formed. Drying produces a stable, non-perishable commodity making the crop ideal for small holders in remote locations.

2.3.1 Fermentation

The fermentation stage is usually very simple. The fresh beans are heaped in a pile or in a wooden box, typically for 5 days. Natural yeasts and bacteria multiply in the pulp, causing the breakdown of the sugars and mucilage. Much of the pulp then drains away as a liquid.

Fermentation is carried out in a variety of ways and some of the common practices will be described below. Different types of cocoa require different amounts of fermentation. Beans from some origins are only partially fermented or not intentionally fermented at all. Generally these beans can be used to manufacture cocoa butter, but if they are used to make other cocoa products, they require blending with fully fermented cocoas.

If the fresh beans are dried without any fermentation, then the nib will be a slaty, grey colour rather than the brown or purple-brown colour of fermented dried cocoa beans. Chocolate made entirely from slaty, unfermented beans tastes very bitter and astringent with little apparent chocolate flavour: it also has a greyish brown appearance.

In West Africa, where smallholders grow nearly all the cocoa, fermentation is usually done in heaps enclosed by banana leaves. Heaps can be used to ferment any quantity from about 25–2500 kg (55–5500 lb) of fresh cocoa beans although intermediate amounts are desirable. Some farmers will mix the beans on the second or third day. The fermentation usually lasts about five days and the end point is determined by experience. This traditional low input system produces the best fermented cocoas.

In plantations, fermentation is normally carried out in large wooden boxes that typically hold 1–2 tonnes of wet beans. Well-designed boxes have provision for the liquefied pulp (the sweatings), to drain away and for entry of air. This is usually achieved by means of small holes in the bottom of the box or preferably through a floor of slats each separated by about 6 mm (0.25 in).

Boxes usually measure 1–1.5 m (3.3–5 ft) across and may be up to 1 m (3.3 ft) deep. However, shallow bean depths (250–500 mm (0.8–1.5 ft)) are preferred, especially at the start of fermentation, to promote good aeration. To increase aeration and ensure uniformity of fermentation, the beans are usually transferred from one box to another each day. The length of fermentation is the same as for smallholders, but some plantations ferment for longer periods such as 6 or 7 days.

2.3.2 Microbiological aspects of fermentation

Micro-organisms are responsible for the breakdown of the pulp that surrounds the beans. Their activities result in the death of the beans and they create the environment that enables the formation of cocoa flavour precursors (see Chapter 8).

The pulp is an excellent medium for the growth of micro-organisms since it contains 10–15% of sugars. When the beans are removed from the pods, the pulp is inoculated naturally with a variety of micro-organisms from the environment. The fermentation process can be considered in three stages:

Stage 1 – Anaerobic yeasts: In the first 24–36 h, yeasts convert sugar into alcohol under conditions of low oxygen and a pH of below 4 (i.e. quite acidic). Bean death usually occurs on the second day and is caused by acetic acid and alcohol (the rise in temperature is relatively unimportant).

Stage 2 – Lactic acid bacteria: These are present from the start of the fermentation, but only become dominant between 48 and 96 h. Lactic acid bacteria convert sugars and some organic acids into lactic acid.

Stage 3 – Acetic acid bacteria: These are also present throughout the fermentation, but become more significant towards the end when aeration increases. They are responsible for converting alcohol into acetic acid. This is a strongly exothermic reaction that is mainly responsible for the rise in temperature. This can reach 50°C (122°F) or higher in some fermentations.

In practice, there is considerable overlap between the stages. The types of micro-organisms vary between fermentations and between regions.

2.3.3 Development of cocoa flavour precursors (see also Chapter 8)

Development of the cocoa flavour precursors occurs in the cotyledons during fermentation and drying. There are two important types of cells within the cotyledons: storage cells containing fat and proteins, and the pigment cells containing polyphenolic compounds and methylxanthines (theobromine and caffeine). During fermentation, there is firstly the initiation of germination of

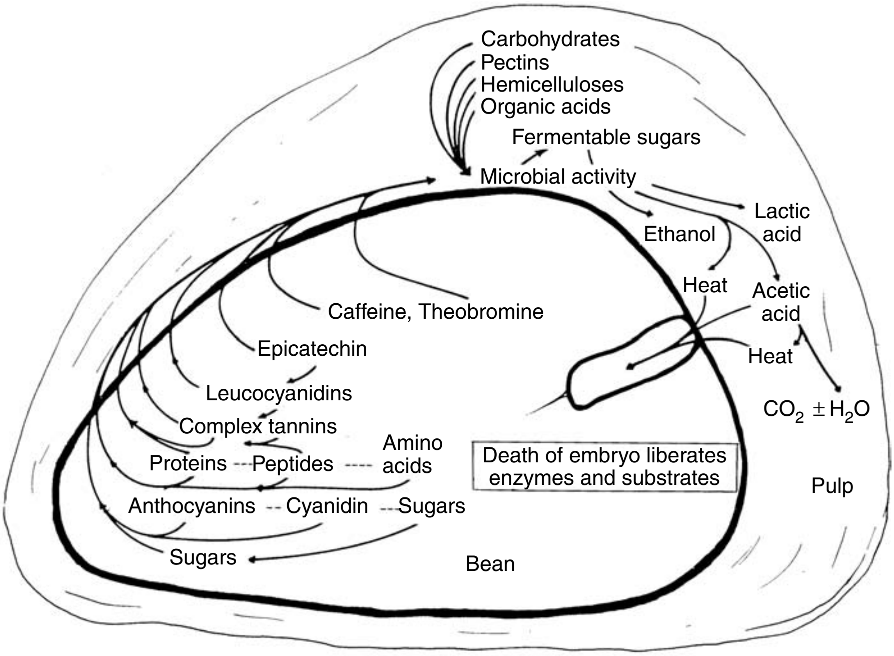


Figure 2.7 Chemical changes within a cocoa bean during fermentation (after Lopez, 1986).

the seed. This causes the uptake of water by the protein vacuoles within the storage cells. Later, after bean death has occurred, the cell walls and membranes break down: allowing the various compounds and enzymes to react together. These reactions produce the cocoa flavour precursors (see Figure 2.7). The reaction rates are determined by the temperature and the level of acidity.

There are several groups of compounds responsible for flavour. The methylxanthines impart bitterness. During fermentation, their levels fall by around 30%, probably due to diffusion from the cotyledons. There are a range of polyphenolic compounds (called flavonoids) which are responsible for the colour, for imparting astringency in the mouth and for the antioxidant health benefits associated with cocoa (see Chapter 27). Their levels drop significantly during fermentation and drying. The anthocyanins (a type of flavonoid) are rapidly hydrolysed to cyanidins and sugars by glycosidase enzymes. This accounts for the bleaching or lightening of the colour of the purple cotyledons in Forastero cocoa. Other enzymes (polyphenol oxidases) convert another type of flavonoid, the flavanols (comprised mainly of (–)-epicatechin) to quinones. Proteins and peptides complex with the polyphenolic compounds to give the brown or brown/purple coloration that is typical in fermented dried cocoa beans. Another important group of compounds is the Maillard reaction precursors. These are formed from the storage proteins and sucrose. Sucrose is converted by invertase into reducing sugars (Chapter 3). The storage proteins are hydrolysed by peptidase enzymes into oligopeptides and amino acids. These cocoa flavour precursors are involved in Maillard reactions during roasting of the cocoa beans to form cocoa flavour compounds.

2.3.4 Drying

When fermentation is finished, the beans are removed from the heap or box for drying. In areas where the weather is comparatively dry at harvest time, the beans are dried in the sun by being spread out during the day in layers about 100 mm (4 in) thick on mats, trays or a terrace on the ground. Sun drying is environmentally friendly, low cost and produces beans of good quality. In West Africa, the beans are spread on any suitable horizontal surface (e.g. a concrete terrace or polythene sheet). The preferred method, which is common in Ghana, is to spread the beans on mats made of split bamboo, which are placed on low wooden frames. The mats can be rolled up to protect the beans when it rains. They have several advantages: it is easier to sort the beans and remove defectives and foreign materials and there is less risk of contamination compared with beans being dried at ground level. In all cases the beans are raked over at intervals and heaped up and protected at night or when it rains (see Figure 2.8). In Central and South America, a common method is to spread the beans on a floor or platform, with a roof

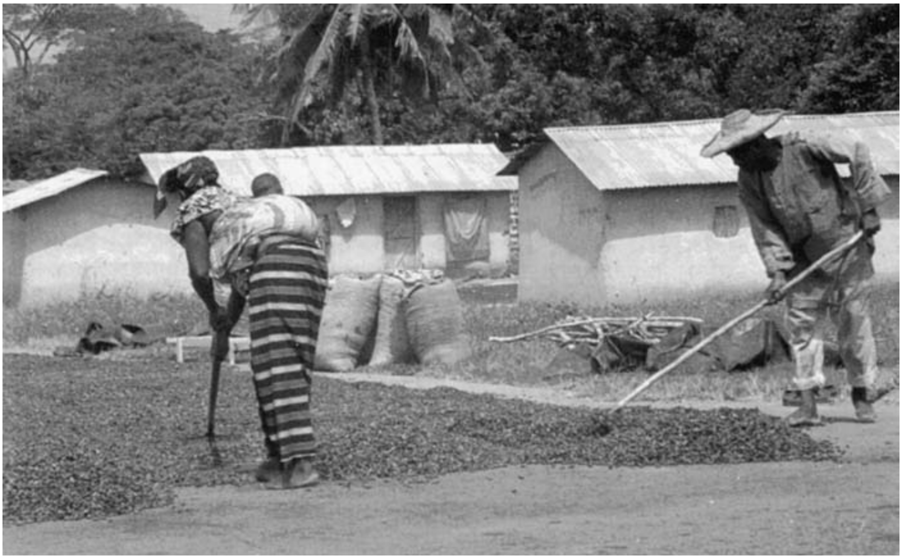


Figure 2.8 Cocoa beans drying on a concrete terrace in Côte d'Ivoire (Ivory Coast).

on wheels that can be pushed back over the floor at night or when it rains. Alternatively, the platforms themselves are arranged on wheels so that several can be run under a single roof, one above the other to save space. It usually takes about a week of sunny weather to dry down to the 7 or 8% moisture content needed to prevent mould growth during storage.

Where the weather is less dry and sunny at harvest time, improved methods of solar drying or artificial drying are adopted. Various low technology solar drying systems have been developed. These generally involve the use of a transparent plastic tent or roof over the cocoa and sometimes additional solar energy collectors. In on-farm trials, some of these systems have proved to be very efficient and effective.

In some circumstances, artificial drying is the only practical solution. In the simplest form, a wood fire is lit in a chamber below the drying platform and the combustion gases are conducted away in a flue that continues beneath the drying platform before becoming a vertical chimney. Convection and radiation from the fire chamber and flue heat the drying platform. Forced air dryers are generally better and, for most fuels, an efficient heat exchanger is required so that no combustion products come into contact with the drying cocoa.

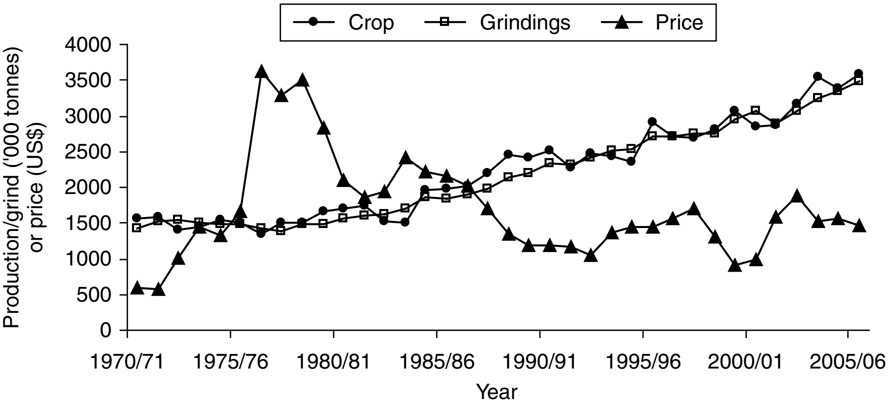
Artificial drying introduces two problems. Firstly, the beans may be dried too quickly resulting in very acidic beans. This is caused by the shell becoming hard and locking or trapping the volatile organic acids inside the bean. Acidity can be reduced by using lower air temperatures or an overnight rest period to allow the moisture in the beans to equilibrate. The reduction in drying capacity or throughput is compensated by lower fuel costs resulting from more efficient drying. The second, more serious, problem with artificial drying is that smoke may find its way on to the beans. This is liable to produce an unpleasant harsh, smoke or tar taste, which cannot be removed from the resulting chocolate by processing. While it is comparatively easy to design a drier in which the smoke is kept away from the cocoa, it is not so easy to maintain one in this state. After a drier has been operated for a number of years, the risk of smoke reaching the cocoa beans too often becomes a reality. This is one of the reasons why cocoas from some areas are in less demand and consequently command lower prices.

Care is also required not to over-dry the beans. Beans dried to below 6% moisture become quite brittle and are easily damaged in subsequent handling.

During or after drying the beans it is necessary to carry out a hand sorting or mechanical sieving/winnowing process to remove debris, clumped and broken beans. The beans are then bagged and maybe stored for a short period prior to sale.

2.4 The cocoa supply chain

Cocoa beans have to get from the many small farmers, who are often in remote areas of developing countries, to the cocoa processing factories that may be located in temperate countries. They can pass through a number of



Prices are an annual average of the daily prices from LIFFE and NYBOT (*Source:* ICCO, 2006). Production and demand are closely balanced and have grown steadily at the same rate. Prices are more volatile and are influenced by stock levels, political and economic factors, the environment and speculator activity.

Figure 2.9 World cocoa production, grindings (demand or usage) and prices. Data with permission from the International Cocoa Organisation (ICCO), London.

intermediaries, each of whom plays an important role. The price of cocoa is given in US$ or GB£ per metric tonne and is determined in the open markets of New York and London. The evolution of prices, production and demand ('grindings') is given in Figure 2.9.

2.4.1 Internal market

Typically, the farmer sells his cocoa to a co-operative or a trader (first level collector). The important points for a farmer are the price received (% of world market price) and the level of service provided (location and frequency of collection; availability of 'free' credit etc.). The cocoa will then be taken and sold to a larger trader or collector in the nearest main town (see Figure 2.10). From here the cocoa will go to the port and into the warehouse of an exporter or shipper.

2.4.2 International cocoa markets

Producers (cocoa growers, co-operatives, government marketing boards, and exporters) need to be able to sell their cocoa at the best price. The size and timing of the crop depends on local weather conditions and other factors. The users of cocoa (processors, grinders, and chocolate manufacturers) require a regular supply of cocoa of assured quality at competitive prices into their factories. The international cocoa markets function as intermediaries between producers and users: allowing prices to be established in an open transparent way and by providing opportunities for risks to be reduced for all parties.

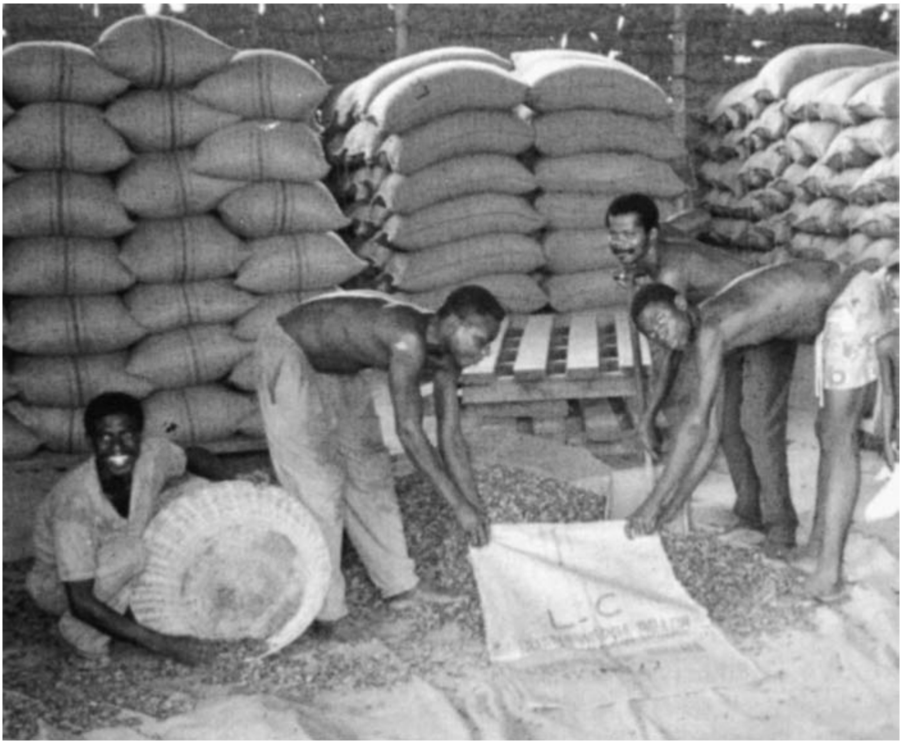


Figure 2.10 A cocoa buying station in Ghana.

There are two types of cocoa market: an 'Actuals', cash or physical market and the 'Futures and Options' or 'Terminal' market.

2.4.2.1 'Actuals' market

Anyone who buys and sells physical cocoa beans can be considered as participating in the 'Actuals' market (Dand, 1999). In practice, virtually all business is conducted using standardized contracts for sales that were developed by the cocoa trade associations. These are the Cocoa Merchants' Association of America (CMAA) and the Federation of Cocoa Commerce (FCC) in Europe.

Both associations provide arbitration procedures to resolve disputes. The basis of the contract prices in the 'Actuals' market is determined by the price in the 'Futures' or 'Terminal' market. In the 'Actuals' market it is possible to buy or sell forward, for example to buy cocoa beans in June for delivery in September.

2.4.2.2 'Futures and Options' or 'Terminal' markets

These markets can be used to minimize the risk of adverse price movements for the producer, trader and the user. They are primarily 'paper' markets in that no physical cocoa usually changes hand. There are two active futures markets: LIFFE (London International Financial Futures and Options Exchange) and NYBOT (New York Board Of Trade, now part of ICE (Intercontinental Exchange)). The markets have standard contracts, which allow the contracts to be interchangeable within each market. The contracts are restricted to certain weights (multiples of ten tonnes, the lot size), certain grades or types of cocoa and where and when the cocoa can be delivered. Each trade passes through a central body or clearing house in the market. Trading is conducted openly so the volume, price and delivery dates are public.

Although futures trading rarely results in the delivery of physical cocoa, this possibility means that the price has to remain close to the actual value of the cocoa. This value is determined by supply and demand and the activity of speculators. The role of speculators is often considered to be negative as their aim is to make a profit. However, they contribute liquidity to the market (e.g. by enabling a producer to sell when users are not buying) and can help stabilize the price by selling at high prices and buying at low ones.

2.4.2.3 Example of a simple hedge using the 'Actuals' and 'Futures' markets (Dand, 1999)

Traders, manufacturers and producers can use a simple hedge to reduce the risks associated with adverse changes in price. For example, it is normal for manufacturers to purchase physical cocoa for delivery in the months ahead. This is to guarantee that the factory will have a supply of cocoa. If we are in May and want to purchase 1000 tonnes of cocoa for delivery in December, we deal with a trader (in the Actuals or physical market) and agree a price of, say, US$1500 per tonne. If we believe that prices may rise above this level in the next few months, we could do nothing and come December we would take delivery of 1000 tonnes of cocoa at what would then be a favourable price. If, however we thought prices might fall, perhaps due to an exceptionally large crop, we would turn to the Futures and Options market. In this market we would sell 100 lots of ten tonnes for delivery in December. The price changes in each market are then likely to offset each other. This can be seen in Table 2.2 where the cocoa price declines by US$100 between May and December.

Table 2.2 Example of simple hedge to reduce risk.

Month	Actuals or physical market	Futures or terminal market
May	Buy 1000 tonnes of cocoa @ US$1500/tonne	Sell 100 lots @ US$1450/tonne for delivery in December
December	Could have purchased 1000 tonnes @ US$1400/tonne Assumed loss US$100 000	Buy 100 lots @US$1350/tonne to square position Profit US$100 000

In this example the manufacturer has made a profit in the Futures market of US$100 000 when he purchased 100 lots to square his position (i.e. to avoid having to deliver the lots of cocoa he sold in May). Whilst this profit is real, had he waited until December to buy his physical cocoa, he would have saved US$100 000 over the price he paid back in May. This is given as an assumed loss in the example above. So, the manufacturer has effectively guaranteed the delivery of cocoa in December into his factory but at the same time has cushioned himself (or hedged) against a fall in prices through the Futures market. Hedges can be used by traders, manufacturers and producers to 'lock' a price and hence reduce the risks associated with price fluctuations. In addition to hedging there are several other trading techniques.

2.4.3 Fairtrade

Cocoa only contributes a small proportion of the shop price for the finished chocolate product. For the farmers or small-holders it is a cash crop with no food or cultural value. Some farmers feel they are unfairly treated by those further along the supply chain as they often do not receive enough money to develop and improve their standard of living. With improving communication, consumers are becoming more aware of these issues and this has led to moves to ensure standards are applied throughout the supply chain. One successful initiative is the Fairtrade movement which has an alternative approach to international trade and campaigns to raise awareness. The name Fairtrade is unfortunate as it could be seen to imply that the remainder of the trade is unfair. Fairtrade organizations set up long-term trading partnerships directly with farmers, providing sustainable development. Importantly, Fairtrade ensures a fair price is paid directly to farmers by guaranteeing a minimum price which is above the cost of production, irrespective of the world price. Manufacturers wishing to use the Fairtrade mark on the wrappers of chocolate products must apply to the relevant national organization, which will be affiliated to Fairtrade Labelling Organisations International (FLO). According to the FLO about 5700 tonnes of cocoa was traded under the Fairtrade banner in 2005 (Anon., 2006). The challenge for the future is how to achieve sustainable development across the remainder of the cocoa supply chain without encouraging over production of cocoa. The International Cocoa Organisation (ICCO) and several chocolate manufacturers have projects in place aiming to achieve sustainable development. These involve farmer training, support for co-operatives and improved supply chain efficiency ensuring a higher proportion of the world price reaches the farmers. In addition, traceability of cocoa bean supplies is assured for the manufacturers. For further information see the ICCO and World Cocoa Foundation websites.

2.4.4 Shipment of cocoa

Cocoa is traditionally stored and transported in jute (or occasionally sisal) sacks containing 60–65 kg (132–143 lb) of dry beans. Jute sacks have a number of positive features: they are strong; stackable (do not slip over each other); breathable (allow moisture to pass through); and are made from natural biodegradable fibres. The process of manufacture of the sacks involves sizing with an oil/emulsifier mix to make the fibres more pliable. It is essential that sacks for cocoa (and other foodstuffs) be sized with suitable approved food grade vegetable oil (see Section 2.5.4).

There are a number of shipment methods and the one actually used will depend upon the facilities available at the ports and quantities shipped. The main systems are:

Breakbulk. This is the standard, traditional method where the jute sacks are stacked directly into the hold of a ship. This method has the disadvantage of requiring significant handling which is both costly and time consuming.

Sling loaded or pre-slung. About twenty to twenty-five sacks are kept together in a sling. There are two advantages: a saving of labour at the port on loading and unloading and improved lot separation. (Slings can be used to keep small lots of cocoa segregated in the hold.)

Containers. They can be stuffed with sacks (12.5 to a maximum of 18 tonnes) or loose filled. Loose-filled containers normally contain 17.5–25 tonnes of beans.

Barges. On the West Africa to northern Europe route, Baco-liner operates a system using barges which can be floated into specially designed mother ships. Each ship takes 12 barges which can be loaded with around 500 tonnes of cocoa, either loose in bulk or in sacks. This method is attractive if the receiving factory or warehouse is located near inland waterways and has the facilities to unload the barges directly. It also helps reduce congestion in the ports.

Mega-bulk. This system comprises loading cocoa beans direct into the hold of a ship (similar to grain shipment). Up to several thousand tonnes can be transported in one hold. It is usual to use ships that have double skin hull or some form of lining to the hold. The top surface of the cocoa is usually covered with moisture absorbent material such as jute or cardboard. There should be a minimum of 1 m (3 ft) between the top of the cocoa and the hatches. The hold should have forced air ventilation.

Bulk shipment methods are gaining in popularity for cocoa transported to Europe and it is estimated that about 70% of cocoa beans shipped to northern European ports now use one of these bulk methods.

2.4.5 Moisture movement during shipment

Moisture can be the cause of problems in commercially dry cocoa when it is transported to colder countries. The West African crop is mainly shipped during the winter months in the Northern Hemisphere. Cocoa at 8% moisture is, for example, in equilibrium with a relative humidity of 75%. It may be loaded at a temperature of about 30°C (86°F). After a few days into the voyage, the temperature both of the air and the sea will start to fall and, within a few more days, on reaching the North Atlantic it may be down close to freezing point. These are the conditions under which moisture will condense on to the cold metal of the ship. But the mass of cocoa will take quite a long time to cool appreciably so that it will keep the air around it warm. This air will diffuse outwards and be cooled by the cold metal of the ship until its relative humidity reaches 100% and water starts condensing on cold surfaces.

Although the cocoa beans are dry, a hold containing 1000 tonnes of cocoa at 7% moisture amounts to 70 000 L (15 000 gal) of water. If the moisture content of the cocoa was reduced only a quarter per cent, there would be 2500 L (560 gal) available for condensation. Such amounts are liable to involve water literally raining down from the hatches above and running down the walls of the hold. There can easily be a sufficient quantity to wet patches of the dry cocoa in bags. These quantities of water also explain why bags of desiccant material, such as silica gel, are not very effective in reducing condensation, although they can delay its onset. Water is taken up quickly by the cooler cocoa beans near the surface, and their moisture levels can go from 7% to 8% (in their dry condition) to 20% or 30% moisture. At these moisture contents and temperatures around 20°C (68°F) moulds can develop in a few days. As a result, occasionally shipments have arrived in Europe and North America with patches of beans that have been wetted and spoilt by the growth of mould.

Precautions to prevent such damage must be taken in ships. The best precaution is to operate mechanical ventilation. This continually removes the moist warm air before the water can condense on to the cold surfaces. In addition, the bags are stacked so that they are not in contact with the cold metal and absorbent mats are spread over the tops of the stacks to catch drips from the roof of the holds.

Condensation can be a problem in containers under similar conditions. The precautions taken include using ventilated containers on some routes and lining the inside of the container with insulating and moisture absorbent materials. Loose-filled containers present less of a problem with moisture migration due to greater bulk and less air space, which mean that the cocoa cools down more slowly.

In the bulk transport systems, the top surface of the cocoa is normally covered with insulating and moisture absorbent materials. This reduces the circulation of moist air and the cocoa cools down more slowly. The space above the cocoa must be ventilated. The critical factors are moisture of cocoa at loading, the rate of temperature change experienced, effectiveness of ventilation systems, duration of the voyage and speed of discharge. On discharge any damp beans near the edges will be thoroughly mixed back into the bulk and the moisture will re-equilibrate quite quickly within the lot, usually before there is time for mould to develop.

2.4.6 Storage of cocoa

In order to prevent the growth of mould during storage, moisture in cocoa beans must not exceed 8%. High moisture levels can result from inadequate drying, moisture pick-up in humid atmospheres and leaking or damp stores.

Bagged cocoa should be stored off the floor (e.g. on wooden pallets) and away from the walls in dry ventilated warehouses. Individual lots of cocoa should be clearly segregated and labelled. Cocoa beans are susceptible to tainting by uptake of certain odorous substances from some other commodities (e.g. spices) and chemicals (e.g. fuels, paints, agrochemicals and cleaning substances). Therefore, they should not be stored in the same warehouse as these materials. Warehouses should also be free from vermin and infestation (see Section 2.4.7).

The warehouse needs to be constructed and maintained to prevent water entry during periods of wet weather and the floor needs to incorporate a water impermeable layer. In the tropics, when it is very humid (e.g. at night or during rainstorms), ventilation can be temporarily stopped and then restored when the humidity drops again (e.g. during the day or in drier weather). Storing cocoa under polythene sheets is not recommended other than for very short periods of time.

The jute sacks allow water vapour to pass through, so that the cocoa beans gradually come into equilibrium with the humidity in which they are stored. The graph in Figure 2.11 shows the equilibrium moisture content for cocoa beans stored at different levels of relative humidity. To maintain beans below 8% moisture the relative humidity must be less than about 75% for Ghanaian and Brazilian beans. The beans from the Dominican Republic are more hygroscopic and would contain about 9% moisture in an atmosphere of 75% relative humidity. They would need to be stored at a relative humidity below about 65% to maintain moisture of 8% or less. This is probably because the beans are only partially fermented from this origin and there will be more sugars and other hygroscopic substances in the dried pulp that adheres to the shell. Therefore, partially fermented beans are more likely to stick together or form clumps and develop mould during storage and transport.

Cocoa can be stored in bulk in large heaps confined by walls to form bays, each bay containing 1000 or more tonnes of beans. A more expensive way of bulk storage is in silos. Storage bays and silos can have forced ventilation systems. This enables control of the temperature and humidity of the beans. It is also possible to apply modified atmosphere – usually air that has a low level of oxygen and a high level of carbon dioxide. This will control any pests within the cocoa (see Section 2.4.7).

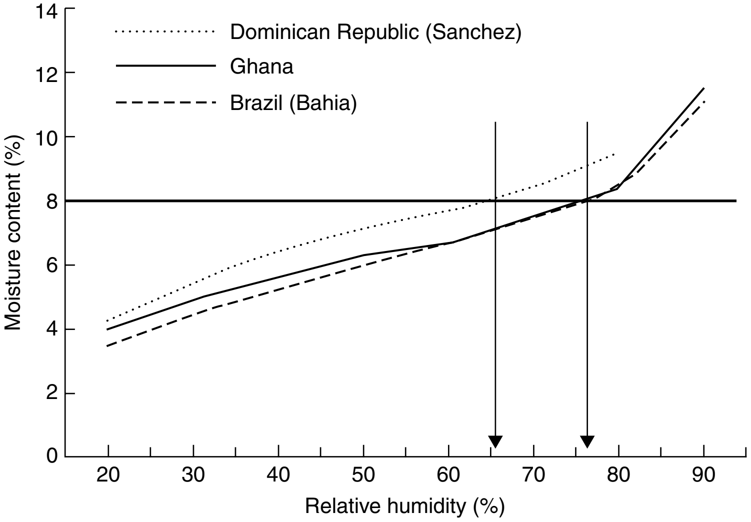


Figure 2.11 Equilibrium moisture content of cocoa beans (after Oyeniran, 1979).

2.4.7 Infestation of cocoa

Once they have been dried, cocoa beans are quite stable and will not deteriorate for several years, provided they are kept under good conditions. These should include an absence of the various insect pests that feed on cocoa beans. Cocoa is vulnerable to a very small moth, the Tropical Warehouse moth (*Ephestia cautella*). The larva (caterpillar) enters a bean, usually where the shell is damaged, and feeds and grows until fully grown. It then leaves the bean to find a suitable site to make a cocoon and pupate – this is often in the seam of the sack, on the walls or structure of the warehouse or in the ship's hold. The Tropical Warehouse moth is a particularly successful pest. Its habit of pupating away from its food enables some moths to avoid fumigation and re-infest other commodities.

Various beetles and their larvae also feed on cocoa beans and can be recognized by the powdery droppings (frass) they leave. Insect damage to cocoa beans is easily seen in the "cut test" where the frass and silk fibres produced by the larvae are obvious in the cut beans (see Section 2.5.3). Some insects only rarely enter the beans, feeding mostly on the residue of pulp adherent to the outside. Their presence can result in a consignment being described as severely infested, even though the cut test on a sample of beans does not reveal any insect damage.

Properly prepared cocoa stored in clean, pest-free areas will not become infested. Precautions must be taken to prevent infestation developing during storage and shipment. The precautions should include routine monitoring for the major pest species. Control measures need to be applied as required to the structure of the store or ship. Only pesticides approved for use in food stores should be used.

Cocoa beans can be fumigated with phosphine under gas-proof sheeting. When carried out properly, fumigation is very effective and the cocoa should not need fumigating again. Unfortunately, very few fumigations are carried out effectively and frequently some stages of the insects (e.g. the eggs) survive the treatment. In some countries, there is evidence that some pests are becoming resistant to phosphine. Various alternative solutions have been tried or are under development, but all are more costly and less convenient. Some methods rely on the use of very low temperatures (below freezing) or warm temperatures (around 50°C (122°F)) to kill the insects. Another method is to use modified atmosphere – usually oxygen depleted with high levels of carbon dioxide. These methods have the advantage that there are no chemical residues.

2.5 Quality assessment of cocoa

2.5.1 Composition of cocoa beans

Cocoa beans are essentially comprised of the cotyledons which are protected by the shell. Broken fragments of cotyledon are called nib. The shell is usually considered to be a waste material and is either used as a fuel or composted and sold as garden mulch. However, it is increasingly being treated, ground to a powder and sold as cocoa fibre products. These materials can be used as a substitute for cocoa powder or incorporated into chocolate to enhance the fibre content (depending on local regulations).

The nib is the most valuable part of the bean. Roasted ground nib (cocoa mass or cocoa liquor) is used directly in chocolate manufacturing. Alternatively it can be pressed to extract the fat, cocoa butter, an essential ingredient in chocolate (see Chapter 6). The residue then becomes cocoa powder which is used mainly in beverages, baking and desserts. Table 2.3 shows the composition of cocoa beans, nib and shell.

2.5.2 Cocoa beans: quality aspects and contracts

The quality aspects of cocoa beans can be divided into three areas:

(1) *Food safety.* These are absolute standards. Some of these limits are covered by the national food legislation in the country where the factory is located or where the products are to be sold. Any cocoa failing to meet food safety standards must not enter the human food chain. The fermentation and drying process results in high microbial levels on raw cocoa beans and the occasional presence of *Salmonella* bacteria. This hazard is controlled at the roasting stage (see Chapter 23), and the presence of *Salmonella* is not a reason to reject a consignment of cocoa beans.

(2) *Economic factors*. These relate to yield of useful material and are key determinants of the price a manufacturer is prepared to pay relative to other cocoas.

Table 2.3 Composition of cocoa beans.

	Whole dried cocoa beans (as traded)			
	%		**Typical range (%)**	
Water/moisture	7.5		5–8	
Shell (dry basis)	12.5		10–16	
Nib (dry basis)	80		78–82	
	Unfermented cocoa beans (dry, fat-free)		**Fermented cocoa beans (dry, fat free)**	
	(mg/g)		**(mg/g)**	
Total polyphenols	150–200		–	
Procyanidins	61		23	
Epicatechin	–		3–16	
	Nib		**Shell**	
	Mean (%)	**Range (%)**	**Mean (%)**	**Range (%)**
Water/moisture[a]	3.7	2–5	7.0	4–11
Fat (cocoa butter and shell fat)	53.5	48–57	2.8	2–6
Protein	12.7	11–16	14.7	13–20
Starch	6.7	6–9	8.1	6.5–9
Fibre (crude)	2.5	2.1–3.2	16.6	13–19
Ash	2.9	2.6–4.2	8.2	6.5–20.7
Theobromine	1.30	0.8–1.4	0.87	0.2–1.3
Caffeine	0.22	0.1–0.7	0.13	0.04–0.3

[a] Will vary according to storage conditions and the degree of drying or roasting.

Note: Values depend on type of beans and method of analysis.
Polyphenol compositions after Wollgast and Anklam (2000).
Nib and shell compositions after Minifie (1989) and Kirk and Sawyer (1991).

(3) *Qualitative aspects.* This includes desirable flavours and absence of off-flavours and some physical properties such as cocoa butter hardness. Qualitative factors determine whether a type of cocoa will be included in blends or recipes for chocolate.

In addition to these three areas, consumers are increasingly concerned about environmental and ethical aspects and some want environment friendly, organic or Fairtrade certification and labelling. This requires total traceability of the cocoa through the supply chain and compliance with the necessary standards. This usually adds cost and is only applied to speciality cocoas that command premium prices (see Section 2.6.9). Quality for speciality cocoas is usually determined on arrival of the cocoa at the port in the destination country.

The quality requirements from a manufacturer's view are summarized in Table 2.4. Further information can be found in Anon. (1996). However,

Table 2.4 Typical cocoa bean quality requirements for chocolate manufacturers.

Criteria		Specification or limits[a]	Reason/Comment
Food safety			
Mouldy beans		<3–5% depending on contract	Off-flavours, potential for mycotoxins, high levels of FFA
Mycotoxins	Aflatoxin	Within limits (<20 ppb in USA in foods)	Carcinogen
	Ochratoxin A (OTA)	<2 or <1 ppb proposed	Some uncertainty regarding limits. Probable carcinogen
Infested or insect damaged		<3–5% depending on contract	Wholesomeness
Pesticides		Absent or below maximum residue limits (MRLs)/ import tolerances/action levels	
Hydrocarbons	Mineral hydrocarbons	Within limits	Source is from mineral batching oils in jute sacks
	PAH (polycyclic aromatic hydrocarbons)	Within limits Proposed 2 ppb for B(a)P (benzo-a-pyrene) in EU	Source is from combustion products for example, during drying of cocoa
Heavy metals	Lead	Within limits. US FDA guidance for lead is <0.1 ppm in chocolate usually consumed by children	Source is environmental contamination
	Cadmium	Various proposals, no current limit for cocoa	Source is from the soil
Economic or yield aspects			
Moisture		<7 or 8%	Prevents mould growth, reduces yield of edible material
Bean size and bean size distribution		Typically 100 beans/100 g or 110 beans/100 g. Per cent of beans retained on certain sized sieves	Operation of processing plant. Yield of edible material. Uniformity of whole bean roasting
Shell		Typically 12–16%	Yield of cocoa nibs
Fat (cocoa butter)		Typically 50–57% in dry nib	Economic (amount of added cocoa butter needed to make chocolate)
Foreign materials		Absent or <1.5% (FCC)	Purity, yield of edible material
Flat, germinated and infested beans		<3% (FAO standard)	Yield of edible material, purity, wholesomeness (see above)

(Continued)

Table 2.4 Continued.

Criteria	Specification or limits[a]	Reason/Comment
Qualitative aspects (flavour and eating quality of chocolate)		
Unfermented (slaty) beans	For example: <5% (FCC good fermented), <10% (NYBOT Ghana main crop)	Excess slaty beans give an astringent taste and greyish colour to the chocolate. They also contain more antioxidants (polyphenols)
Cocoa flavour and desirable ancillary flavours	Various, often not specified	Flavour
Off-flavours (e.g. smoky, hammy)	Absent	Flavour
Cocoa butter hardness	Various	Eating quality (snap and melting properties) of chocolate
Free fatty acids (FFA) in cocoa butter	<1.75% in cocoa butter (EU maximum)	Eating quality (snap and melting properties) of chocolate

[a] Frequently limits are specified for finished products not cocoa beans. Where they are specified for cocoa beans, they often apply to the whole bean (i.e. including the shell).

Table 2.5 Comparison of cocoa bean contract standards (adapted from ITC, 2001).

	Description (example of growth/ grade)	Bean count	Faults			Moisture (%)	Foreign material (%)
			Mould (%)	Slate (%)	Infested (%)		
FAO model ordinance[a]	Grade 1	NS[b] (uniform in size)	3	3	3[c]	7.5	'Virtually free'
FCC[d] (Europe)	Good fermented. Main crop	100/100 g	5[e]	5	–[e]	NS	<1.5%[f]
ICE/CMAA[g] (USA)	Ghana (main crop)	1000/ kg	4[h]	10	4[h]	NS	NS

[a] FAO specifies that cocoa must be fermented, free of foreign odours and must not be adulterated.

[b] NS = not specified.

[c] Includes germinated and flat beans as well as insect damaged.

[d] FCC specifies the beans shall be uniform in size, homogenous and fit for the production of foodstuffs. The beans must be virtually free from contamination, which includes smoky, hammy or other off-flavour, taste or smell.

[e] Max 5% defectives (= mouldy + infested).

[f] <1.5% waste passing through 5 mm sieve. Additionally flat beans, bean clusters, broken beans and foreign material must not be excessive.

[g] ICE/CMAA specifies that hammy or smoky cocoas are not deliverable.

[h] Maximum amount of mould + infestation is 6% (US FDA Defect Action Levels).

most cocoa is purchased using standard trade contracts, which may not include all the aspects considered important by the manufacturer. In Europe, the Federation of Cocoa Commerce (FCC) set contract standards for cocoa bean quality. In the USA, the Food & Drugs Administration (FDA) and the Intercontinental Exchange (ICE) set the standards (see Table 2.5). The cocoa trade associations have arbitration schemes to cover the rare occasions when the lots of cocoa tendered fail to meet the contract terms and this may result in the supplier having to pay an allowance or replace the disputed beans. The producing countries usually have their own internal standards that are often mandatory. These standards are frequently based on the United Nations Food & Agricultural Organisation (FAO) model ordinance (reprinted in Anon., 1996).

2.5.3 Cocoa beans: sampling and the 'cut test'

Proper sampling is an essential first step to making an assessment of quality. Cocoa beans in sacks are sampled using a trier or sampling stick, which is inserted between the fibres of the bag. Typically between 20% and one third of the sacks will be sampled according to one of several proscribed procedures. Alternative arrangements are made for cocoa shipped in bulk. The samples maybe combined and bulked or mixed, and then reduced in size ('quartered').

Firstly, beans are classified by weight (usually the number of beans in 100g (3.5oz) or 1kg (2.2lb). Many methods specify that 300 beans will be weighed (to give the bean count per 100g (3.5oz)). In USA 250g (8.5oz) of beans are weighed out, the number of beans counted and multiplied by four to give a bean count per kilogramme. The FCC method specifies weighing out 600g of beans, counting and dividing by 6 to get the bean count per 100g.

Secondly, the level of unsatisfactory beans (also termed faulty or defective beans) is determined by the 'cut test'. This test identifies beans that are visibly mouldy, slaty (i.e. unfermented), infested, germinated, or flat (i.e. containing no nib or cotyledon). The cut test normally uses the same beans that have been weighed and counted. Many methods specify that 300 beans will be cut lengthwise to expose the cotyledon. This is somewhat tedious and the number of beans is frequently reduced, which also lowers markedly the statistical validity of the results. Alternatively, a guillotine device is available (Magra cutter), which will cut 50 beans at a time.

Mould is especially undesirable: even as few as 3% visibly mouldy beans can give unpleasant musty or mouldy flavours to chocolate. Some moulds under certain conditions also produce harmful fungal toxins, collectively called mycotoxins (see Section 2.5.4). Mouldy beans can have high levels of free fatty acids which affects the quality of the cocoa butter (see Section 2.5.5).

Slaty beans are beans in which more than 50% of the cotyledon is grey or slaty in colour. These beans have not undergone fermentation and they have a low level of cocoa flavour with high levels of astringency. The 'cut test' is often used to assess the degree of fermentation by counting the fully brown, brown/purple and purple coloured beans. This is very subjective and is unreliable except when a single assessor is checking beans from a single source. The results do not correlate well with the quality of the chocolate made from the beans.

Insect-damaged beans are those where the bean has been penetrated by an insect, which feeds on the cotyledon. These should not be present. Any number will involve loss of material and a risk of contamination with fragments of the insect. Germinated beans are those where the seed has started to grow before being killed during the fermentation or drying process and the shell has been pierced by the growth of the first root. In the dry germinated bean, the root usually drops out, leaving a hole, which makes the bean more easily attacked by insects and moulds. Flat beans are those which have begun to form, but have not developed or filled out. There is no useful cotyledon in them so they simply add to the shell content, which is waste.

For the chocolate manufacturer the yield of nib from a lot of cocoa is very important, as is the amount of cocoa butter within the nib. Higher levels of cocoa butter mean that lower amounts will need to be added later on in the manufacturing process. Nib yields are determined in the laboratory, normally by shelling a number of beans by hand. Results are usually expressed on a dry basis (i.e. at 0% moisture). It is important to note that laboratory measurements do not take account of bean cleaning losses and ease of winnowing. Therefore, actual yields should be assessed on the production plant (see Chapters 6 and 21).

2.5.4 Contaminants and residues (see Chapter 23)

Modern methods of analysis can detect minute or trace levels of undesirable materials in foodstuffs. This has given rise both to some legitimate concerns and some 'food scares' which were not based on sound rationale.

Heavy metals, such as lead and cadmium, are found at very low levels in many foodstuffs including cocoa products. The source is mainly environmental including soil type, fertilizers, pesticides or vehicle emissions. The levels found depend on the origins of the cocoa materials and the recipe and process. There is a concern that some products could provide a significant proportion of the tolerable daily intake. However, it is not known how 'available' the heavy metals are within cocoa: i.e., it is possible that the majority will be excreted and not absorbed by the human body. Studies are underway within the industry to minimize the contamination and assess the risks.

Mineral hydrocarbons have traditionally been used in the manufacture of the jute sacks. Very small quantities of mineral oil was transferred to the cocoa beans and then into cocoa products. As a result of a joint initiative covering several foodstuffs, the sack manufacturers carried out some developments and have switched to using a food grade vegetable oil. Recently, attention has focussed on polycyclic aromatic hydrocarbons (PAH), such as benzo-a-pyrene (B(a)P) which result from combustion products and are generally present at low levels in the environment. In cocoa, the main risk is from artificial drying or sun drying in polluted areas such as roadsides. Hydrocarbons are fat soluble and will be found at higher concentrations in cocoa butter.

Mycotoxins such as (Ochratoxin A or Aflatoxin) are produced by some types of moulds under certain conditions. However, there is no correlation between the level of visible mould revealed in the cut test and the amount of mycotoxins present. Generally, aflatoxin is not a concern in cocoa. Ochratoxin A (or OTA) is present in cereals and most agricultural commodities. In cocoa, it is frequently present at extremely low levels, and cocoa products are not a significant source of OTA in the diet. OTA appears to develop in damaged pods prior to the fermentation stage.

The manufacturer needs to have a monitoring process in place for these contaminants and also needs to keep aware of new, potential contaminants. In all cases, the manufacturer must ensure food safety and compliance to the relevant legislation.

2.5.5 Cocoa butter hardness

The quantity of fat and its melting characteristics, especially hardness, depend on the variety or type of cocoa, the fermentation and drying and the environmental conditions. In particular, the average daily temperature during the last few months of pod development affects the hardness of the cocoa butter: lower temperatures give butters that are softer or have a lower melting point. Generally cocoa butters made from Indonesian beans are harder than West African butters, which in turn are harder than Brazilian butters.

Mouldy cocoa beans caused by inadequate drying contain high levels of free fatty acids (FFA). This also has an undesirable softening effect on the cocoa butter and the level of FFA is limited by regulations in some countries (e.g. 1.75% in the European Union) and FCC contract rules.

2.5.6 Sensory evaluation

Flavour is the most important property for chocolate manufacturers. Off-flavours (such as smoke or putrid over-fermentation flavours) can be readily detected by tasting roasted ground nib or cocoa mass (cocoa liquor) directly. Alternatively these can be made more palatable by mixing the mass with finely ground sugar and/or water or preparing a small-scale dark chocolate. These tests are essential for beans from origins that are inconsistent in quality or prone to off-flavours. The level of cocoa flavour and other flavours (such as acidity, bitterness, astringency and any ancillary flavours for fine cocoas) are more difficult to assess. A well-trained sensory evaluation panel with appropriate test designs and statistical analysis of results is required. Quality criteria that can be applied to the semi-processed cocoa materials (cocoa butter, powder and mass) are described in Chapter 6.

2.6 Types and origins of cocoa beans used in chocolate

2.6.1 Sources of bulk cocoas

Over 95% of the world's cocoa production is classified as 'bulk', 'basic' or 'ordinary' cocoa. This does not refer to the delivery size or method of transportation; neither does it imply cocoa of inferior quality. Bulk cocoas generally come from the Forastero-type cocoa trees (see Section 2.2.2). They are used to manufacture milk and dark chocolate, cocoa mass, cocoa butter and cocoa powder. The other type of cocoa is 'fine' or 'flavour' cocoa (see Section 2.6.9).

Chocolate manufacturers need to produce a product of consistent quality from a raw material that may be variable. It is usual to apply some selection to the origin and type of cocoa beans used for chocolate making. The only significant volumes of cocoa exports in the world are from West Africa and Indonesia: the other large producing countries having internal markets for their cocoa products. Manufacturers will frequently blend beans from different origins to achieve a consistent end product of the desired quality.

In choosing the type of cocoa and the recipe or blend there are a number of factors to consider. These include availability of the required quantity, the reliability of supply, consistency of quality (especially flavour), price, yield (both of cocoa mass and the % fat in the mass) and how easy it is to process. Blending can be carried out before or after roasting. If it is carried out after roasting, this allows different levels of roasting to be used for different types of beans.

It is also common practice for chocolate manufacturers to purchase cocoa mass or liquor from cocoa processors. Increasingly, these may be situated in the cocoa producing countries (known as origin processors). Some chocolate manufacturers are reluctant to purchase this origin cocoa mass because of fears of poor hygiene leading to a risk of *Salmonella* contamination. They lose control of the quality of the cocoa beans and they cannot define the level of roast. However, standards have improved in recent years and most origin factories produce consistent good quality cocoa mass, butter and powder.

Some of the quality characteristics of the main origins and types of cocoa are described below.

2.6.2 Côte d'Ivoire (Ivory Coast)

Cocoa production increased dramatically since 1970, and from 1977 the Côte d'Ivoire (Ivory Coast) has been the world's largest producer of cocoa. The country now produces about 1.3–1.4 million tonnes of beans each year (40% of the world crop – see Figure 2.2). The cocoa is nearly all grown by smallholders, many of whom are immigrants. Recently (2000 onwards) ethnic and religious tensions have led to political instability, which has adversely affected industrial and agricultural development and increased the vulnerability of supply. A small proportion of the cocoa finds its way into neighbouring countries for sale and export.

The Côte d'Ivoire does not have an effective internal grading scheme. The result is that some of the cocoa is badly prepared, being inadequately fermented and dried. This leads to higher levels of both mould in the beans and FFA in the cocoa butter. Cocoa beans are blended in the ports to achieve minimum export grade standards. An increasing quantity of Côte d'Ivoire cocoa is processed locally and the semi-finished products exported. The local market for confectionery is very small.

Perfectly good chocolate can be made from good fermented Côte d'Ivoire beans. This cocoa tends to have a lower yield of nib and cocoa butter than cocoa from Ghana: a fact which is reflected in the price.

2.6.3 Ghana

In the late nineteenth century, cocoa was brought to Ghana, from the island of Fernando Po (Bioko). Cocoa growing developed strongly during the twentieth century. Ghana is currently the second largest producer in the world with around 20% of the world crop (around 700 000 tonnes – see Figure 2.2). An increasing amount of the cocoa beans is processed locally.

The Ghanaian farmer uses the traditional heap method to ferment the cocoa and drying is on raised mats in the sun. Owing to absence of artificial drying, there is no risk of smoke contamination. The hybrid planting material, based on Upper Amazon Forastero and Amelonado varieties, and the traditional processing methods give a full chocolate flavour very suitable for the manufacture of chocolate. The quality control in the internal cocoa marketing system is also well established and effective. This has resulted in Ghana cocoa being the world's foremost quality bulk cocoa against which other cocoas are judged. Hence, it commands a price premium on the world market.

2.6.4 Indonesia

Cocoa production in Indonesia expanded rapidly at the end of the twentieth century: production in 1980 was about 10 000 tonnes rising to and stabilizing at 400 000–450 000 tonnes in the early twenty-first century. Cocoa is grown in most parts of Indonesia, but the principal areas are Sulawesi, Sumatra and Java. There is potential for substantial increase in Indonesian cocoa production, but this is dependant on local political and economic factors.

Indonesia is mainly a bulk cocoa producer with the cocoa coming from similar planting materials to those found in Malaysia (varieties derived from Upper Amazon and Trinitario types).

In Sulawesi, most of the production is from smallholders but some 95% of the production currently receives little or no fermentation. The cocoa is normally dried in the sun and is consequently free from the smoke contamination frequently associated with artificial drying. The lack of fermentation produces a cocoa that is very bitter and astringent. Fermented or partially fermented Sulawesi cocoa has a medium level of cocoa flavour. It has high shell content and a low percentage of fat in the nib. These factors explain why Sulawesi cocoa is traded at a discount. For chocolate makers, the plus points are the hard cocoa butter (high melting point) and the absence of off-flavours (the bitterness and astringency are flavours normal to cocoa). Sulawesi cocoa can be included at low levels in blends with other beans to make chocolate.

Generally, Indonesian bulk cocoa is of variable quality although efforts are underway to improve the quality. A proportion of the crop is processed in Indonesia, Malaysia and Singapore. Purchasers of cocoa materials should note that these factories also import cocoa from West Africa and other origins, mainly to improve the quality of the cocoa products.

There is a small production of a fine cocoa that is concentrated in Java. This is a light-breaking, 'Criollo' type of cocoa (also called Java Fine or Edel cocoa). Actually, this is not a true Criollo cocoa but a Trinitario type that produces white cocoa seeds. Java light-breaking cocoa is mainly used for its colour. A dark chocolate made from these beans has the light brown appearance of a milk chocolate.

2.6.5 Nigeria

Production levels are relatively stable at around 180 000–200 000 tonnes. Smallholders produce all Nigerian cocoa and in general the trees are old (many are 25–75 years old). Nigerian cocoa used to have a reputation for quality that approached Ghana. However, several years ago, the internal market was quickly deregulated. Local traders inexperienced in cocoa entered the market and the quality controls were lost. The quality of Nigerian cocoa is variable and it sells on the market for similar prices to Côte d'Ivoire.

2.6.6 Cameroon

Unlike the rest of West Africa, Cameroonian cocoa is of the Trinitario variety. It is generally purchased to make reddish coloured cocoa powder. Very little Cameroonian cocoa is used to make chocolate due to the risk of smoke flavour (from the artificial drying) and the price which is sometimes at a premium.

2.6.7 Brazil

Brazil used to be a substantial producer and exporter of cocoa. The largest cocoa growing area in Brazil is in Bahia, where cocoa is grown on both medium sized farms and in large plantations. Brazilian production grew strongly reaching just over 400 000 tonnes in the 1984/85 season. It then declined in the late 1980s and 1990s due to Witches' Broom disease becoming established in Bahia. The low level of cocoa prices meant there was no economic way to control this disease, with the result that production is now around 160 000–170 000 tonnes per year.

Brazilian cocoa has a good level of cocoa flavour. It tends to be more acidic than West African due to the fermentation method (in large wooden boxes). In addition, artificial drying is the practice and it is not always done satisfactorily. There is a risk of finding smoky flavours, which can be reduced by careful selection of the beans. Brazilian cocoa butter from Bahia has a lower melting point (i.e. it is softer) than West African.

There is a substantial local processing industry and market for chocolate products and consequently there is little export of cocoa beans.

2.6.8 Ecuador

Ecuador is an exporter of both bulk and 'fine' or 'flavour' cocoas. Unfortunately, some of the cocoa is poorly prepared and inconsistent in quality so

Table 2.6 Export of fine or flavour cocoas by country.

Country	Volume of cocoa beans exported[a]	Percentage of total exports considered to be fine cocoa[b]	Approximate volume of fine cocoa exported	Special character (taste or colour)
Ecuador[c]	74 200	75	55 650	Arriba: aromatic, floral, spicy, green
Grenada	600	100	600	Brown fruit, molasses
Indonesia	339 900	1	3 400	Java light breaking: caramel, acidic
Jamaica	500	100	500	Fruity, raisin
Madagascar	5 090	100	5 090	Light breaking criollo: nutty
Papua New Guinea	41 320	25%	10 330	Fruity, floral, acidic
São Tomé and Principe	3 120	35%	1 090	Fruity, acidic
Trinidad and Tobago	1 110	100%	1 110	Molasses, caramel and raisin
Venezuela	7 638	100%	7 640	Various types exhibiting most of above
Total			**85 400**	

[a] 3 year average 2002/05 (ICCO, 2006).
[b] ICCO (2005).
[c] Percentage of fine cocoa exported by Ecuador may only be 30–40% due to mixing.

it sells at a lower price. There is a small local processing industry. Ecuador is the world's largest producer of fine cocoa (see Table 2.6). The fine cocoa character comes from the Nacional cocoa and hybrids of Nacional with Venezuelan Trinitario. This cocoa, which is called Arriba, has a full cocoa flavour with additional floral, spicy flavours. Some manufacturers seek and pay substantial premiums for good quality Arriba cocoa for use in speciality dark chocolate. The availability of this cocoa is limited. New plantings of cocoa in Ecuador are usually of varieties that do not give Arriba flavour.

2.6.9 Speciality, origin and 'fine' or 'flavour' cocoas

The term speciality cocoa covers a range of types or grades, which generally command premium prices over bulk cocoas. They are not traded as a commodity but have their own supply chains which preserve the identity of the individual lots and frequently allow for the purchaser to test the quality prior to delivery. The cocoas maybe from specific geographic origins, varieties, environment friendly growing regimes (e.g. certified organic, rainforest protection) or purchased under schemes that directly benefit the growers (e.g. Fairtrade) (see Sections 2.2.2, 2.2.9 and 2.4.3).

The market for chocolate products made from speciality cocoas has shown rapid growth in the early twenty-first century, which has not been matched by a growth in production. There are various estimates for the production of speciality cocoas: certified organic is probably around 15 000–25 000 tonnes and Fairtrade around 6000 tonnes for 2005/06 (n.b. some cocoa can be both organic and Fairtrade).

'Fine' or 'flavour' cocoas are the oldest and largest category of speciality cocoas and the production is about 85 000 tonnes. There is no agreed definition of 'fine' or 'flavour' cocoas except they are purchased at a premium price for their flavour or colour (e.g. light breaking). Fine or flavour cocoas have some ancillary flavours that are described variously as fruity, raisin, brown fruit, floral, spicy, aromatic, nutty, molasses and caramel (Fowler, 1994). They are mainly used to make dark chocolate in which their special flavours (or colour) can be appreciated. These cocoas generally come from Criollo, Trinitario or Nacional-type trees. However, not all cocoas of these varieties are classified as 'fine' or 'flavour'. If they do not have the desirable flavour characteristics or, if the fermentation and drying is poor, they are traded as bulk cocoas and may even sell at a discount to the main origins.

In addition to the Arriba from Ecuador and the Java light-breaking cocoa from Indonesia mentioned above, 'fine' or 'flavour' cocoas can be obtained from Venezuela, the Caribbean, São Tomé and Principe, Madagascar and Papua New Guinea. Most of this cocoa is from varieties of Trinitario trees, but some from Madagascar and Venezuela is from much sought after light-breaking Criollo varieties (although not all their production is necessarily of this type). Prices depend on supply and demand for each type; typical premiums start from about 20% rising to double or even treble the bulk cocoa bean prices.

Conclusions

It is impossible to make chocolate without cocoa and its quality and availability is of paramount importance to the confectionery industry. With cocoa production concentrated in West Africa, future supplies are by no means assured. Cocoa makes a substantial economic contribution to many rural economies. There exists great potential to improve both yields of cocoa plantings and farmer incomes. Compared to many other crops it is environmentally friendly.

Demand for cocoa products is expected to continue to increase, mainly due to the universal appeal of the unique cocoa flavour. In the developed markets, there is a clear trend towards speciality chocolate products which are showing rapid growth (albeit from a small base). Quality, including food safety, traceability, sustainability and environmental impact are key and will continue to provide challenging issues to the complex supply chain that exists with cocoa (for further information see Flood and Murphy, 2004).

No chocolate manufacture can afford to neglect this vital ingredient and remain divorced from the issues surrounding cocoa production. As has been shown, many changes have taken place in recent years and are likely to continue to do so over the foreseeable future.

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Abbreviations/Acronyms/Websites

CMAA	Cocoa Merchants' Association of America	http://www.cocoamerchants.com
ED&F Man	Cocoa trader (cocoa statistics, free registration)	http://www.edfman.com/Cocoa.php
FAO	Food & Agricultural Organisation of the United Nations	http://www.fao.org/
FCC	Federation of Cocoa Commerce	http://www.cocoafederation.com
FDA	US Food & Drug Administration	http://www.fda.gov/
FLO	Fairtrade Labelling Organisations International	http://www.fairtrade.net
ICA (formerly IOCCC)	International Confectionery Association (source of ICA/IOCCC analytical methods)	http://www.international-confectionery.com/
ICCO	International Cocoa Organisation	http://www.icco.org
ICE	Intercontinental Exchange	http://www.theice.com/cocoa.jhtm/
LIFFE	London International Financial Futures and Options Exchange	http://www.liffe.com
NYBOT	New York Board Of Trade	http://www.nybot.com
WCF	World Cocoa Foundation	http://www.worldcocoafoundation.org/

Chapter 3

SUGAR AND BULK SWEETENERS

Ch. Krüger

3.1 Introduction

Sugar is the sweet-tasting crystallized saccharide extracted from sugar cane or sugar beet. Both the beet and the cane produce an identical natural substance, which is chemically termed 'sucrose' or 'saccharose'. Sugar cane has been grown in Melanesia, India and China since prehistoric times. The discovery of sucrose in the beet plant *Beta vulgaris* was made in Prussia in the eighteenth century. The first method of extracting the sucrose from beet was developed by Franz Karl Achard, the director of the Academy of Sciences in Berlin, at the end of the eighteenth century. In 1799 this was even considered by the author of a scientific publication as 'the most important discovery of the eighteenth century' (Bruhns, 1997).

Sucrose is a disaccharide composed of the chemically linked monosaccharides glucose and fructose. This linkage, however, may be cleaved hydrolytically by acids or by the enzyme invertase (β-ᴅ-fructofuranosidase). The resulting mixture consists of equal parts of glucose and fructose, and is called invert sugar.

A great many other saccharides also exist, such as the monosaccharides glucose (dextrose) and fructose, the disaccharide lactose, and sugar alcohols, for instance sorbitol and xylitol. For the production of chocolate, sucrose is by far the most important sugar. With the increasing demand for low calorie, reduced glycaemic index, or toothfriendly products, however, other sweeteners are becoming more widely used.

3.2 The production of sugar

For the production of beet sugar, the sugar beet, which contain about 14–17% sucrose, are cleaned and cut into beet slices. These are then extracted in hot water by counter-flow processes. Together with the sugar, mineral and organic substances from the beet find their way into the raw juice produced. Since these non-sugar substances strongly inhibit the crystallization of the sugar, the solution must be purified. This is carried out by adding slaked

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lime in order to flocculate or precipitate the majority of the contaminants and even decompose a small proportion of them. When carbon dioxide is subsequently bubbled through the solution it precipitates the excess calcium hydroxide from the slaked lime in the form of calcium carbonate. This is then filtered off together with the precipitated non-sugar substances.

The clarified weak sugar solution produced in this way has a solids content of approximately 15% and is subsequently evaporated to about 70% dry solids. This solution is then further concentrated under vacuum until crystallization starts. Cooling this syrup-crystal mix leads to further crystallization of the sugar. The separation of the sugar from the first molasses or mother syrup is frequently performed in a centrifuging process. The crystallization always requires several processing stages, since it is not possible to recover all of the sugar in a single step. White sugar therefore has to be crystallized in three or four different steps. Raw sugar factories produce brown raw sugar as an interim product by a simplified crystallization process. This type of sugar contains impurities that are removed by means of further recrystallization in sugar refineries. A by-product, called molasses, is the syrup obtained during the final crystallization step, from which sugar can no longer be crystallized because of the high concentration of non-sugar substances. Beet molasses with about 83% dry solids contains about 50% sucrose and up to 11% inorganic substances, 4–5% organic acids and about 13% nitrogenous organic compounds. In addition, about 1–2% of the trisaccharide raffinose and traces of invert sugar may be found (Hoffmann *et al.*, 2002).

Sugar cane has a sucrose content of 11–17%. The raw juice in this case is manufactured by squeezing the crushed stalks on roller mills or by means of extraction equipment in combination with roller mills. What remains is the so-called bagasse, which serves either as fuel or as raw material for the production of paper, cardboard, hard particle board, etc. Since raw juice from sugar cane contains more invert sugar than the equivalent beet juice, a more gentle treatment is required to clarify the juice. A lime treatment, as used for the beet, would degrade the invert sugar, leading to the formation of undesirable brown colours. The chemical treatment required may be carried out by one of the following methods:

- a gentle lime treatment;
- a lime treatment plus ‘sulphitation’ with sulphur dioxide;
- a lime treatment plus ‘carbonation’ with carbon dioxide. This resembles juice clarification in the beet sugar industry, without, however, using the high temperatures normally employed in the latter.

The chemical juice clarification is preceded by a mechanical separation of suspended plant particles, for example by using hydrocyclones and bow-shaped sieves. Evaporation and crystallization closely resemble the procedures used for the production of beet sugar. However, special purification, as well as the above clarification steps, are necessary in refining of raw cane sugar because of the different composition of the non-sugar contaminants. These include carbonation with slaked lime and carbon dioxide or phosphatation, i.e. a slaked lime phosphoric acid treatment as well as a special colour removal with activated carbon.

Cane molasses of 75–83% dry solids contain about 30–40% sucrose as well as 4–9% glucose, 5–12% fructose, 1–4% other reducing substances (as invert sugar), 2–5% other carbohydrates, 7–15% inorganic substances, 2–8% organic acids and 2–5% nitrogenous organic compounds (Chen *et al.*, 1993).

3.3 Sugar qualities

The sugar industry supplies a wide range of crystallized and liquid sugars. Crystallized sugar is graded according to its purity and crystal size. The purity of all types of white crystallized sugars is extremely good. The sucrose content is generally more than 99.9% and only rarely falls below 99.7%. Any differences in quality result from minute quantities of non-sugar substances, which are mostly present in the syrup layer surrounding the sugar crystals.

In Europe, the quality criteria for sugar are determined by European Union (EU) market regulations and national legislation on sugar types. The EU sugar market regulations break crystallized sugars down into four categories, the quality criteria of which are summarized in Table 3.1.

The degree of optical rotation is a yardstick for the sugar purity. Refined sugar, as a rule, gives values of 99.9°S (this is a purity measurement, not degrees of rotation). The water content must not exceed 0.06% and in general does not exceed 0.03% in good quality crystallized sugar. The amount of invert sugar present should not be more than 0.04%. Once again the values obtained in practice are frequently much lower. Colour in solution

Table 3.1 Quality criteria of white crystallized sugar according to EU market regulations.

Category	**1 Refined sugar**	**2 White sugar standard quality**	**3**	**4**
Optical rotation (°S, min)	–	99.7	99.7	99.5
Water (%, max.)	0.06	0.06	0.06	–
Invert sugar (%, max.)	0.04	0.04	0.04	–
ICUMSA colour type colour type	(2)	(4.5)	(6)	–
unit (max. points, 0.5 units = 1 point)	4	9	12	–
Ash by conductivity (%)				
(max. points, 0.0018% = 1 point)	0.0108	0.0270	–	–
	6	15		
Colour in solution ICUMSA units,	(22.5)	(45)	–	–
max. points (7.5 units = 1 point)	3	6	–	–
Total score according to EU Point score (max.)	8	22	–	–

Table 3.2 Different grades of sugar according to their particle size.

Coarse sugar	1.0–2.5 mm grain size (0.04–0.1 in.)
Medium fine sugar	0.6–1.0 mm grain size (0.02–0.04 in.)
Fine sugar	0.1–0.6 mm grain size (0.004–0.02 in.)
Icing sugar	0.005–0.1 mm grain size (0.2×10^{-3} – 0.004 in.)

is measured in a 50% solution with a pH value of 7.0 at a wavelength of 420 nm. The coefficient of extinction established in this way and multiplied by 1000 represents one ICUMSA unit (International Commission for Uniform Methods of Sugar Analysis). The ICUMSA colour type (Braunschweig system) is determined by visual comparison with calibrated colour standards, which may be obtained from the Nordzucker InnoCenter GmbH, formerly The Institute for Technology of Carbohydrates – Sugar Institute, Braunschweig, Germany. The ash content is determined in a 28% solution by conductivity measurements as the so-called 'conductivity ash'. According to the method employed, 1 μS/cm in a 28% solution represents 5.76×10^{-4}% ash. The values thus determined are converted into points and the points added up to give a total score for the sugar. As a rule, category 2 sugar is used for the manufacture of chocolate. Category 3 sugar is slightly cheaper and of a quality, which in most cases suffices for the manufacture of chocolate. It is, however, not available in many countries.

White crystallized sugar should be free flowing and have crystals of uniform particle size. There are no legal stipulations regarding grains or particle size. Nevertheless, the following grading (see Table 3.2) may be carried out by sieving and is more or less generally accepted (Diefenthäler, 1974).

The manufacture of chocolate masses is predominantly based on the use of medium fine sugar. Some chocolate manufacturers, however, insist on certain specifications concerning the particle spectrum. For example, some factories, which refine masses in a two-step procedure (see Chapter 7) specify a spectrum of 0.5–1.25 mm (0.02–0.05 in.) with an amount of fine grain (<0.2 mm (0.008 in.)) up to, but not exceeding, 2%.

3.4 The storage of sugar

In most cases, sugar is delivered to the chocolate industry by means of road tankers and not, as in the past, in bags or sacks. The sugar is pneumatically discharged from the vehicles into silos, where it is stored until further processing. Four factors are important in the silo storage of crystal sugar (Kelm, 1983): grain structure, moisture content, apparent of bulk density and angle of repose.

The grain structure of crystallized sugar is determined by the grain size, shape of the grains and the grain size distribution. The sugar industry supplies sugar that has been sifted to well-defined particle sizes, shows a good fluidity and is thus suitable for silo storage. In European countries, such as the UK, France and Germany, the chocolate industry is mainly supplied with sugar within the size range 0.5–1.5 mm (0.02–0.06 in.). The amount of dust (grain size <0.1 mm (0.004 in.)) is generally below 1% at the time of delivery in a road tanker.

The sugar should, if possible, consist of regular-shaped individual crystals, since irregular conglomerates have a detrimental effect on the bulk sugar's rheological properties. Problems may also arise from sugar dust. This may be formed during pneumatic handling because of friction against the inner surfaces of pipelines, especially at the site of manifolds. The amount of fine grain (<0.2 mm (0.008 in.)) and dust (<0.1 mm (0.004 in.)) present in the sugar correlates with its flowability and both should therefore be kept as low as possible. With 10% dust, storage and discharge problems are likely to occur. At dust levels of 15% or more, proper silo storage becomes impractical (Gaupp, 1972). Thus, special attention should be paid to ensuring an optimum layout of handling equipment, such as pipeline design, manifold radius and feeding rate, in order to keep the mechanical breakage of the sugar as low as possible.

A minimum feed rate of about 11 m/s (36 ft/s) is required for sugar transport. However, the handling conditions should be designed in such a way that the feeding rate does not exceed a speed of about 22 m/s (72 ft/s) (Tills, 1970).

The moisture content of sugar is extremely low. Its actual level, however, has a decisive influence on its storability. After drying and cooling, freshly produced sugar has a total water content of about 0.1%, which is further reduced to 0.03–0.06% by conditioning in the silo of the sugar factory.

The surface moisture of the sugar changes as a function of the relative humidity of the ambient air. Figure 3.1 shows this dependency by means of the sorption isotherms of sugars of differing purities at 20°C (68°F) (Kelm, 1983). Each sorption isotherm is a function of the sugar's purity and also of its ash content, traces of invert sugar and crystal size. As may be seen, the curve runs almost parallel to the abscissa at 20–60% air relative humidity. This implies that there is practically no water uptake even when the relative humidity of the air is increasing. Only when the relative humidity of the air exceeds 65% water is increasingly absorbed on the crystal surface. This implies that proper storage requires a temperature of 20°C (68°F) and a relative humidity ranging from 20% to 60%.

A relative humidity of more than 65% exponentially increases the water content in the sugar. Wet sugar must be avoided at all costs as it can become chemically and microbiologically contaminated. In addition, if wet sugar is stored at a relative humidity below its equilibrium relative humidity (ERH) the sugar will cake during drying and become lumpy.

Purer sugars (category 1 with lower ash content) and sugars with a coarser particle structure possess superior storage properties. On delivery, the surface water content of any sugar should not exceed 0.03% (Neumann, 1974).

According to 1972 EU sugar regulations, the water content in crystallized sugar, measured by loss on drying may reach a maximum of 0.06%.

External sugar silos should be equipped with adequate insulation as well as with heating elements in the silo walls to avoid the problem of condensation.

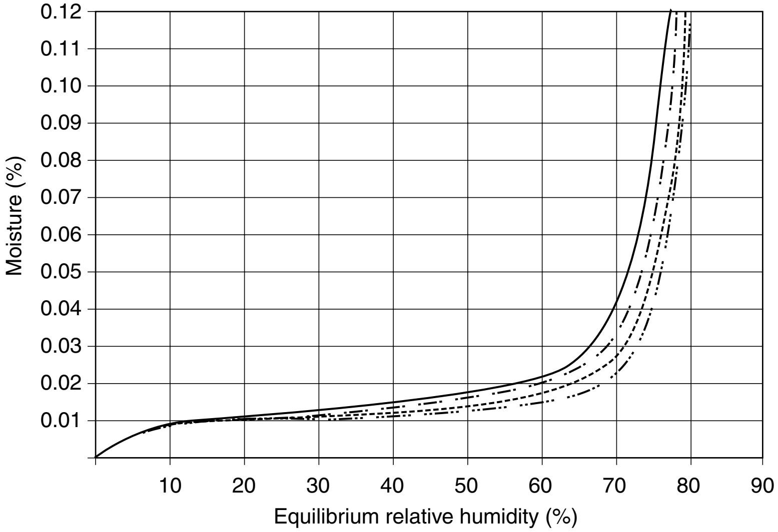

Figure 3.1 Sorption isotherms for crystallized sugars at 20°C (68°F) (Kelm, 1983), Key: —, white sugar, fine, 0.0130% ash content; —·—·—, white sugar, coarse, 0.0135% ash content; ------, refined sugar, fine, 0.012% ash content; —· · —· · —, refined sugar, coarse, 0.0012% ash content.

However, some outdoor silos are constructed without insulation, but the headspace in the silos is continuously filled with dried air, fed in through pipelines. Sometimes only the supporting case is heated.

The bulk density depends on crystal size and size distribution, but for a typical standard white granular sugar the maximum bulk density may be taken to be 850 kg/m³ (53 lb/ft³). When designing silo systems in practice, however, it is somewhat less and only reaches 750 kg/m³ (47 lb/ft³) during filling. At a surface moisture of 0.02–0.04%, the angle of repose of the sugar varies between 35° and 41°. The layout of sugar silos is often based on an angle of repose of 45–50°, with the discharge level in the tapered part being inclined at least 55° towards the horizontal. If the discharge angle is too small, proper discharge may be impeded. This may even lead to partial segregation, since larger crystals fall out more easily, whereas the smaller ones stick to the slip plane, where they build up into a layer.

3.5 Sugar grinding and the prevention of sugar dust explosions

In contemporary chocolate production a two-stage refining process is normally used (Chapter 7). This employs a two-roll pre-refiner to pre-grind granulated sugar together with other solid ingredients, which then become the feed material for a five-roll operation. More traditionally, in some chocolate factories the sugar is still pre-crushed to powdered or icing sugar, before being mixed with the cocoa mass, the milk powder and other ingredients and then roller refined in a single stage process. Crystallized sugar is a brittle, medium-hard material. Its crushing during grinding takes place following fracturing processes, triggered by elastic tensions within the crystal. These fractures start propagating in the areas of minute structural flaws, which are always present in solid bodies. Since the frequency of such structural flaws is reduced with decreasing particle size, a higher energy input is required for the production of new interfaces when very fine sugar is desired.

Three stress mechanisms are involved in the crushing of solid bodies by mechanical means (Rumpf, 1959):

- compression crushing between two solid surfaces;
- impact crushing by a solid surface or by particle–particle collisions;
- using the surrounding medium to shear the material, i.e. solid surfaces are not involved.

Impact stressing is the most effective way of crushing sugar (Niedieck, 1971, 1972), and crushing by impacting with a single solid surface is the most common principle of present-day sugar mills. Table 3.3 shows a classification of sugar mills according to the type of breaking mechanism employed (Heidenreich and Huth, 1976).

Obtaining a closely defined particle spectrum during the grinding process is a major objective in the crushing of granulated sugar, because it results in improved flow properties of the chocolate masse produced. However, each mill will give its own particle size distribution in practice (see Chapter 7). For organoleptic reasons the maximum particle size should not exceed about 30 μm (1.2×10^{-3} in.) in chocolate. On the other hand, 6 μm (0.2×10^{-3} in.) is the minimum size, if optimum flow properties are to be achieved in the chocolate masse (Niedieck, 1971, 1972) (see Chapter 10). Numerous attempts have been made to fine-grind crystallized sugar within these limits. However, practice has shown that these restrictions are extremely difficult to conform

Table 3.3 Classification of sugar mills according to their operating mechanisms.

1. Mills with stress exerted by means of one solid surface or by the collision of two particles
    1.1. Mills with rotating grinding devices
        1.1.1. Mills with a grinding track
            - Hammer mill
            - Turbo mill
            - Impact pulverizer
        1.1.2. Mills without a grinding track
            - Pin mill
    1.2. Mills without moving mechanical parts
        - Air jet mills
2. Mills with stress exerted between two solid surfaces
    - Roll mill
    - Ball mill

to, even when the grinding process is combined with a separation/classification stage. It is equally impractical to achieve a controlled crystallization of the sugar within this narrow particle range at the production stage in the sugar factory (Heidenreich and Huth, 1976). Also for taste reasons it is not advisable to use sugar ground separately to its final fineness (see Section 3.6). In order to obtain ultimate fineness in chocolate with a satisfactory texture, the masse containing relatively coarse sugar is normally processed by means of roller refining.

Icing sugar shows a tendency to form lumps. This is because freshly ground crystallized sugar possesses amorphous surface layers, which are able to take up moisture at higher rates and lower relative humidities than is the case for the crystallized parts. Those amorphous surface layers take up water vapour until they recrystallize, expelling water in the process. This leads to the formation of sugar solution, which bonds the particles together and becomes even firmer as the solution solidifies on drying. It is these solid bonds between the particles that cause a hardening of the icing sugar (Roth, 1977). It is thus advisable to process any ground sugar as speedily as possible and to use a tank with an agitator and screw discharge.

The risk of sugar dust explosions calls for special attention. The explosion of a sugar dust/air mixture may be triggered when a minimum concentration of sugar dust has been reached simultaneously with high ignition energy. This may be due to electrostatic charging, friction or impact sparks. Only particle sizes of about 400 μm (160×10^{-3} in.) and bigger cannot cause explosions. Tests have shown that a concentration of 30 g/m^3 (0.8 oz/yd^3) of sugar dust with particle sizes up to 250 μm (0.01 in.) is sufficient to cause an explosion (Schneider, 1969). These conditions can be roughly determined by visibility. With a concentration of 20 g/m^3 (0.5 oz/yd^3), the visibility is 1 m (3.3 ft) at the most. At a concentration of 50 g/m^3 (1.3 oz/yd^3), a 25 W light bulb is barely visible from a distance of 3 m (9 ft) (Dietl, 1961).

A great many preventive measures can be taken to avoid explosions and it is not possible to discuss them all here in detail. However, it is useful to briefly discuss some of the most important safety measurers (Schneider, 1969).

Powder mills should be situated in separate, enclosed rooms, which should, if possible, have a high ceiling, be well ventilated and situated on the top floor. Massive, sufficiently pressure-proof walls and fire-resistant doors, opening to the outside, should separate these rooms from all other production facilities. A lightweight exterior wall or a ‘louvred’ ceiling, which pressure vents to outside atmosphere, can serve as a pressure release system.

The equipment in the silos, the mill casing and the drive shaft must be electro-statically earthed. The feed devices should be equipped with magnetic solenoids to detect and remove any metal impurities, which might cause sparks, leading to an explosion inside the mill. These magnets should be interlocked with the mill drive in such a manner that the powder mill automatically shuts down under failure. Mill and elevator heads must be fitted with explosion ducts that vent a long distance away over the roof. Any dust accumulation must be removed from the point of formation.

Within the production localities, the concentration of the sugar dust in the air, when kept within normal operating conditions, is far below the level at which explosions can occur. However, dust deposits can give rise to an unexpected danger. This is because they may be carried up within any piece of production equipment by the pressure wave of a primary explosion within that machine and may then ignite themselves. It is absolutely essential to prevent any dust deposits building up in the production rooms. This is achieved by reducing dust production to a technically feasible minimum, frequent cleaning and a high standard of housekeeping. Suitable measures include the installation of air filters and the use of stationary vacuum equipment for the removal of sugar dust from the air and floor (Kordes, 1998).

All electrical installations should be kept out of rooms with an explosion risk. For example, it is preferable to install switches for electric lighting outside the milling rooms.

3.6 Amorphous sugar

Normally sugar is present in the crystalline state. Even the so-called 'acucar amorfo' made in Brazil is not a truly amorphous sucrose, but only refined sugar of extremely small crystal size made from crude cane sugar (Bezerra, 1993). Truly amorphous sugar may be produced by spraying a sucrose solution into a hot and very dry atmosphere or by drying a thin film of sucrose solution at an extremely low relative humidity. The material produced in this way is highly hygroscopic (Powers, 1980).

Whilst crystallized sugar produces a sharp X-ray diffraction pattern, freshly prepared freeze-dried concentrated sugar solution, for instance, as well as sugar that has been ground over a longer period of time, does not produce such a diffraction pattern; that is to say it is amorphous. The heat of solution for crystallized sucrose is 16.75 J/g; however, for amorphous sucrose a heat of –41 to –45 J/g may be recorded (Van Hook, 1981). It is also known that amorphous surface layers are formed when icing sugar is produced by grinding crystallized sugar. The estimated proportion of this amorphous phase comes to approximately 2%, with an average layer thickness of 0.75×10^{-2} µm (0.3×10^{-6} in.) (Roth, 1977).

Apart from rapid moisture uptake from the ambient air, the other interesting facet of amorphous sugar from the chocolate manufacturer's point of view is its flavour absorption properties (Niedieck, 1981). It has been estimated that about 30–90% of the sugar become amorphous during the roller refining of chocolate masses. This has a decisive influence on the chocolate taste since amorphous sugar can absorb large quantities of different flavour compounds.

Chocolate masse made experimentally with sugar already ground to its final fineness is unsatisfactory in taste. This is thought to be because the amorphous sugar, normally produced during the refining stage, is missing and thus not available for flavour absorption. However, the rate of recrystallization increases with increasing temperatures and relative humidities.

At very high air humidities, the amorphous sugar that has just been produced may recrystallize immediately after passing through the roll refiner. The flavour components absorbed by the amorphous sugar during the refining of the chocolate masse are then released again during recrystallization. Under normal conditions, even after a storage period, there is still some amorphous sugar in the finished chocolate.

Amorphous sugar may also have a positive influence in improving the heat stability of chocolate (Niedieck, 1981). A heat stable chocolate may be produced by adding 1–10% of finely ground amorphous sugar pastes to the conched chocolate masse. This is then subjected to several days' heat treatment at temperatures between 20°C and 35°C (68°F and 95°F). A network of matted sugar particles is then formed and stabilizes the moulded chocolate, which will not soften again even at higher temperatures. The amorphous sugar may be made, for example, from something like a high boiled candy mass, which includes sucrose and invert sugar or dextrose.

The advantage of some freshly manufactured crumb chocolates, as far as heat stability is concerned (compared with using single components, such as cocoa mass, milk powder and sugar) is that the sugar present in this crumb is at least partially in the amorphous state (see Chapter 5). This may be because the other ingredients of crumb, such as lactoproteins, fat and non-fat cocoa components are likely to have a pronounced retarding effect on the recrystallization of the sugar.

3.7 Other sugars and bulk sweeteners

Apart from sucrose, there are numerous other sugars and sugar alcohols (polyols), some of which are important in the production of confectionery articles or have received special attention in recent years. More often than not they have major differences as far as physical, chemical or physiological characteristics are concerned and not all of them are suitable for the production of chocolate masses.

3.7.1 Invert sugar

Invert sugar is a mixture consisting of equal parts of the monosaccharides fructose and glucose (dextrose) that is produced during hydrolytic cleavage of the disaccharide sucrose, using either the activity of specific enzymes or that of acids. It is commercially available as syrup or as a partially crystallized paste with a dry solids content of 65–80%. Invert sugar is naturally present in many fruits and in honey. This product is not suitable for the manufacture of chocolate because it is almost exclusively supplied as an aqueous solution. Publications from Japan, however, refer to the manufacture of a pseudo-chocolate using freeze-dried dates in which the natural sweetness is almost exclusively made up of invert sugar. The sweetening power of invert sugar corresponds closely to that of sucrose (Anon., 1981).

3.7.2 Glucose

The monosaccharide glucose, also known as dextrose, is present in nature where it is found, together with fructose, in many fruits and in honey (invert sugar). Since it was prepared in the past from grapes, glucose is also known as grape sugar.

Today, glucose is normally produced industrially by an extensive hydrolysis of starch into high-conversion glucose syrup, from which it is crystallized in the form of glucose monohydrate. About 9% water is retained as a constituent of the glucose. Part of this water of crystallization is released at temperatures that are commonly reached during the conching and produces an adverse effect on the rheological properties of the chocolate (see Chapter 10). It is preferable, therefore, to use glucose with no water content (anhydrous dextrose) for the manufacture of chocolate (Hogenbirk, 1985).

Although there have been many attempts to produce glucose chocolate, chocolates sweetened with only glucose have never become very popular because their taste characteristics differ from the standard product. This, however, does not prevent glucose being used in small quantities together with sucrose for the sweetening of chocolate. The sweetening power of glucose is only slightly more than half of that of sucrose. The current EU regulations allow for it to replace any or all of the sucrose in any chocolate recipe.

A variety of glucose syrups (corn syrups) with solids contents of about 70–80% may be produced by means of partial saccharification of starch. These syrups, together with glucose, may also contain maltose and other saccharides of higher molecular weight. Furthermore, syrups with various degrees of fructose are made by means of partial enzymatic isomerization of glucose. Glucose syrups are not used commercially to make chocolate on account of their water content, and nothing has yet been reported concerning the use of spray-dried glucose syrups in chocolates. On the other hand, large amounts of glucose syrup are used for the manufacture of hard boiled candies, toffees, fondants, etc.

3.7.3 Fructose

Fructose is a monosacchride, also known as fruit sugar, which is present, together with glucose, in almost all fruits and in honey (invert sugar). Fructose is currently produced in most large-scale processes by isolation and subsequent crystallization from fructose containing glucose or invert sugar syrups. Fructose is naturally hygroscopic. The sweetening power of fructose is usually considered to be higher than that of sucrose. This, however, depends on a number of different factors (see also Section 3.9). The sweetening character of the monosaccharide fructose is somewhat different from that of the disaccharide sucrose (see also Section 3.10). Fructose is of importance for the manufacture of chocolates with low or reduced glycaemic response and suitable for diabetics. This is because there is only a low blood sugar increase in the body after eating fructose, unlike sucrose or glucose. Fructose is absorbed more slowly than glucose and only a small proportion is converted into glucose during absorption. This slow absorption, as well as the speedy metabolism, of the fructose reduces any rapid peaks in blood glucose concentration. Furthermore, fructose is mainly metabolised in the liver, i.e. without insulin involvement, whereas the corresponding glucose metabolism reaction depends on insulin. This makes fructose a valuable sugar substitute in diabetics and low glycaemic diets. It should, however, be used only in moderate quantities in order to avoid overstressing the fructose metabolism.

Certain factors need to be taken into account when fructose is used in the manufacture of chocolate. For instance, the water content of the other ingredients, such as milk powder, should be kept as low as possible and the temperature during the conching processes should not exceed 40°C (104°F). Failure to do so may result in a gritty mouthfeel and/or the formation of degradation or reaction products that give off-flavours. This risk is very high since fructose caramelizes and takes part in Maillard reactions fairly easily.

3.7.4 Tagatose

Tagatose is a monosaccharide, which has a similar structure to fructose. Traces of tagatose can be found in heat-treated dairy products for example sterilized cow milk and milk powder (Levin *et al.*, 1995). It is produced from lactose, by enzymatic hydrolization to glucose and galactose, which are separated by a chromatographic fractionation. Then galactose is isomerized to tagatose under alkaline conditions, using calcium hydroxide. By treatment with carbon dioxide the suspension is neutralized and the calcium carbonate, which is formed is removed by filtration. Tagatose is a reducing sugar with a sweetening power of 92% compared to that of sucrose (Arla Food Ingredients, 2004). However, as a monosaccharide it has a somewhat different sweetening character than sucrose (see Section 3.10).

Tagatose is metabolized like fructose, but only 15–20% of the tagatose is absorbed in the small intestine. The major part of ingested tagatose is fermented in the colon by the indigenous microflora (Calorie Control Council, 2004). Therefore tagatose has a low calorific value, prebiotic effects and a low glycaemic response (Arla Food Ingredients, 2004). However, it has a similar laxative potential as the sugar alcohols (Levine *et al.*, 1995).

Tagatose can be used for tooth-friendly confectionery products (Nordzucker InnoCenter, 2005). Like fructose and other monosaccharides, it has a sweetness character with some scratchy and burning aftertaste, particularly when used to make chocolate. However, the sweetness profile of chocolates made with disaccharide alcohols, or combinations of these sweeteners with polydextrose and sweetened up with intense sweeteners, can be further improved by adding a few per cent of a monosaccharide, for example about 6% tagatose (see Section 3.10). Here tagatose has the advantage being tooth-friendly and because it is a reducing sugar, it also possesses flavour-enhancing properties.

3.7.5 Lactose

Lactose, also called milk sugar, is a disaccharide consisting of the monosaccharides glucose and galactose and is an integral part of all types of milk. In cow's milk it amounts to about 4.5%. The present-day large-scale production of lactose is based on whey, from which it is isolated to a very high degree of purity following several purification steps (see Chapter 4). Lactose crystallizes with one molecule of water as a monohydrate. It does not expel this water even when heated to 100°C (212°F). Lactose has been used traditionally in the production of milk chocolate as a constituent of full cream milk powder, skimmed milk powder or chocolate crumb. However, pure lactose has more and more frequently been added in small quantities in the manufacture of chocolate (Hogenbirk, 1985).

Lactose monohydrate is non-hygroscopic and forms crystals harder than those of sucrose. Compared with sucrose, its sweetening power is very low.

3.7.6 Isomaltulose

Isomaltulose, which is also known by the trade name 'Palatinose', has been detected in very small quantities in honey and cane sugar extract. It is produced by enzymatic conversion from sucrose. Isomaltulose is a disaccharide made up of the monosaccharides glucose and fructose that crystallizes with one molecule of constituent water. It has less sweetening power than sucrose. Isomaltulose has like sucrose a calorific value of 4 kcal/g but a lower glycaemic response than sucrose, is tooth-friendly and well tolerated. It has been recommended as a sugar substitute for confectionery and chocolate items (Kaga and Minzutani, 1985).

3.7.7 Trehalose

Trehalose is a naturally occurring disaccharide consisting of two glucose molecules, which recrystallizes as a dehydrate. It is found in small quantities in mushrooms, honey and shrimps and is produced enzymatically from starch. It has less sweetening power than sucrose. Trehalose, like sucrose, has a calorific value of 4 kcal/g. However, it has a lower glycaemic response than sucrose and is described having 'less cariogenicity' (Figura and Michaelis, 2003).

3.7.8 Polydextrose

Polydextrose is made up of glucose and small amounts of sorbitol, which, because of its manufacturing process, also contains minor residues of citric acid. It is sold as an amorphous powder in several different quality standards. The original grades were not only hygroscopic, but also contained relatively large amounts of citric acid and had a tart and slightly bitter aftertaste. Newer grades, for example Litesse®II and Litesse®Ultra™, are much improved. They have a clean, mildly sweet flavour and can be used satisfactorily in chocolate when combined with other bulk sweeteners for example lactitol and further sweetened with an intense sweetener (Krüger *et al.*, 1996; Krüger and Fairs, 2000). Because polydextrose types such as Litesse®II, can caramelize, the flavour of chocolates made with polyols is enriched when these sweeteners are used together with a suitable polydextrose grade. The further developed Litesse®Ultra™ does not caramelize and therefore cannot participate in this Maillard reaction. It is, however, used in combination with sugar alcohols for the manufacture of sugarless and non-cariogenic chocolates (sometimes for flavour reasons blended with one of the caramelizing polydextrose grades). Because polydextrose is an amorphous powder, an exothermic reaction takes place when it dissolves in water. This means that there is a 'warming sensation' when it is dissolved in the saliva in the mouth. This can be used to offset the heat of solution of sugar alcohols when they are used together with polydextrose in chocolate. This means that sometimes undesirable 'cooling effects' of sugar alcohol sweetened chocolates can be overcome (see Section 3.10).

Since polydextrose is only partly metabolized in the human body, it is also used as a bulking agent for low calorie food. The FDA has recognized it as containing not more than 4 kJ/g, whereas sucrose and other carbohydrates contain about 17 kJ/g (Liebrand and Smiles, 1981). Polydextrose is also regarded as either a resistant polysaccharide (RP) or resistant oligosaccharide (RO), providing those physiological benefits associated with fibre (Craig *et al.*, 1996) and prebiotic effects (Probert *et al.*, 2004). It is in fact classified as fibre and prebiotic ingredient in a number of countries.

Generally polydextrose can be eaten in larger quantities than sugar alcohols. In the EU and other European countries no laxative warning label is necessary for products containing even more than 10% polydextrose. During the last few years polydextrose has been particularly used for calorie reduced, 'Low Carb', as well as low and reduced glycaemic products. It is also a suitable ingredient for tooth-friendly chocolates (Roulet *et al.*, 2001).

3.7.9 Inulin

Inulin is a naturally occurring carbohydrate. It functions as a carbohydrate reserve in thousands of plants and is produced commercially from chicory roots, which contain about 17% inulin. Nutritionally it is classified as dietary fibre and prebiotic ingredient, low calorie and suitable for diabetics (De Soete, 1995). It cannot be used to make tooth-friendly chocolates (Krüger, 1997), however, because it can be fermented by oral microorganisms. A lower percentage of inulin can be used in combination with sugar alcohols or fructose in 'no added sugar' or chocolates for diabetics.

3.7.10 Sorbitol

Sorbitol is a monosaccharide alcohol that is present in small quantities in numerous fruits. The commercial production process is based on catalytic hydrogenation of glucose. Sorbitol is hygroscopic and its sweetening power is about half that of sucrose. The heat of solution of sorbitol is such that it generates a slight cooling effect when it dissolves in the mouth. In the past sorbitol was one of the sweeteners used in the production of chocolates for diabetics (Caliari, 1983). Nowadays, diabetic chocolates are more often produced with fructose or disaccharide alcohols, for example maltitol or lactitol, often in combination with polydextrose.

3.7.11 Mannitol

Mannitol is a monosaccharide alcohol present in manna, the dried juice of the flowering or manna ash. Its large-scale industrial production is a catalytic hydrogenation process based on pure invert sugar, which results in a mixture of sorbitol and mannitol, from which mannitol is separated in a multistep process. Mannitol has a low solubility and its sweetening power is comparable or slightly less than that of sorbitol. In combination with sorbitol and enhanced in its sweetening power by intense sweeteners, it was occasionally used for the production of chocolates for diabetics. However, of all the sugar alcohols, mannitol manifests the greatest laxative effect; the safe daily intake for adults is only about 10 g (0.35 oz) (Kammerer, 1972).

3.7.12 Xylitol

Xylitol is a monosaccharide alcohol, which has only five carbon atoms unlike sorbitol and mannitol, which have six carbon atoms each. Xylitol is a naturally occurring sweetener and is present in numerous mushrooms, vegetables and fruits. Furthermore, xylitol is an inherent part of the normal human metabolism. Every human generates between 5 and 15 g (0.2 and 0.5 oz) of xylitol every day as part of the normal carbohydrate metabolism. The large-scale production of xylitol is based on birch wood, corncobs, straw and other plant material containing a high amount of xylan. Xylan, a polymer of xylose, is hydrolysed to xylose by means of acids once it has been isolated from the raw material. Following further isolation and purification of the xylose, it is hydrogenated into xylitol. Now xylitol is also produced by enzymatic conversion of glucose.

Xylitol is non-hygroscopic and has a very high heat of solution (153.1 J/g), which results in a remarkable cooling effect when melted in the mouth. The sweetening power of xylitol is the highest of all sugar alcohols and comparable to that of sucrose (Pepper and Olinger, 1988). However, as a monosaccharide, xylitol has a somewhat different sweetening character than sucrose (see also Section 3.10).

Xylitol's excellent characteristic is its prophylactic benefit with respect to dental caries. It inhibits the growth of the cariogenic bacteria *Streptococcus mutans* and other closely related bacteria in the oral cavity (Mäkinen *et al.* 1989). As the highly publicized Turku studies proved, the progression of caries was arrested in people eating xylitol containing sweets over a period of 2 years (Scheinin and Mäkinen, 1975). Furthermore, two extensive studies initiated by the World Health Organization, each encompassing more than 900 school pupils in Hungary and Polynesia over the period 1981–1984, showed that caries progression may be significantly slowed if 15–20 g (0.5–0.7 oz) of xylitol in the form of xylitol containing chocolate and candy is eaten together with a normal, sucrose containing diet (Scheinin *et al.*, 1985; Kandelmann *et al.*, 1988). Chocolates may be manufactured with xylitol without any special processing. However, these have a noticeable cooling effect in the mouth.

3.7.13 Erythritol

Erythritol is a monosaccharide alcohol, which has only four carbon atoms. It occurs naturally in many fruits and vegetables. It is produced industrially by fermentation of glucose with an osmophile yeast.

Erythritol has a very high heat of solution (191.3 J/kg) which results in a strong cooling effect when melted in the mouth. Its sweetening power is about 70% of that of sucrose (Cerestar, 2004). As a monosaccharide with a very low molecular weight, erythritol has different sweetening characteristics from sucrose. This is perceived particularly in chocolates as a 'burning, scratchy' aftertaste. Depending upon their lower molecular weight, this is a sensory property of monosaccharides (see Section 3.10).

Erythritol has however very different metabolic properties. It is absorbed very quickly from the small intestine and after absorption, about 80% of the erythritol remains unmetabolized and is excreted unchanged in the urine (Bornet *et al.* 1996). This is not only the reason for its very low calorific value, but also for its high digestive tolerance. Erythritol has a very low calorific value of only 0.2 kcal/g, a glycaemic response of 0. It is suitable for diabetics and is tooth-friendly (Cerestar, 2004). Like xylitol it can significantly reduce the caries bacteria *Streptococcus mutans* (Mäkinen *et al.*, 2005).

Milk chocolates made with erythritol can be conched up to 70°C (158°F) and plain chocolates up to 80°C (176°F) (Bechert and Wastijn, 2002).

3.7.14 Maltitol

The disaccharide alcohol, maltitol is produced by hydrogenation of maltose. Maltitol is non-hygroscopic and is slightly less sweet than sucrose, but sweeter than sorbitol and is suitable for confectionery items for diabetics. Although oral lactobacilli may ferment maltitol, it is not fermentable by streptococci and that is why maltitol is considered a tooth-friendly bulk sweetener (Lichtel, 1985). Because it is an anhydrous sweetener, maltitol can be conched at temperatures up to 80°C (176°F) (Happel, 1995). In order to compensate for a sweetening power that is slightly inferior to that of sucrose, intense sweeteners are sometimes added to chocolates sweetened with maltitol. In combination with polydextrose, maltitol has been used to produce 'Low Carb' chocolates.

3.7.15 Maltitol syrup

Maltitol syrups are hydrogenated maltose syrups containing maltitol, hydrogenated higher polysaccharides and sorbitol. They are commercially available under different trade names. The product is used for hard boiled candies and as a crystallization inhibitor of other sugar alcohols in tooth-friendly confectionery articles. Maltitol syrup cannot be used in chocolates because of its high moisture content.

3.7.16 Isomalt

Standard isomalt is a mixture of equal parts of two disaccharide alcohols. It is produced by means of enzymatic conversion of sucrose into isomaltulose, which is then hydrogenated. One of these two sugar alcohols crystallizes with two molecules of water, the other exhibits an anhydrous crystallization. The total bound water content of the product reaches 5%. Isomalt is non-hygroscopic and about 40% as sweet as sucrose. It is used for the production of tooth-friendly candy and confectionery articles, which are also low or reduced glycaemic index. The low sweetening power of isomalt in chocolate can be offset by means of intense sweeteners. Because standard isomalt loses its water of crystallization at relatively low temperatures the conching temperature of isomalt chocolates may not be higher than 45°C (112°F). Recently isomalt variants for special applications, including one for chocolates, have been developed and marketed. The dried quality 'Isomalt LM' does not contain more than 1% moisture and can be used for plain chocolate masses to be conched up to 80°C (176°F) and milk chocolate masses to be conched up to 70°C (158°F) (Palatinit GmbH, 2004). However, even with this isomalt it is advisable to conche milk chocolate masses containing high milk powder contents below 60–65°C (140–149°F) to avoid gritty agglomerates. A maximum conching temperature of 75°C (167°F) is however possible when using isomalt milk crumb (Bollinger and Keme, 1988).

The higher hygroscopicity of 'Isomalt LM' has to be taken into consideration when it is being stored.

3.7.17 Lactitol

Lactitol is a disaccharide alcohol produced by the hydrogenation of lactose. It can be crystallized out as a mono- or dehydrate as well as in an anhydrous crystalline form. Lactitol is not hygroscopic and has a sweetening power of about 40% of that of sucrose. Lactitol monohydrate and anhydrous lactitol are suitable for the production of no sugar added chocolates, diabetic products and tooth-friendly confectionery when combined with intense sweeteners. Lactitol has prebiotic properties (Probert *et al.*, 2004) and can be used to produce low or reduced glycaemic index products. Lactitol monohydrate does not lose its water of crystallization very easily, which means that conching temperatures up to about 60°C (140°F) can be used without any adverse effect on the flow properties of the chocolate. Chocolates made with anhydrous lactitol can be conched at temperatures as high as 80°C (176°F). Lactitol chocolates have viscosities comparable to those of sugar chocolates (Arntzen, 1992). Chocolates produced using lactitol, polydextrose type Litesse®II and the intense sweetener aspartame were found to be not significantly different from sucrose sweetened chocolate when evaluated by a trained sensory panel (Krüger *et al.*, 1996).

3.8 Physiological characteristics of sugars and bulk sweeteners

The bulk sweeteners, sugar alcohols are also known as polyalcohols or polyols. Because of their sweetening power and/or their lower calorific value, they are used as sugar substitutes. Sugar alcohols and polydextrose are applied in 'no added sugar', sugarless, diabetic, 'low carb', low or reduced glycaemic index and calorie reduced confectionery and chocolate products. Fructose, isomaltulose and tagagose can be used for diabetics and low or reduced glycaemic index products. In addition, sugar alcohols, polydextrose, isomaltulose and tagatose are tooth-friendly sugar substitutes as they are scarcely, if at all, converted into acids by oral micro-organisms, unlike sucrose, fructose and other saccharides. It is important, however, to take into account the laxative effects of the sugar alcohols and tagatose.

The EU Scientific Committee on Foods (SFC) has emphasized that the laxative effect of sugar alcohols should not be neglected and stated that 'consumption of the order of 20 g (0.7 oz) per person per day of polyols is unlikely to cause undesirable laxative symptoms. The safe level for individual polyols ingested singly is higher in many cases'. The Committee was fully aware that most people will tolerate sugar alcohols even at levels of 30–50 g (1.1–1.8 oz) per day without any laxative effect (van Esch, 1987). The sugar alcohol, erythritol, has an even higher digestive tolerance (Cerestar, 2004).

A daily consumption of about 50 g (1.8 oz) of polydextrose, even consumed as single dose, is unlikely to cause gastrointestinal effects. The mean laxative dose of polydextrose is 90 g (3.2 oz) per day (Pfizer, 1978).

Table 3.4 summarizes daily intake values as a function of body weight to illustrate the levels at which some of the sugar alcohols and polydextrose can be eaten without any undesirable side effects (Kammerer, 1972; Craig *et al.*, 1998).

All sugar alcohols have less metabolizable energy than sugar. This fact has been taken into account by legislative bodies. The current EU Nutritive Labelling Directive designates an energy value of 2.4 kcal/g (10 kJ/g) for all sugar alcohols, which is 40% less than the value for sugar, which is 4 kcal/g (17 kJ/g). A summary of European and USA legislative calorific values for sugar substitutes is given in Table 3.5. The glycaemic response and the suitability of these ingredients for diabetics and tooth-friendly products is presented in Table 3.6.

Table 3.4 Amounts of sugars, sugar alcohols (adapted from Kammerer, 1972) and polydextrose (adapted from Craig *et al.*, 1998) that can be tolerated in the diet.

	Average daily intake in g/day (oz/day)		
	1 kg (2.2 lb) body weight	**70 kg (154 lb) body weight (adult)**	**20 kg (44 lb) body weight (child)**
Mannitol	0.14 (0.005)	10 (0.35)	2.8 (0.1)
Sorbitol	0.43 (0.02)	30 (1.1)	8.6 (0.3)
Xylitol	0.43–0.71 (0.02–0.025)	30–50 (1.1–1.8)	8.6–14.3 (0.3–0.5)
Fructose	0.71 (0.025)	50 (1.8)	14.3 (0.5)
Sucrose	1.00–1.28 (0.035–0.045)	70–90 (2.5–3.2)	20–25 (0.7–0.9)
Polydextrose	1.28 (0.045)	90 –	– –

Table 3.5 Calorific value of sugar substitutes (kcal/g).

	Europe	**USA**
Maltitol	2.4	2.1
Lactitol	2.4	2.0
Isomalt	2.4	2.0
Sorbitol	2.4	2.6
Xylitol	2.4	2.4
Tagatose	[a]	1.5
Erythritol	[a]	0.2
Polydextrose	1.0	1.0
Inulin	1.0	[a]

[a] No current legislation.

Foods with low glycaemic effects (blood glucose raising ability) have been scientifically validated as having an important role in the dietary management of weight reduction, diabetes and reducing the risk of heart disease and hypertension (Leeds *et al.*, 1998). Sugar alcohols, polydextrose, inulin, as well as fructose, tagatose and isomaltulose are a means to producing low or reduced glycaemic index confectionery products, because they have low glycaemic responses as can be seen in Table 3.6.

It should be noted that there is no correlation between the glycaemic response of polyols or speciality carbohydrates and their molecular weight or number of carbon atoms per molecule. Molecular size is a poor indicator of physiological properties. The glycaemic response depends strongly upon

Table 3.6 Glycaemic response and suitability of sugar substitutes for diabetic and tooth-friendly chocolate.

Sugar substitute	Substance group	Glycaemic response vs glucose = 100[a]	Suitable for diabetics	Suitable for tooth-friendly chocolate
Sorbitol	Sugar alcohol	<5	+	+
Mannitol	Sugar alcohol	<5	+	+
Isomalt	Sugar alcohol	4.7	+	+
Maltitol	Sugar alcohol	34	+	+
Lactitol	Sugar alcohol	2	+	+
Xylitol	Sugar alcohol	8	+	++
Erythritol	Sugar alcohol	0	+	+
Fructose	Saccharide	19	+	−
Tagatose	Saccharide	3	+	+
PDX Litesse®II	Polysaccharide	7	+	+
PDX Litesse®Ultra	Polysaccharide	4	+	+
Inulin	Polysaccharide	4	+	−

[a] Foster-Powell *et al.* (2002); Sydney University Glycaemic Research Service (2001); Sydney University Glycaemic Research Service (2004) and Cerestar (2004).

the rate and efficiency of digestion by microbiological fermentation in the colon and its absorption and metabolism (Mitchell, 2002).

Even sucrose sweetened chocolates do not have a high glycaemic index. But using suitable sugar replacers can significantly reduce it even further. This is demonstrated in Table 3.8 for milk chocolates made using the recipe given in Table 3.7.

Table 3.7 Milk chocolate made with sucrose and sweeteners.

Cocoa liquor	11.00%
Cocoa butter	22.00%
Full cream milk powder	20.00%
Skimmed milk powder	1.48%
Sugar/Sweetener[a]	45.00%
Lecithin	0.50%
Vanillin	0.02%

[a] **1.** 45% sucrose **2.** 45% maltitol **3.** 33.00% anhydrous lactitol with 11.85% polydextrose, 0.13% aspartame, 0.02% acesulfame K.

Table 3.8 Glycaemic response of milk chocolate made with 45% sucrose or sweeteners.[a]

1 Sucrose	37
2 Maltitol	19
3 Lactitol/polydextrose	6

[a] Sydney University Glycaemic Research Service (2004).

Table 3.9 Relative degree of sweetness of different sugars and sugar alcohols (adapted from Carpenter, 1984).

Sugar	Relative sweetness
Sucrose	1.0
Xylitol	1.0
Fructose	1.2
Maltitol	0.8
Sorbitol	0.6
Mannitol	0.6
Isomaltulose	0.5
Isomalt	0.45
Lactitol	0.35

3.9 The sweetening power of sugars and bulk sweeteners

In the sensory evaluation of the sweetening power, sucrose generally serves as a standard to which the sweetness of the other bulk sweeteners is compared. 'Sweetening power' and 'degree of sweetness' are the terms employed. The sweetening power is the intensity of sweetness expressed as a percentage in comparison with sucrose, which is assumed to be 100%. The degree of sweetness expresses the intensity of the sweet taste as a fraction of the sucrose's sweetness, which is equal to 1.00. Table 3.9 lists the degrees of sweetness of important sugars and sugar alcohols (Hyvönen *et al.*, 1977; Carpenter, 1984; Krüger *et al.*, 1996).

As can be seen from Table 3.9, fructose is sweeter than sucrose and the sugar alcohol, xylitol, is as sweet as sucrose. This table is representative of many publications. However, it only provides guideline values for the confectioner, because many comparisons were apparently based on aqueous solutions of pure sugars and, more often than not, statements regarding the solids content of the sampled solutions are missing. It is, moreover, important to remember that the sweetening power of various sweeteners does not increase linearly with concentration and is dependent on temperature and other raw material ingredients in the foodstuffs, as well as the pH value.

There are also synergistic effects. These phenomena cause sugars in mixtures to mutually enhance their sweetening power as well as their other sweetness characteristics. Fructose in milk chocolate has been found to taste only slightly sweeter than sucrose, yet mixtures of fructose and sucrose were very much sweeter. Even though glucose in a 10% aqueous solution shows a markedly lower sweetening power than sucrose, milk chocolates sweetened by anhydrous dextrose tasted almost as sweet as those made with sucrose. The sweetness also increased when part of the sucrose was replaced by anhydrous dextrose. However, glucose leaves a burning taste in the mouth, which rather enhances the impression of sweetness instead of moderating it. Fructose also gives a 'pungent' sweetness in milk chocolate, but is felt to be pleasantly mild in, for example, chocolate drinks (Krüger *et al.*, 1987).

At present, theoretical calculations are unable to predict the sweetness of cocoa containing, or other products, in which some or all of the sucrose is replaced by another type of sugar or by a sugar substitute. They can only provide rough guidelines and it is always necessary to carry out sensory evaluation on actual samples of the product. In order to obtain the best results, a range of recipes should be tested.

3.10 Other sensory properties of sugars and bulk sweeteners

Sweeteners differ not only in their degree of sweetness but also in their sweetening character (Krüger and Fairs, 2000). There is a very important difference between monosaccharides and monosaccharide alcohols on the one hand and disaccharides, disaccharide alcohols and polysaccharides on the other.

Monosaccharides, like the sugars glucose, fructose and tagatose and the monosaccharide alcohols sorbitol, mannitol, xylitol and erythritol, have a 'burning, scratchy' aftertaste in chocolates and fat fillings. Disaccharides, such as sucrose and lactose, and disaccharide alcohols, such as maltitol, isomalt and lactitol, and polysaccharides, such as polydextrose and inulin, have a mild sweetness and no aftertaste in chocolates and fat fillings. This is possibly a result of the higher osmotic pressure (i.e. the pressure needed to stop a solution flowing through a semi-permeable membrane) caused by the dissolution of the monosaccharides in the saliva compared with that of the disaccharides and polysaccharides. The osmotic pressure depends on the molecular weight of the dissolved substance; the smaller the molecular weight, the bigger is the osmotic pressure at the same concentration. Compared to disaccharides and disaccharide alcohols, monosaccharides and monosaccharide alcohols have significantly smaller molecular weights, which cause higher osmotic pressures. This means, the smaller the molecular weight of a sweetener is, the more it causes a 'burning scratchy' aftertaste.

On the other hand chocolates made with polydextrose and/or disaccharide alcohols and sweetened up with intense sweeteners, like aspartame, sucralose etc. often have a somewhat 'flat' sweetness. This can be improved by using about 6% fructose or about 5% xylitol or about 4% erythritol. Table 3.10 gives the molecular weights of common sugars and bulk sweeteners.

As noted earlier, a further sensorial difference between sugar and sugar alcohols is in their heats of dissolution in water. In the case of erythritol and xylitol, for example, this produces a noticeable cooling effect in the mouth. In contrast, polydextrose and inulin release heat of solution (De Soete, 1995). The heat of solution of common bulk sweeteners and sugars in comparison to sucrose is given in Figure 3.2.

Table 3.10 Molecular weights of sugars and bulk sweeteners.

Poly-/Disaccharides	Mol. weight	Monosaccharides	Mol. weight
Polydextrose	~2000	Sorbitol	182
Lactitol	344	Glucose	180
Maltitol	344	Fructose	180
Isomalt	344	Tagatose	180
Sucrose	342	Xylitol	152
Lactose	342	Erythritol	122

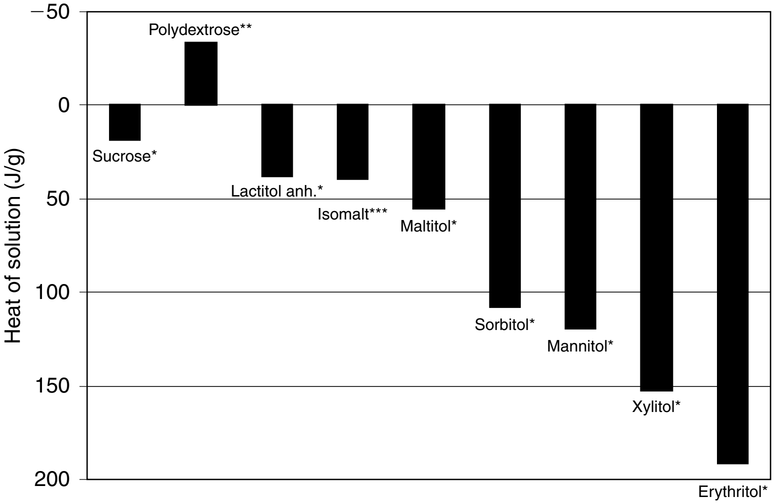

Figure 3.2 Heat of solution of bulk sweeteners and sugars.
* Gehrich (2002).
** Craig *et al.* (1996).
*** Sträter (1989).

In comparison to sucrose, erythritol, xylitol and sorbitol have strong cooling effects. This can be advantageous for the production of refreshing peppermint or fruit fillings for pralines and filled chocolates. In unfilled plain and milk chocolate tablets and bars, a cooling effect is not expected and therefore normally considered undesirable. In this case the cooling effect of the various polyols or fructose can be balanced by combining these sweeteners with polydextrose or inulin.

3.11 Solubilities and melting points of sugars and bulk sweeteners

The solubility and melting point of a bulk sweetener are very important from a processing point of view. High solubilities or low melting points can result in gritty agglomerates at higher conching temperatures. Table 3.11 lists

Table 3.11 Saturation g/100 g solution at 20°C (68°F).

Sugar/Sweetener	Saturation
Sucrose	66.7
Fructose	78.9
Tagatose	58.0
Glucose	47.2
Glucose syrup	Non-crystallizing
Lactose	16.0
Sorbitol	68.7
Xylitol	62.8
Maltitol	62.3
Maltitol syrup	Non-crystallizing
Lactitol	56.5
Isomalt	24.5
Mannitol	14.5
Erythritol	37.0
Polydextrose	Non-crystallizing

the saturation concentrations of sucrose and the common bulk sweeteners, whilst Table 3.12 gives their melting points.

Table 3.12 Melting points of sugars and bulk sweeteners.

	Melting point	
Sugar/Sweetener	°C	°F
Lactose (monohydrate)	>200	>392
Sucrose	185–186	365–367
Mannitol	165–169	329–336
Lactitol (anhydrous)	149–152	300–306
Dextrose (anhydrous)	146	295
Isomalt	145–150	293–302
Maltitol	147	297
Tagatose	133–137	271–279
Erythritol	126	259
Polydextrose	125–135	257–275
Fructose	102–105	215–221
Lactitol (monohydrate)	94–100	201–212
Sorbitol	92–96	198–205
Xylitol	92–96	198–205
Dextrose (monohydrate)	83	181

3.12 Maximum conching temperatures of chocolate masses with different bulk sweeteners

In addition to solubility and melting point, the presence or absence of water of crystallization determines the maximum temperature at which a chocolate containing a bulk sweetener can be conched. At higher temperatures this water can be released, risking the formation of gritty agglomerates and producing unsuitable chocolate flow properties. Although the amorphous polydextrose cannot be completely dried, it can be used at temperatures of up to 80°C (176°F) when combined with anhydrous lactitol (Parsons and Fairs, 1998). Table 3.13 lists the maximum conching temperatures for chocolate masses made with different bulk sweeteners.

Table 3.13 Maximum conching temperatures of chocolate masses with different bulk sweeteners.

			Maximum temperature with conventional conching	
Sweetener	**Water of crystallization**	**Anhydrous**	**°C**	**°F**
Fructose		+	40	104
Sorbitol		+	40	104
Xylitol		+	50	122
Standard Isomalt	+		40	104
Isomalt LM		(+)	80	176
Maltitol		+	80	176
Lactitol monohydrate	+		60	140
Lactitol anhydrous		+	80	176
Polydextrose (in combination with anhydrous lactitol)		(+)	80	176

A special conching process has been developed, which enables the taste and texture of 'no added sugar chocolates' to be improved and gritty agglomerates avoided. In this process the mixture of cocoa liquor and milk powder, with a proportion of the cocoa butter, is conched at any temperature without the sweetener and before roller refining. After this conching, the sweeteners are added and the masse is roller refined (Krüger *et al.*, 1996).

Conclusions

The past few years have seen many developments in the field of bulk sweeteners and speciality carbohydrates, with regard to their processing and the quality of the product. The advances have been such that it can now be very difficult to distinguish a 'no added sugar' product from a standard one in taste and texture. There is still the remaining problem of limited tolerance due to the laxative side effects of sugar alcohols. In recent years some progress has been made by combining sugar alcohols with more highly tolerated sugar substitutes such as polydextrose and fructose.

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Chapter 4

INGREDIENTS FROM MILK

S.J. Haylock and T.M. Dodds

4.1 Introduction

The first use of milk in a solid chocolate product is commonly attributed to Daniel Peter in 1875. Before this, combinations of milk and cocoa solids were consumed as beverages during the eighteenth century. Much has changed since Daniel Peter's time with respect to the technologies used to process both milk ingredients and chocolate. However, the same benefits enjoyed by Peter's first consumers of milk chocolate are now experienced by millions of people every day.

Milk chocolate is the most popular type of chocolate, and milk ingredients are critical in delivering the highly desired properties and taste profile to consumers. Milk ingredients also have a significant effect on chocolate processing. Understanding the effect that milk ingredients have on chocolate processing and on the sensory properties of milk chocolate requires in turn an understanding of some of the key properties of milk and milk ingredients.

Milk is one of the most complex raw materials used by the food industry. A typical bovine whole milk has a solids content of about 13.5%, comprising about 3.4% protein, 4.6% fat, 4.7% lactose and 0.7% minerals. Within these broad categories, there are further levels of differentiation, particularly for proteins and fats.

Milk proteins can be classified as either caseins or whey proteins – typically found in milk at a ratio of about 5:1 respectively. Laboratory techniques are able to separate these groups further, with more than 30 specific proteins identified in milk (Yamada *et al.*, 2002). The bioactive function of these minor proteins is still being determined and currently their impact in bulk milk ingredients is not clear. Milk proteins are one of the best sources of quality protein. Their nutritional properties are the basis of the beneficial claims advertised on many consumer products.

Milk fat is a complex mixture of triglycerides (triacylglycerols) and other minor lipid components. In milk fat, the triglycerides account for more than 98% of the product with significant minor components being phospholipids, diglycerides (diacylglycerols) and sterols.

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Lactose, or milk sugar, is a disaccharide formed from the monosaccharides, glucose and galactose. It can be hydrolysed into these constituent sugars using β-galactosidase. As a reducing sugar, either lactose itself or its constituent monosaccharide components after hydrolysis can undergo Maillard reactions with proteins (see Chapters 5 and 8). Products from these reactions make an important contribution to the properties of many foods, in this case to the delicate caramel notes in milk chocolate.

Minerals are the least abundant component found in milk; however, milk is an excellent source of important nutritional minerals such as calcium and potassium. Other minerals found in milk in significant quantities are sodium, phosphorus and magnesium.

Milk-origin and farming and processing practices are becoming factors of increasing interest to ingredient buyers. Important consumer claims such as 'organic', 'free range', 'fair trade' and 'kosher' are all possible by selection or control of farming and ingredient processing practices.

The technology used to process milk has developed rapidly in recent years. The cost benefits of spray drying have resulted in spray driers almost completely replacing roller driers. Gains in processing efficiencies have continued with the installation of spray driers that can dry 24 tonnes of milk powder per hour. Throughput rates of traditional roller driers were of the order of only 1 tonne per hour. Technologies such as membrane separation, fat fractionation and crystallization now enable the components in milk to be separated cost effectively and recombined in ways designed to optimize the performance and cost of milk ingredients in any given application. The key to the success of designing ingredients for specific products is understanding the requirements of the final application. Milk chocolate has a number of requirements that are unique to it. These different requirements result in dairy ingredient manufacturers modifying standard dairy products and developing new products to provide greater benefit to chocolate manufacturers and their consumers.

The diversity and the reactivity of milk components, together with the adoption of new processing technologies, enable a wide range of ingredient products to be manufactured from milk. Figure 4.1 summarizes a number of the processes that are used to produce the array of different milk ingredients. Differentiation between industrial ingredients can be achieved both through manipulation of composition and by using different processes during manufacture. Also, ingredients that provide specific properties in milk chocolate manufacture can be produced by optimizing the different interactions that occur between the milk components during the processing.

This chapter discusses milk from the point of view of an industrial ingredient, where functional performance, sensory properties, cost, and milk-origin and processing practices are all critical factors in determining the benefits provided by an ingredient. The main industrial ingredients produced from milk are covered by way of their composition, specifications, suitability for use in chocolate and shelf life, as well as the other factors that need to be considered when using these ingredients in the manufacture of milk chocolate.

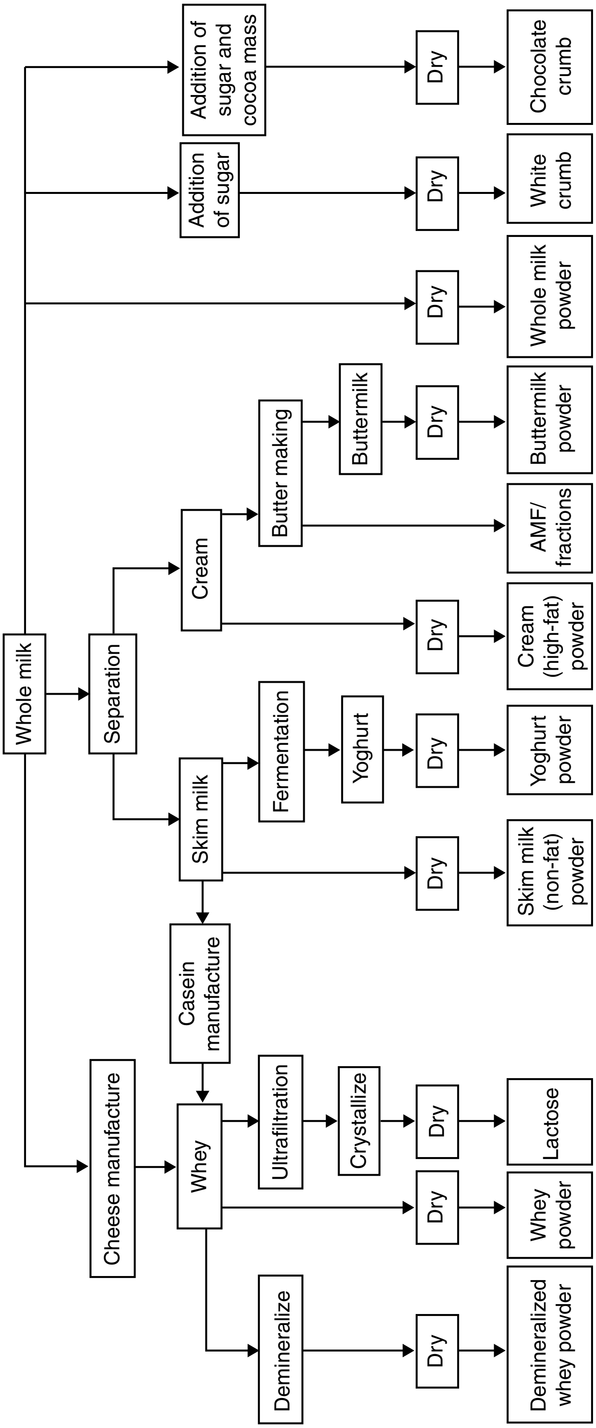

Figure 4.1 Flow chart of dairy processes and products used in milk chocolate.

4.2 Milk fat

Milk fat as an ingredient for use in chocolate manufacture is generally supplied as anhydrous milk fat (AMF) or butter oil, although a number of the powder products discussed later may also contribute significant quantities of milk fat to a chocolate.

Of the different components in chocolate, the fat phase has the greatest influence on its quality. The fat phase affects the rheological properties of fluid chocolate, release from the mould, snap, gloss, prevention of bloom, melting properties and flavour release (Timms, 1980). Milk fat and cocoa butter are the two main forms of fat used in chocolate manufacture to provide these properties. Other fats such as vegetable oils may be used to modify these properties or to produce economical chocolate products (Chapter 19). However, in most regions of the world, these products cannot legally be called chocolate. Such products are usually declared as compound or chocolate-flavoured confectionery. In many countries, milk fat is the only fat other than cocoa butter that is permitted in chocolate without such declarations (Chapter 25).

The distribution and approximate composition of the lipid classes typically found in milk fat is shown in Table 4.1 (Mulder and Walstra, 1974). The diglycerides, monoglycerides (monoacylglycerols), fatty acids, phospholipids and sterols are often referred to as the minor lipids. Milk fat typically contains 96–98.5% triglycerides and 1.5–3% minor lipids. Diglycerides, monoglycerides and free fatty acids are formed during the biosynthesis of triglycerides. Their proportions will increase if lipolysis occurs in milk. Lipases are enzymes that are naturally present in raw milk and may also be introduced through contamination by microorganisms. Lipolysis is the breakdown of fats caused by lipases. The free fatty acid level in milk is usually an indicator of the degree of hydrolytic rancidity in milk and milk fat. Typical fatty acid groups found in milk fat are shown in Table 4.2.

Table 4.1 Components of milk fat.

Component	Weight (%)
Triglycerides	98.3
Diglycerides	0.3
Monoglycerides	0.1
Free fatty acid	0.1
Phospholipids	0.8
Sterol	0.35
Carotenoid	Trace
Vitamins (mainly A, D and E)	Trace
Flavour compounds	Trace

Table 4.2 Fatty acid composition of milk fat.

Fatty acid	Weight (%)
C4:0 Butyric	4.1
C6:0 Caproic	2.4
C8:0 Caprylic	1.4
C10:0 Capric	2.9
C10:1 Caproleic	0.3
C12:0 Lauric	3.5
C14:0 Myristic	11.4
C16:0 Palmitic	23.2
C18:0 Stearic	12.4
C18:1 Oleic	25.2
C18:2 Linoleic	2.6
C18:3 Linolenic	0.9
Others	10.0

Table 4.3 Typical composition of dairy ingredients used in confectionery.

Ingredient	Protein (%)	Fat (%)	Lactose (%)	Minerals (%)	Moisture (%)
Anhydrous milk fat	0.0	99.9	0.0	0.0	0.1
Skim milk powder	33.4	0.8	54.1	7.9	3.8
Whole milk powder	25.0	26.8	39.1	5.8	3.3
High-fat powder (55%)	15.6	54.8	24.3	3.5	1.8
Buttermilk powder	31.0	7.8	50.0	7.4	3.8
Formulated milk powder	12.0	27.4	52.0	5.9	2.7
Whey powder					
Standard	12.6	0.9	74.5	7.5	4.5
Demineralized[a]	11.0	1.2	82.6	1.2	4.0
Milk crumb	7.6	31.0[b]	7.9[c]	1.7	1.3
Lactose	0.3	0.0	99.3	0.34	0.06

[a] Products with lower levels of demineralization are available.
[b] Includes milk fat and cocoa butter.
[c] Total carbohydrate content 55.8%, including 47.9% sucrose.

4.2.1 Anhydrous milk fat

The composition of AMF, the most common milk fat ingredient, is shown in Table 4.3. AMF is prepared from either fresh cream or butter. In the process using fresh cream, the cream is concentrated to approximately 75% fat and then a water-in-oil emulsion is formed by rupturing the membranes from the milk fat globules. The water and oil phases are then separated. The oil phase is dehydrated to remove moisture and to reduce dissolved oxygen prior to cooling and packaging. AMF is typically packed into drums. There has been, however, an increase recently in the use of larger bulk packs that contain typically 1 tonne of AMF.

To manufacture AMF from butter, the butter is melted and then the butter oil is separated from the water phase. The guidelines for the composition and other properties of AMF according to Codex Alimentarius (Codex, 1999a) are shown in Table 4.4. AMF is not permitted to contain antioxidants, whereas other milk fat products may contain certain antioxidants up to the levels specified in the codex standard.

Table 4.5 shows the shelf life of dairy ingredients. The main cause of the deterioration of AMF is oxidation. Anhydrous products are not generally susceptible to deterioration resulting from bacterial growth as the moisture content is too low to support micro-organisms.

Table 4.4 Guidelines for the composition and other properties of AMF.

Measured property	Typical AMF specification
Minimum milk fat (% m/m)	99.8
Maximum water (% m/m)	0.1
Maximum free fatty acid (% m/m as oleic acid)	0.3
Peroxide value (milli-equivalents of O_2/kg of fat)	0.3
Taste and colour	Acceptable for market requirements after heating a sample to 40–45°C (104–113°F)
Texture	Smooth and fine granules to liquid depending on temperature
Maximum copper (mg/kg)	0.05
Maximum iron (mg/kg)	0.2

Codex (1999a) standard for milk fat products CODEX STAN A-2–1973, rev.1-1999.

Table 4.5 Shelf life and primary cause of deterioration of milk ingredients.

Product	Typical shelf life[a]	Primary cause of failure
Anhydrous milk fat	12 months in drums at 15–20°C (59–68°F)	Oxidation
Skim milk powder	24 months plus at 25°C (77°F), standard atmosphere	Development of aged flavours
Whole milk powder	24 months at 25°C (77°F) under nitrogen, dry storage	Oxidation, development of aged flavours
High-fat powders	9 months at 25°C (77°F) under nitrogen, dry storage	Oxidation
Buttermilk powder	24 months at 25°C (77°F) under nitrogen, dry storage	Oxidation
Formulated milk powder	24 months at 25°C (77°F) under nitrogen	Oxidation
Whey powder	24 months	Caking, aged flavours
Milk crumb	24 months	Development of aged flavours
Lactose	24 months	Caking

[a] Assumes storage at relative humidity below 65% and in an odour-free environment.

The oxidation of AMF is measured using the peroxide value. Peroxide values are typically 0.10–0.15 meq O_2/kg in good quality AMF. However, care needs to be taken in using a direct correlation between peroxide value and the shelf life of AMF. The compounds detected in the peroxide value test are intermediates in the oxidation reaction, in the later stages of oxidation, when oxygen is limited, these compounds will have been decomposed to give rise to off-flavours and will be low in concentration themselves. Therefore the peroxide value may be low, but the flavour of the fat may be poor.

Mechanisms that can be used to reduce the rate of oxidation and thereby enhance the shelf life of AMF are:

(1) removing the oxygen by flushing with nitrogen;
(2) using oxygen barrier packaging;
(3) maintaining an appropriate storage temperature (often ambient or chilled to 4°C (41°F));
(4) avoiding the presence of oxidation catalysts.

It is nearly impossible to remove all of the oxygen from AMF to prevent oxidation, therefore controlling the storage temperature to reduce the rate of oxidation is recommended for products in which a long shelf life is required.

Copper and iron are catalysts in the oxidation reaction. Their involvement in the oxidation of AMF can be reduced by using stainless-steel processing equipment. However, copper processing vessels are often used in chocolate manufacture and are thought to enhance the reaction in chocolate, resulting in the formation of desirable flavour compounds in chocolate and confectionery products.

Some wrapping and packaging materials and inks may contain oxidation-catalysing substances. AMF should be kept away from such materials.

4.2.2 Flavour of milk fat

Many different compounds are responsible for the flavour of milk fat and varying their individual proportions alters its overall flavour. Some of the important classes of compound that are present are free fatty acids, lactones, methyl ketones and esters.

One of the most important functions of milk fat in chocolate is its role as a flavour precursor. The fats in dairy ingredients can provide flavours by a number of mechanisms that occur during the manufacture of chocolate. These include hydrolysis or lipolysis, dehydration and decarboxylation. Although lipolysis is considered to be undesirable in most dairy products, it can be used to advantage in milk chocolate. Fresh milk contains lipases, which hydrolyse the triglyceride molecules and release fatty acids including butyric, caproic and capric acids. These volatile flavourful fatty acids can impart a 'buttery', 'creamy' flavour in milk chocolate. The natural milk lipase is normally inactivated during pasteurization. Heating applied during some chocolate processes may be sufficient to release these fatty acids; however, this is not generally the case. Hydrolysed milk fats have been produced to enhance the buttery flavour of milk chocolate (Campbell and Pavlasek, 1987). The controlled use of lipolysis of milk fat is normally associated with chocolate manufactured in the USA; however, it is also used at lower levels of reaction in many European chocolates. The level of lipolysis needs to be carefully controlled to avoid the cheesy flavours that are characteristic of a high degree of lipolysis. Lactones and methyl ketones are also thought to be important in the flavour of milk chocolate. These compounds are formed when milk fat is heated.

Oxidative rancidity is caused by the accumulation of several highly flavoured compounds that are generated by the oxidation of lipids containing unsaturated fatty acids. The compounds formed as a result of oxidative rancidity may be low in concentration and individually undetectable. However, collectively, they are thought to be responsible for a range of off-flavours including the 'cardboardy' flavour sometimes found in chocolate. Therefore, exposure to oxygen should be avoided during the storage of chocolate, in particular white chocolate (where the natural anti-oxidants found in non-fat cocoa solids are not present), by using appropriate packaging materials.

4.2.3 Interactions of milk fat and cocoa butter

Milk fat is able to become part of the continuous fat phase of chocolate. Milk fat and cocoa butter have different stable crystal forms and therefore the two fats will not mix completely in the solid state (see also Chapters 12 and 19). Milk fat alters the temperatures at which the various crystal forms of cocoa butter occur. Milk fat also tends to slow the rate of cocoa butter crystallization in mixtures of cocoa butter and milk fat and this is expected to occur in chocolate containing mixtures of these two fats (Timms, 2003). Adding increasing amounts of milk fat alters the physical and functional properties of chocolate including hardness, ability to temper and melting point (Barna *et al.*, 1992).

Figure 4.2 shows that, compared with cocoa butter, most other natural fats have a much lower solid fat content at ambient temperatures. Milk fat is unlike cocoa butter in that it contains numerous different fatty acids, especially short-chain fatty acids. However, the compatibility of milk fat with cocoa butter is not caused by unique milk fat triglycerides, but occurs because the milk fat does not change the polymorphic form of cocoa butter at the typical level of milk fat addition to chocolate. The level of milk fat addition to cocoa butter required to cause changes to the crystal forms of cocoa butter is approximately 50% (Timms, 2003). The incompatibility of milk fat and cocoa butter at levels greater than this is not of practical concern to chocolate manufacturers because the level of addition of milk fat is usually limited to 30% of the total fat. At levels of milk fat addition above 30% of the

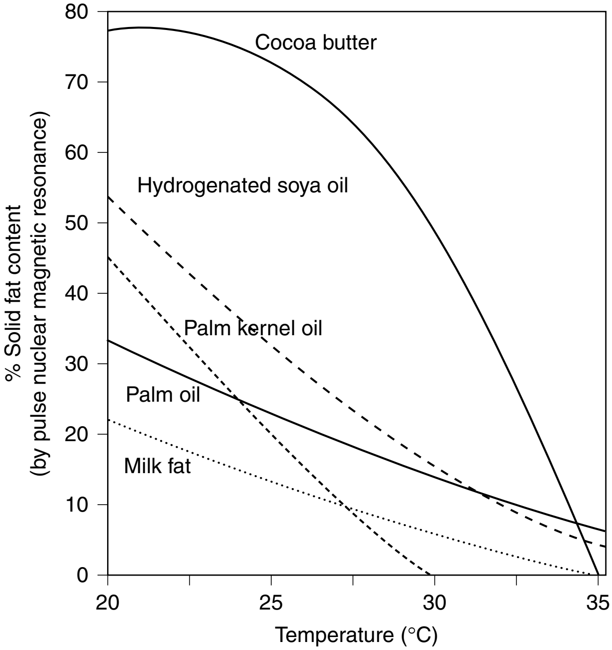

Figure 4.2 Typical solid fat content profiles of different fats at a range of temperatures. Note: hydrogenated soya oil is hydrogenated to a slip point of 35°C (95°F). The slip point is the temperature at which the fat softens and becomes sufficiently fluid to slip in an open capillary tube (Iverson, 1991).

total fat, chocolate becomes soft because more liquid fat is present at these very high proportions of milk fat. Softer products may be less acceptable to consumers and may bloom more readily if subjected to thermal abuse.

Most commercial milk chocolate products are made with a ratio of milk fat to total fat of between 12% and 32%. A general guideline is that, in order to achieve the desired physical properties of chocolate, a minimum solid fat content of 45% is required. Tempering conditions will need to be optimized to achieve this.

Timms (1980) has shown that different portions of milk fat have different effects when mixed with cocoa butter. The low-melting triglycerides in milk fat have the effect of diluting the cocoa butter and hence soften the chocolate because of their lower solid fat contents. The middle-melting triglycerides form a eutectic between cocoa butter and milk fat; that is, the solid fat content of the mixture of the two fats is less at any given temperature than a simple summation of the contributions to the solid fat content of the two components. The formation of a eutectic is shown in the simplified phase diagram in Figure 4.3. The overall effect of adding milk fat to chocolate is softening because of the low- and middle-melting triglycerides.

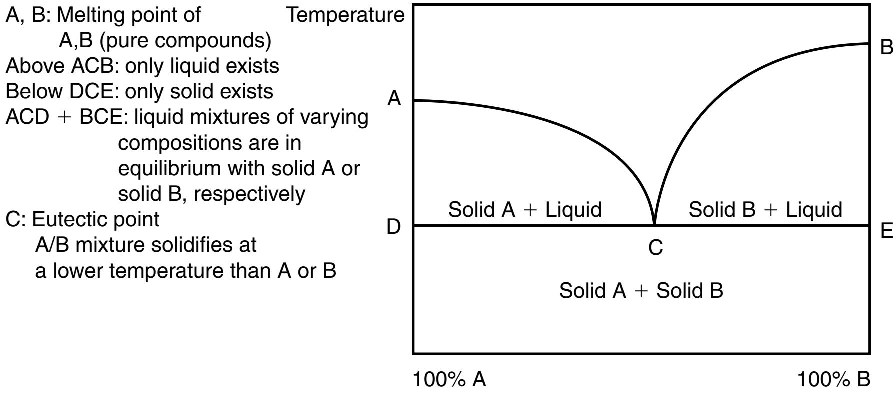

Figure 4.3 Phase diagram of a simple binary system (e.g. cocoa butter and milk fat).

4.2.4 Milk fat fractions

The traditional high cost of cocoa butter and the legislative constraints on the fats that can be used in chocolate have resulted in considerable interest in replacing cocoa butter with milk fat fractions.

Kaylegian and Lindsay (1995) have extensively described the technologies for milk fat fractionation. The milk fat fractionation processes discussed here are those that have been used for significant commercial production or are of experimental interest. The process of dry fractionation of milk fat or crystallization from a melt starts by heating milk fat to ensure that all the fat crystals are melted. The liquid fat is then cooled to the desired fractionation temperature and held there with agitation. The crystal phase, or stearin, formed during crystallization is separated from the milk fat slurry. The remaining liquid, or olein, can be further crystallized at a lower temperature to produce further fractions. One of the major advantages of dry fractionation is that there are no additives. The fat fractions can be separated in a number of ways including vacuum filtration, membrane filtration and centrifugation. One disadvantage of dry fractionation is that some liquid fat remains trapped in the stearin. Dry fractionation is also a slow batch process. Membrane filters adopted for milk fat fractionation in the 1980s allow more defined separation of the stearin and olein phases. Membrane filtration of the crystallized slurry also has the advantage that the process can be totally enclosed, therefore minimizing exposure of the milk fat and fractions to the atmosphere and potential oxidation.

Detergent separation as an alternative to filtration was developed to reduce the entrapment of liquid fat in the fat crystals. However, in the detergent fractionation process, the crystal slurry comes into intimate contact with a detergent solution, which, although the fraction can be washed, can result in traces of detergent being entrapped in the stearin or crystal fraction. Detergent fractionation is still used extensively for fats such as palm oil and palm kernel oil; however, it has been effectively rejected for milk fat fractionation.

Solvent fractionation was developed in the 1950s for palm oil for the manufacture of cocoa butter substitutes and extenders. The process typically uses acetone or hexane. Solvent fractionation improved the removal of entrapped liquid from the stearin and allowed for a continuous fractionation process. However, solvent fractionation is both expensive and hazardous. In addition, the levels of solvent residues in the fat fractions are unacceptable for food applications unless the fat fractions are fully refined after the fractionation process. If applied to milk fat fractions, the solvent fractionation process would remove all the natural flavour and colour, therefore eliminating the main advantages of using milk fat as an ingredient.

Supercritical fluid extraction separates fractions according to their molecular weight rather than on melting point. Carbon dioxide is the supercritical fluid used in experimental processes for the production of milk fat fractions, as it is non-toxic, non-polluting and relatively inexpensive. Milk fat fractions are dissolved in the supercritical carbon dioxide as the temperature and pressure of the system are altered. At low pressures, the low molecular weight fractions are dissolved into the supercritical fluid and the high molecular weight fractions remain undissolved. The milk fat fractions are collected when the system returns to atmospheric conditions and the carbon dioxide evaporates, leaving no residue in the fat fraction. Further fractions are obtained by altering the pressure, at constant temperature, of the supercritical fluid. The main advantage of supercritical fluid extraction is the low operating costs. The main disadvantage is that the fractions have been separated according to their molecular weight and so they may not have the melting characteristics that are required for the application. The high capital cost of the supercritical fluid extraction process means that it is unlikely to be a commercial option for milk fat fractionation.

Milk fat fractions are typically described as three major groups:

(1) high-melting fractions (HMFs), which are typically solid at 30°C (86°F);
(2) middle-melting (or intermediate) fractions (MMFs), which are typically solid at 20°C (68°F) and have melting points typically between 10°C and 20°C (50°F and 68°F) or above;
(3) low-melting fractions (LMFs), which are liquid at 10°C (50°F).

Figure 4.4 shows the solid fat content of mixtures of cocoa butter and milk fat fractionated to 40°C (104°F). Jordan (1986) showed that the use of an HMF of milk fat enabled a further 3% of milk fat to be incorporated into milk chocolate with no difference to the solid fat content. However, the HMF of milk fat does not substantially increase the hardness of chocolate over the addition of an equivalent amount of standard milk fat (Timms, 1980). MMF has been found to soften chocolate to a greater extent than standard milk fat because of the eutectic effect of the middle-melting

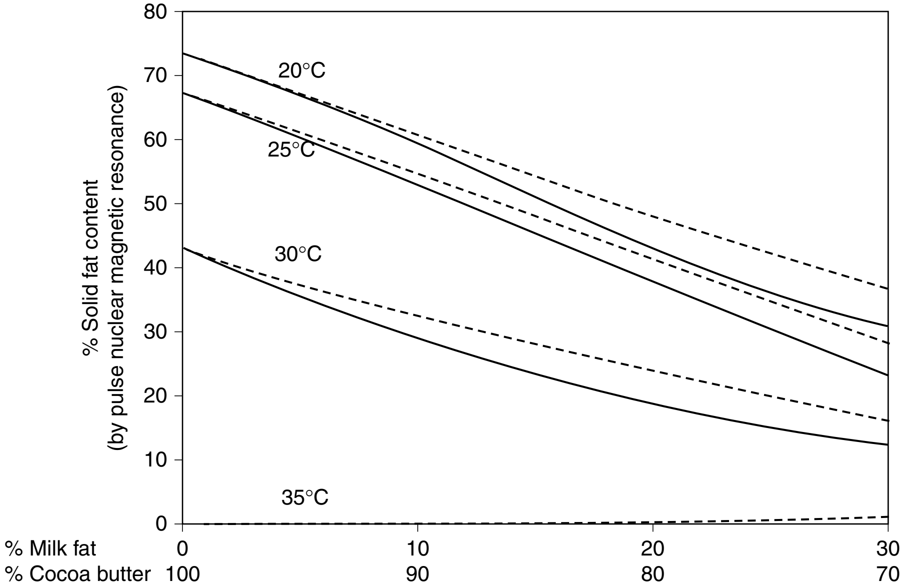

Figure 4.4 Solid fat content values for mixtures of cocoa butter and milk fat or fractionated milk fat (fractionated to give a 40°C (104°F) melting point) (Iverson, 1991). (——) Milk fat; (– – –) fractionated milk fat.

triglycerides. However, MMF may reduce the brittleness of chocolate coatings for frozen confections.

4.2.5 'Free' and 'bound' milk fat

Milk fat influences the properties of chocolate depending on the form of the fat. It can be added to chocolate via roller-dried or spray-dried whole milk powder (WMP) and through the use of AMF. Spray-dried WMP, in which typically most of the fat remains bound, is termed a low-free-fat system (see Section 4.3.2). Replacing spray-dried WMP with skim milk powder (SMP) and AMF, so that all of the milk fat is available as 'free' fat, is termed a high-free-fat system, and this results in modification to the processing and sensory properties of the chocolate. The flavour differences between chocolate made using the two systems may be partly attributed to the different stages of the chocolate process at which the milk fat is added. AMF, when used with SMP in a high-free-fat system, is usually added at the viscosity adjustment stage, unlike the milk fat present in WMP, which is added at the start of the chocolate process. AMF in the high-free-fat system is sometimes not present at conching, when heating and some flavour generation occur.

Some manufacturers prefer the flexibility of being able to adjust the levels of SMP and milk fat independently in their milk chocolate formulations. However, this advantage can be outweighed by the need to carry supplies of two ingredients. In addition, specialized systems to handle both powders and liquid fats are required. Figure 4.5 shows the effect on the plastic viscosity (Chapter 10) in milk chocolate for a low-free-fat system (WMP) and a high-free-fat system (SMP and AMF). It is clear that there are significant rheological advantages (leading to potential savings in milk fat or cocoa butter) in having a higher level of free milk fat. However, this advantage is offset by the softening effect of high levels of free milk fat. Figure 4.6 shows the hardness of chocolate products for a low-free-fat system and a high-free-fat system. There is a substantial softening in the chocolate product manufactured with high levels of free milk fat.

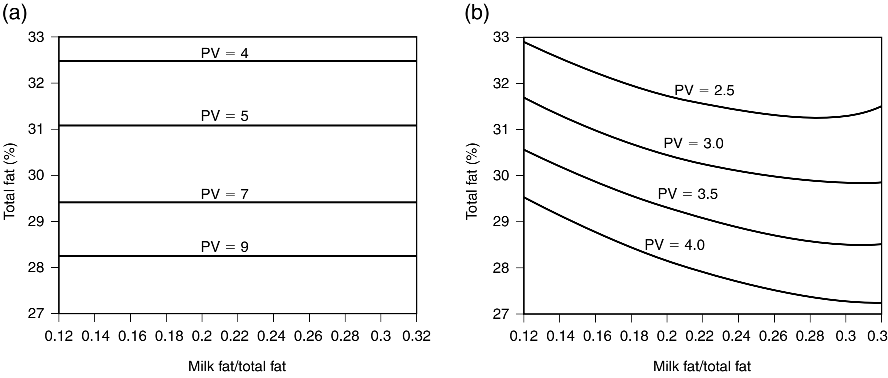

Figure 4.5 Effect of total fat and milk fat/total fat ratio on the plastic viscosity (Pa s) of (a) a low-free-milk-fat (WMP)-based milk chocolate and (b) a high-free-milk-fat (SMP and AMF)-based milk chocolate. PV = plastic viscosity.

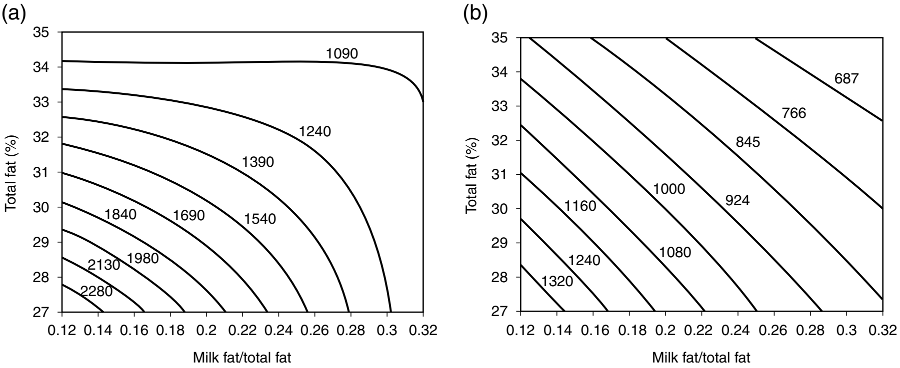

Figure 4.6 Effect of total fat and milk fat/total fat ratio on the chocolate hardness (g) of (a) a low-free-milk-fat (WMP)-based milk chocolate and (b) a high-free-milk-fat (SMP and AMF)-based milk chocolate.

4.2.6 Bloom

Fat bloom in chocolate is often characterized by the loss of gloss and dulling of the chocolate surface through to the presence of grey/white clusters that have the appearance of mould (Hartel, 1999; Timms, 2003; Aguilera *et al.*, 2004). Fat bloom also affects the texture of chocolate and has been described as the development of a new phase in the fat throughout the chocolate. There are many reasons why bloom occurs, including incorrect tempering, use of incompatible fats and temperature fluctuations or abuse within the supply chain. The transformation of cocoa butter crystals from polymorph V to form VI (Chapter 12) is thought to be one of the most common causes of bloom in chocolates containing cocoa butter. Form V is the form that commercial chocolate is manufactured to produce, but it is not the most stable form. Over time, cocoa butter transforms into the more stable form VI polymorph. However, the transformation from form V to form VI occurs over a long period, typically beyond the consumption date of chocolate. So, form V is usually suitable for commercial chocolate manufacture. Bloom commonly occurs due to the uncontrolled crystallization of form VI. Although there are many theories, the exact mechanism of fat and oil migration through chocolate, which also results in bloom, is still largely unknown.

Timms (2003) has described a number of ways of preventing bloom, including the use of milk fat as a bloom inhibitor. Most of the work on bloom inhibition has been conducted on dark chocolate, in which bloom is more obvious on the dark background and in which milk fat levels are usually lower. The addition of 1–2% milk fat to a dark chocolate formulation is able to delay bloom formation.

There are various theories on how milk fat prevents bloom. Milk fat crystallizes in a solid formation with cocoa butter and the triglycerides that are unique to milk fat prevent or slow down the transformation of the form V crystal structure of cocoa butter to form VI (Timms, 2003). When chocolate crystallizes more slowly, as happens when milk fat is present, microscopic cracks are less likely to occur within it (Kleinert, 1961). A further theory claims that milk fat inhibits bloom by maintaining a solution in which the unstable forms of cocoa butter are held (Cook, 1984). Whatever the mechanism, there is very good evidence that free milk fat can assist in preventing bloom.

Use of milk fat through a high-free-fat system (SMP and AMF) is thought to be more effective than the use of WMP in preventing bloom in products in which oil migration is a likely cause, for example, in chocolates containing nuts (Urbanski, 2000).

Higher melting fractions of milk fat are more effective in preventing bloom than non-fractionated milk fat. Lohman and Hartel (1994) have shown that HMFs, in chocolate containing 30% of the fat as milk fat, inhibit bloom. LMFs have been shown either to have no effect on bloom inhibition or to actually induce bloom. Lohman and Hartel (1994) have suggested that the reason why lower melting milk fat fractions induce bloom is because the addition of more liquid fat increases the mobility of the unstable triglycerides. Although it appears that it is a high-melting component of milk fat that prevents bloom, the exact components responsible and their mechanism are unknown.

Tietz and Hartel (2000) and Wright *et al.* (2000) have shown that the minor lipids of milk fat affect the crystallization of cocoa butter and milk fat in chocolate and have suggested that the minor components also influence bloom formation through their influence on the crystal structure of cocoa butter. However, research on the exact mechanism by which these minor components prevent bloom is still at an early stage.

Hartel (1999) and Liang and Hartel (2004) have suggested that the structure of the non-fat or dispersed phase of chocolate (sugar, milk powders and non-fat cocoa particles) also has an influence on bloom formation. How milk fat interacts with this solid phase may affect the rate of bloom inhibition. The form of milk fat, whether it is free milk fat added directly to chocolate or through the use of fat-containing dairy powders, may also have different effects on the bloom stability of chocolate. Further work is still required to fully understand the mechanism of bloom development and the mechanism of bloom resistance by milk fat.

Other modified fats or compounds are available as bloom inhibitors (Timms, 2003), but many of these do not have regulatory approval in many countries. Milk fat as a bloom inhibitor has the advantage of being able to be legally added to chocolate in most countries of the world.

4.3 Milk powder

Milk powder manufacture in its simplest form involves solids concentration of liquid milk (usually through evaporation) followed by drying and packaging. The liquid milk stream will have been formulated or standardized to ensure the correct ratio of components in the final dried product. Masters (1991) and Caric (1994) provide more detailed information on drying technology.

4.3.1 Skim milk powder: non-fat dried milk

Separation of whole milk into cream and skim milk and the subsequent evaporation and drying of the skim milk stream are the primary processing steps used for the manufacture of SMP or non-fat dried milk (NFDM). Table 4.3 shows the composition of SMP. Codex Alimentarius (Codex, 1999b) provides standards for the raw materials and the composition of milk products (although specific country regulations can override these). For SMP, the key compositional factors are maximum milk fat (1.5%), maximum water content (5%) and minimum milk protein in non-fat milk solids (34%). In addition to milk and cream, milk retentate, milk permeate and lactose are permitted ingredients in SMP manufacture. With the introduction of this standard in 1999, both manufacturers and their customers found advantages in standardizing the protein content to an approved level, rather than allowing this to vary significantly with seasonal changes in milk composition. Levels of milk fat greater than 1% in the powder are usually an indication of poor separation of cream from skim milk during processing.

The most common use of SMP is in products where it is reconstituted in water during the manufacture of a food or beverage product. In chocolate manufacture, SMP is not used in this way and therefore different specification criteria are appropriate. Table 4.6 shows a typical profile for SMP that is suitable for chocolate. The chemical, physical and microbiological properties of the product are all important. The key chemical parameters are titratable acidity and the whey protein nitrogen index (WPNI). The WPNI is a measure of the level of preheat treatment to which a powder is subjected prior to spray drying. Powders with high titratable acidity levels are an indication of poor raw milk handling procedures prior to powder manufacture. High titratable acidities are often found in products with significant off-flavours.

A number of the physical specifications that are critical for powder performance in aqueous systems are less important to chocolate manufacturers, for example solubility index, scorched particles and powder colour. Flavour and odour are important, but requirements will often depend on the specific application. For SMP used in chocolate, often high heat treatments (leading to low WPNI values) are applied to develop cooked flavours. Bulk density and particle size distribution are factors that vary depending on the drier type and configuration used. To date, there has been limited work

Table 4.6 Typical profile for powder products used in chocolate manufacture.

		Typical specification		
Property type	**Measured property**	**SMP**	**WMP**	**BMP**
Chemical	Titratable acidity (%)	<0.15	<0.15	<0.15
	Free fat (% powder)	[a]	2.5	[a]
	WPNI (mg/g)	1–6	1.6	[a]
Physical	Insolubility index (mL)	<1.0	<1.0	<1.0
	Bulk density (g/mL)	0.70	0.60	0.65
Microbiological	Aerobic plate count ($\times 10^4$/g)	<2	<2	<2
	Coliforms (per g)	Absent	Absent	Absent
	E. coli (per g)	Absent	Absent	Absent
	Yeasts and moulds (per g)	<50	<50	<50
	Salmonella (per g)	Absent	Absent	Absent
	Coagulase-positive *Staphylococci*	Absent	Absent	Absent

[a] Typically not specified.

Milk powders will also have specifications for flavour, odour and foreign matter.

linking specifications for these parameters to any benefits in milk chocolate manufacture; however, generally higher bulk density and an even particle size distribution will be of benefit in minimizing total fat requirements in the chocolate formulation. Tight microbiological specifications are required to provide confidence in the processing and post-manufacturing handling procedures. Chocolate is typically processed at temperatures below pasteurization. Therefore, SMP that is produced within specified microbiological limits should be used in chocolate to ensure low levels of micro-organisms in the final chocolate product.

The use of different processing conditions for SMP results in changes in two important properties – the level of native whey protein and the size of air vacuoles in the final powder. Pepper and Holgate (1985) reported that the physical properties of the chocolate were not affected by powders with different preheat treatments, although they did not describe the WPNI levels in these products in this paper. They inferred from this that the absorption of fat in the chocolate manufacturing process was not altered by denaturation of whey protein at the milk powder particle surface. Thus SMP receiving a medium to high heat treatment will be acceptable for chocolate manufacture.

Table 4.5 showed the shelf life of SMP compared with that of other powdered products. The keeping quality of SMP is considered to be superior to that of other milk powders. The predominant limitation on shelf life is the development of stale and aged flavours.

Yoghurt powder, a fermented product, from skim milk (Figure 4.1) is manufactured using processes typical of other fermented milk products, with the exception that the viscosity of the product is maintained at a level that is suitable for spray drying. Yoghurt powders are not commonly used in milk or dark chocolate products, but have been popular components in white chocolate and coatings. The fermentation process used in manufacture results in a low pH and this is responsible for these powders providing a tangy, acidic flavour in the final products. As these powders are used primarily in white products, the stability of the white colour is important throughout their shelf life. Darkening during storage is the main cause of coating deterioration and this can arise as a consequence of browning reactions and the action of residual lipase enzymes.

A range of high-protein products known as milk protein concentrates (Figure 4.1) are commercially available, although little information is available about their use in milk chocolate. These products could be used to either partly or wholly replace SMP in a chocolate formulation. However, the higher cost of these ingredients compared with standard SMP means that they would only be used in formulations supporting specific consumer claims such as those relating to higher protein content.

4.3.2 Whole milk powder

Table 4.3 shows the composition of a typical WMP. Codex also provides standards for the raw materials and composition of WMP: minimum milk fat (26%), maximum water content (5%) and minimum milk protein in non-fat milk solids (34%). As with SMP, milk retentate, milk permeate and lactose are permitted ingredients for protein adjustment. Most WMP products have standardized fat and protein levels to overcome day-to-day and seasonal variations in the raw milk.

The free fat content of WMP is a critical parameter that has a significant influence on the performance of milk powders in chocolate (Liang and Hartel, 2004). Roller-dried powders have been preferred by confectionery manufacturers over spray-dried powders because of the rheological benefits they provide (Verhey, 1986). These rheological benefits arise substantially from the high level of free fat that is associated with roller-dried powders (see Section 4.2.5). Achieving high free-fat levels in spray-dried milk powder is a target for a number of milk powder manufacturers. These products aim to deliver the functional benefits of a high free fat with the cost advantages of spray drying (Attaie *et al.*, 2003). One important method is the use of a manufacturing procedure that results in a high level of crystallized lactose in the final powder. This can be achieved by a number of techniques, including rewetting powders followed by secondary drying in a fluid bed, or by seeding milk concentrates with lactose prior to drying (King, 1965; Bohren *et al.*, 1987; Koc *et al.*, 2003). A number of researchers have postulated that the mechanism that changes spray-dried WMPs from having a low free-fat level to a high free-fat level is the presence of large lactose crystals. While forming, these large lactose crystals cause the development of a network of fine cracks in the powder particle that are permeable to fat and result in the migration of fat from within the particle to the fat surface (King, 1965). When WMP with crystallized lactose is used in milk chocolate, some sensory properties are also modified (Aguilar *et al.*, 1994).

The particle shape of roller-dried powders (which are platelets, c.f. the spherical shape for spray-dried powders) has also been suggested as a factor in providing the beneficial rheological properties. However, Pepper and Holgate's work did not support this view when they found that roller-dried powders prepared with low levels of free fat gave little or no rheological advantage (Pepper and Holgate, 1985). In spray-dried powders, the use of processes to minimize occluded air during powder manufacture is important to ensure effective utilization of fat in the chocolate formulation (Hansen and Hansen, 1990).

Techniques aiming to provide physical disruption to the milk fat globule membrane during liquid processing have also been used to achieve high free-fat levels in WMP. The use of high homogenization pressure during the WMP manufacturing process is one technique that has been used successfully, although without generating the same level of free fat and process control as can be achieved in powders with crystallized lactose.

The shelf life of WMP is generally shorter than that of SMP because of the higher level of milk fat in the product. Modern processing techniques for WMP now include packaging the product under an inert gas such as nitrogen. Processing in this way can extend the acceptable shelf life to 24 months at 25°C (77°F) before the level of oxidative flavours becomes unacceptable. WMP not packaged under an inert gas may have a shelf life of only 9 months.

In selecting WMP for use in milk chocolate, it is important to ensure that appropriate specifications, particularly for particle size and free fat, have been provided. There are limited data on the effect of the preheat treatment of WMP on the properties of milk chocolate. High heat specifications for WMP have been recommended in the past. These products generally have greater resistance to oxidation and the recommendation to use higher heat powders has been made as much to ensure a longer product shelf life as for any functional advantage that the high preheat conditions may provide. The availability of inert-gas-flushed WMP should enable powders with lower preheat treatments to be used successfully in milk chocolate.

4.3.3 High-fat powders

High-fat powders or spray-dried creams have been available for a number of years, although the use of older drying and packaging technology often meant that these products were more difficult to manufacture and distribute than powders containing lower levels of fat. Table 4.3 shows the composition of a high-fat powder containing 55% fat. Advances in drying and packaging technology now enable powders with fat contents greater than 80% to be manufactured.

High-fat powders are usually manufactured by first standardizing cream to a specific fat level. These products are often considered to have a better, creamier flavour than AMF and this advantage can be carried through into milk chocolate when these powders are used. Powders with high fat contents often have high free-fat levels. The higher level of free fat can result in an increased tendency to oxidize. In addition excess fat on the surface of powders can cause particles to clump together and thus reduce powder flowability (King, 1965).

These products are typically packed under an inert gas, such as nitrogen. However, even with this treatment, the shelf life is often limited to about 9 months. Fat oxidation is the primary cause of failure (Table 4.5). Chocolate manufacturers usually require a specific functional or flavour benefit to justify the use of a cream powder ingredient, as these products typically sell at a premium to other powder products.

4.3.4 Buttermilk powder

Buttermilk is the serum derived from cream during the manufacture of butter or AMF. Table 4.3 shows that buttermilk powder (BMP) has a fat content intermediate between those of SMP and WMP. Thus, with an appropriate milk chocolate formulation, BMP offers an alternative to these two ingredients.

During butter manufacture, the milk fat globule membrane is ruptured, resulting in the release of polar phospholipid material from the globule membrane into the serum phase. This material forms a small but significant component of BMP. What is not apparent from the data in Table 4.3 is the nature of the fat and protein material in BMP. Up to 20% of the fat in BMP is dairy phospholipids, which compares with about 3% in standard WMP. Dairy phospholipid is a complex mixture of surface-active molecules. A number of researchers have reported the benefits of using dairy-phospholipid-rich ingredients in chocolate. Kinsella (1970) and O'Riordan (1990) have reported that dairy phospholipids do display surface-active properties in milk chocolate and thus can contribute to the functionality provided by the added soy lecithin. Kinsella has also reported that dairy phospholipids may also retard bloom formation. Together with the added lecithin, however, they may reach a phospholipid level, which causes the yield value to increase (Chapter 10).

Martin (1987) has reported the use of BMP in compound coating and has indicated that this results in a rich buttery flavour in the product. Campbell and Pavlasek (1987) have also reported the unique flavour contribution that the inclusion of BMP can make to chocolate products. These results are somewhat in contrast to results of trials carried out at the Fonterra Research Centre, in which buttermilk was used at levels of up to 13% in a milk chocolate formulation. In these trials, no modification to the milk chocolate flavour profile was detected in comparison with chocolate prepared from standard WMP.

BMP is often sold on the international commodity market at a price discount to an equivalent SMP – thus, using BMP as a replacement for SMP or WMP can provide formulation cost savings. The extended processing that the components in BMP receive through primary milk treatment, butter processing and finally BMP manufacture means that these products are susceptible to greater batch-to-batch variability, flavour defects and poor microbiological quality. Improved processing, and greater awareness that these products are valuable ingredients that can be used in milk chocolate manufacture, should see greater quantities of BMP used in milk chocolate. Certainly, the cost savings offered by the use of BMP should be of interest to all chocolate manufacturers.

In selecting BMP for use in milk chocolate, it is appropriate to use specifications similar to those given in Table 4.6. It is also important to be aware of the potential variation in composition, particularly with regard to total fat level and phospholipid level. Where the use of BMP has resulted in increased yield values in milk chocolate, the inclusion of polyglycerol polyricinoleate towards the end of the conching process will control the yield value to desirable levels. However, this emulsifier adds extra cost and is not approved for use in milk chocolate in all countries.

4.3.5 Formulated milk powders

The availability of lactose-rich product streams and high-lactose powders has prompted the development of a range of formulated milk powder products for use in milk chocolate. Milk protein is by far the most valuable component in milk and this is reflected in the international prices of milk protein products compared with those of milk fat and lactose. Often the level of milk protein used in a formulated food product is critical in determining the sensory and functional performance of the food. Milk chocolate is something of an exception. Chocolate manufacturers have found that they can increase the level of lactose and reduce the level of milk protein in milk chocolate within certain limits without substantial effects on product quality. The motivation for making changes of this type is economic, where the chocolate manufacturer can purchase a high-lactose formulated milk powder at a lower price than a standard product. Both full-fat and non-fat formulated milk powder products are now available. The composition of a typical full-fat product is shown in Table 4.3. It is anticipated that the trend of replacement of expensive milk solids by lower-cost milk solids will continue.

4.3.6 Whey powders

Whey powders are manufactured as by-products of cheese and casein manufacture. There are a number of broad classifications of whey powders and acceptability in a specific application is often determined by the whey powder type. Whey is produced at the pH at which the cheese or casein is manufactured. This pH has a major bearing on the mineral content of the final whey powder. The lower the pH of the initial whey, generally the more minerals will be present in the whey powder. To compound this, acid wheys are often neutralized, requiring addition of sodium or calcium hydroxide. Neutralized acid wheys generally have a salty flavour, whereas whey produced at near-neutral pH, such as rennet casein whey, generally has a much lower level of saltiness. It is possible to demineralize whey by electrodialysis using specific membranes; however, these processes inevitably add cost to the ingredient, which partly reduces the benefit of using whey solids.

Table 4.3 shows the compositions of a standard whey powder and a demineralized whey powder. These products are generally used as replacers for SMP to reduce cost. There are no fixed guidelines on the amount of whey powder that can be used to replace SMP before a discernible change occurs in the final chocolate products. The level of whey powder that can be used is affected by the quality of the whey powder and the positioning of the final chocolate product. The use of whey powder and lactose in confectionery has been covered extensively in publications by Mohler *et al.* (1981) and Campbell and Pavlasek (1987).

4.4 Milk crumb

Milk crumb was traditionally used in chocolate because it had better keeping qualities than milk powder. The superior keeping quality results from the natural antioxidant properties of components in the cocoa liquor. Crumb manufacture promotes the formation of Maillard products and these may also contribute antioxidant properties. This meant that manufacturers would produce crumb when supplies of milk were plentiful and cheap, ensuring a stock of milk ingredients for chocolate manufacture over a long period. However, as the keeping quality of dried milk powder has increased as a result of improved manufacture and packaging, the advantage that crumb had is no longer the primary reason for its continued use in chocolate.

Crumb provides caramel flavours in milk chocolate. Chocolate made from crumb is thought to have a smoother texture than chocolate made from milk powder. In addition, using crumb results in less cocoa butter being needed in the chocolate formulation than if a low-free-fat spray-dried WMP is used. The typical composition of crumb is shown in Table 4.3. Further details about chocolate crumb and its manufacture are given in Chapter 5.

The manufacture of crumb is expensive relative to the cost of producing milk powder because of the high capital and running expenses. Mixtures of milk and sugar that have been dried by methods other than vacuum drying may offer economical advantages to chocolate manufacturers, while providing some flavour differentiation over traditional dried milk powders.

4.5 Lactose

Lactose is the most abundant component in milk and dried-milk products such as SMP and WMP. Apart from its contribution to these products, lactose has an important role in chocolate manufacture as an ingredient in its own right. Whey is produced during cheese and casein manufacture (Figure 4.1). After protein removal, crystalline lactose is isolated from these streams using concentration and crystallization processes. Lactose produced in this way is crystalline and is different from the amorphous lactose that is present in most spray-dried milk powders.

Lactose, being a disaccharide, is often compared with sucrose, yet some of its properties are quite different from those of sucrose (see also Chapter 3). Lactose is only about one-fifth as sweet as sucrose and is also far less soluble (17 g/100 mL water compared with sucrose at 67 g/100 mL water at 20°C (68°F)). Lactose is a reducing sugar and hence readily undergoes Maillard reactions with protein components and caramelization reactions. Both of these reaction types are critical in achieving the rich, caramelized, cooked dairy flavour typical of milk chocolate.

Lactose as a single ingredient can be used in two ways in milk chocolate manufacture. First, it can be used to replace sucrose when the sweetness of a formulation is too great. As lactose is a disaccharide, it responds in a similar way to sucrose when processed in milk chocolate. Second, lactose, because it is isolated entirely from milk, can also be used to replace other non-fat milk solids in milk chocolate (when regulations allow). This approach offers chocolate manufacturers a further means of reducing costs, while still achieving levels of milk solids specified in regulations. This is a similar approach to using the formulated milk powder products discussed in Section 4.3.5. Replacement of high levels of standard milk powders with lactose does cause detectable changes in the sensory properties of the milk chocolate.

Crystallization of amorphous lactose during the holding of bulk chocolate has been proposed as the cause of uncontrolled thickening of chocolate in bulk storage tanks over time. In most spray-dried milk powders, the lactose is in an amorphous form. If crystallization occurs, moisture is released, resulting in bridging between milk powder particles and an increase in the viscosity of the bulk chocolate (Ziegleder *et al.*, 2004).

4.6 New consumer requirements

This chapter has described how milk ingredients are able to provide the right functional and flavour contribution to chocolate formulations. However, in recent times, there has been an increase in products responding to consumers' cultural and personal beliefs. In this category, we can list organic, halal, kosher, free range and fair trade. To achieve these claims, products will usually need to undergo a certification process with associated requirements for the ingredients used in manufacturing the products. Dairy ingredient suppliers now provide a range of ingredients to meet the requirements of these product trends. Significant volumes of products that comply with the strict requirements from organizations for organic, halal and kosher registration are now manufactured. We can expect that these, along with other emerging consumer trends, will continue to ensure the need for new milk ingredient products to be developed.

Summary

A broad range of dairy products is available to the confectionery manufacturer. This range of products will continue to develop and change. Chocolate manufacturers wishing to produce premium products will have a wide range of differentiated products to choose from. Premium confectionery will continue to require high-quality ingredients designed specifically for their purpose. Users of standard ingredients, on the other hand, will seek the advantages offered by less expensive and/or more functional sources of dairy solids. Overall, the dairy industry and the confectionery industry will continue to work together to develop better cost-effective ingredients for use in confectionery products.

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Chapter 5

CHOCOLATE CRUMB

M.A. Wells

5.1 Introduction and history

Milk chocolate crumb is the name given historically to a co-dried mixture of milk, sugar and cocoa liquor whose lumpy, aerated structure resembles that of bread crumb (Figure 5.1).

Its invention can be traced back to the 1870s when Daniel Peter first attempted to produce milk chocolate in Vevey, Switzerland. His main concern was to remove water from the milk that he was using and keep it from developing mould. In the milk processing factory next door Henri Nestlé

Figure 5.1 Typical appearance of milk crumb.

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had solved the problem by condensing milk in the presence of sugar. Daniel Peter found that by drying his dark chocolate paste with Nestlé's sweetened condensed milk he could achieve his aim. In the process he developed the first crumb-based milk chocolate. Peter was also allied by marriage to Cailler, another Swiss chocolate maker. Between them they were able to create a sizeable market for quality milk chocolate first of all in Switzerland and then in the UK as well. Cailler today claims to make the only Swiss milk chocolate containing condensed milk in its recipe.

UK chocolate makers introduced their own milk chocolate bars based on milk powder in the 1890s, but the milk powder was of poor and variable quality and the finished units were no match for the Swiss imports. The threat, particularly from Cailler's high milk solids version of milk chocolate, led to the development of a fresh milk process and in 1905 to the launch of the highly successful Cadbury Dairy Milk brand. This product was based solely on crumb produced at milk processing factories first at Knighton, then at Frampton, then finally at Marlbrook in Herefordshire. Rowntree first introduced crumb manufacture into Mallow in the Republic of Ireland in 1946 (Fitzgerald, 1995).

Hershey in the USA also moved into milk chocolate production via a crumb route in the early 1900s. Milton Hershey chose Derry Church, Pennsylvania for his factory because of the abundance of fresh milk in the area, and made his first crumb-based milk chocolate bars in 1905.

In addition to Switzerland, the UK and the USA, crumb chocolate processes have also been successfully introduced to the Irish Republic and countries belonging to the old British Commonwealth. Cadbury, Nestlé (Rowntree) and Mars have been the main initiators of this expansion. Kraft/Marabou in Sweden also employ a crumb making process. In a number of these markets the early introduction of crumb chocolates has led to market domination, due to their quite distinctive flavour characteristics.

Since the early days, other types of crumb have been developed without either the non-fat cocoa solids or some of the milk components. White crumb comprising co-dried sugar, milk and cocoa butter is currently used by Mars Inc. A similar material has been manufactured by Coberco in Europe. In addition, crumb manufacture has progressed from the original batch processes into continuous ones.

5.2 Benefits of milk crumb

The main benefit of crumb manufacture is still that it offers a unique, fruity, caramelized flavour to milk chocolate that cannot be matched by the use of recipes which add the milk, cocoa and sugar as dry ingredients. There are also other benefits too. These are:

- In contrast to dried milk, dried milk crumb can be stored for long periods without fat rancidity or staleness developing. This is because of the presence of polyphenolic antioxidants such as epicatechin in the cocoa.

- This stability allowed the original manufacturers to make use of milk when it was readily available in the 'flush' and safely store crumb for chocolate making in less plentiful milk supply periods. It is possible to store crumb in cool conditions for up to 12 months without perceptible flavour deterioration.
- A typical crumb recipe contains some 85% of the ingredients for chocolate making. This means that the subsequent chocolate manufacture is simplified to processing crumb, fats and emulsifiers.
- Since most of the flavour of the chocolate has been developed during crumb making it is not necessary to conche the chocolate for long periods of time to initiate Maillard browning and caramelization reactions (see Chapters 8 and 9). This means that advantage can be taken of some of the rapid chocolate liquefaction techniques described in Chapter 17.

5.3 Typical crumb recipes

Table 5.1 gives the composition of some typical crumb recipes. These assume that full cream milk is used and the cocoa liquor or mass contains 55% cocoa butter. It is perfectly possible to use other ingredients such as skimmed or partially skimmed milk, cocoa powder and sugars other than sucrose. The regulations in particular countries may also permit the use of separate milk components such as whey, casein or lactose.

Table 5.1 Composition of typical chocolate crumbs.

Ingredient (%)	Full milk crumb	Low mass crumb	White crumb
Sucrose	52–64	67	55
Full cream milk solids	17–25	28	44
Cocoa solids	10–18	4	
Water	1	1	1
Lactose	6–9	10.0	15.6
Milk protein	4–6.4	7.2	11.3
Milk fat	5.4–8	8.9	14.0
Cocoa butter	5.5–10	2.2	
Total fat	13.5–17.3	11.1	14.0

5.4 Flavour development in chocolate crumb

It has been recognised for some time (Hanlon, 1984) that Maillard reactions (Davies and Labuza, 1998) are responsible for the development of flavour in milk chocolate crumb. This flavour is difficult, if not impossible, to replicate by conching for long times at high temperatures because of the much lower water contents at this stage of chocolate making (see Chapter 8).

The Maillard reaction is essentially a reaction between a reducing sugar (containing a reactive aldehyde group) and a free amino group on a protein. In the case of milk crumb the reducing sugar is lactose from the milk (see also Chapter 4). The main source of free amino groups comes from lysine and arginine, which are amino acids in the milk proteins. There is also a significant contribution from the cocoa proteins: where cocoa is added in the crumb process there is a definite effect on the final flavour.

A much simplified version of Hodge's original Maillard reaction scheme (Hodge, 1953) as it applies to crumb making is presented in Figure 5.2. The initial reaction takes place between protein and sugar to give Amadori rearrangement products. Further reaction then takes place alone or with sugar and amino acids to give the range of flavour volatiles described.

One of the final products is the characteristic brown pigment which explains why the reaction is often called a Maillard or non-enzymatic browning reaction.

Many of these compounds have quite characteristic flavours and have been described for example as:

Furfural – 'sweet, woody, almond, baked bread'
Maltol – 'sweet caramel toffee'

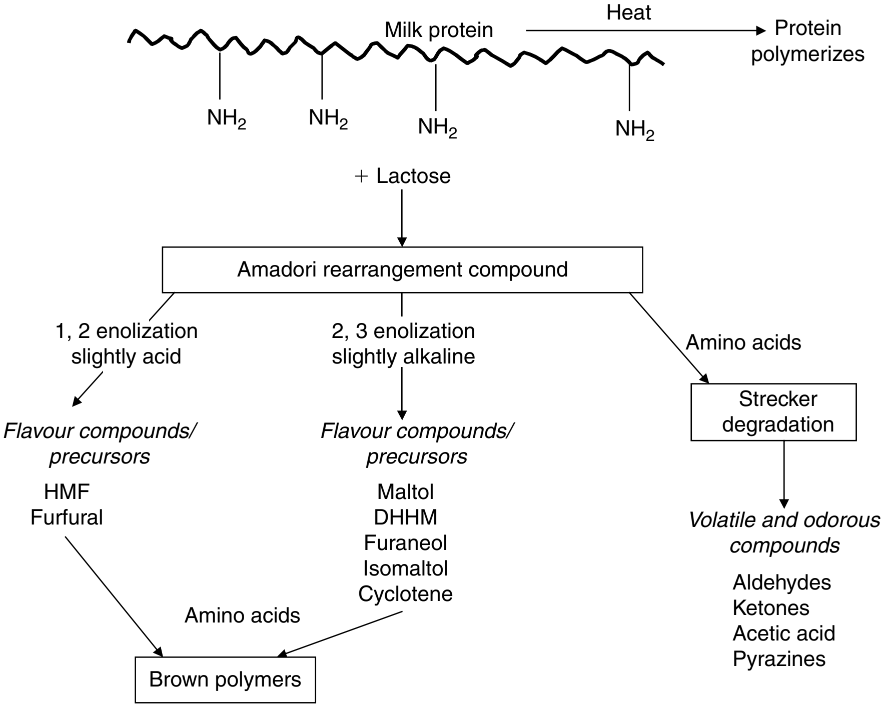

Figure 5.2 Schematic diagram of Maillard reaction.

Cyclotene – powerful: 'spicy to maple syrup'
Furaneol – powerful: 'strawberry, brown fruit, candy floss'.

Excessive browning of crumb leads to burnt and bitter flavours, overcoming the pleasant 'fruit cake' characteristics.

Many other compounds, as yet unidentified, doubtless contribute to the overall flavour. More details of the chemistry of this complicated set of reactions are found in Chapter 8.

The final crumb flavour is dependent on three major factors:

- the moisture content
- the temperature
- the time at each stage.

These three factors are largely determined by the processing equipment chosen to make the crumb.

The effect of moisture content can be as illustrated as shown in Figure 5.3 (Bouwman-Timmermans, 1995).

Initially, the crumb mixture contains a lot of water and so the optimum moisture for browning is at quite an advanced stage of the drying process, when the moisture has been reduced to below 10%. The optimum time for other products of the Maillard reaction does not occur at this moisture content. In the case of some flavour volatiles the effect of moisture is quite weak as can be seen in Figures 5.4 and 5.5.

The effect of temperature is by far the most significant of the three factors. Figure 5.4 shows the contours of the flavour volatile dihydro-hydroxymaltol (DHHM) with moisture and temperature.

Similar contours were obtained by *tasting* finished crumb paste. Equivalent contours were obtained for the taste descriptors 'brown-fruit' and 'treacle'.

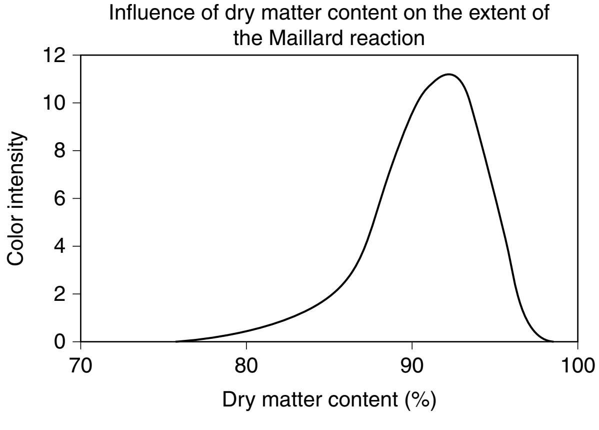

Figure 5.3 Moisture content and the Maillard Browning reaction.

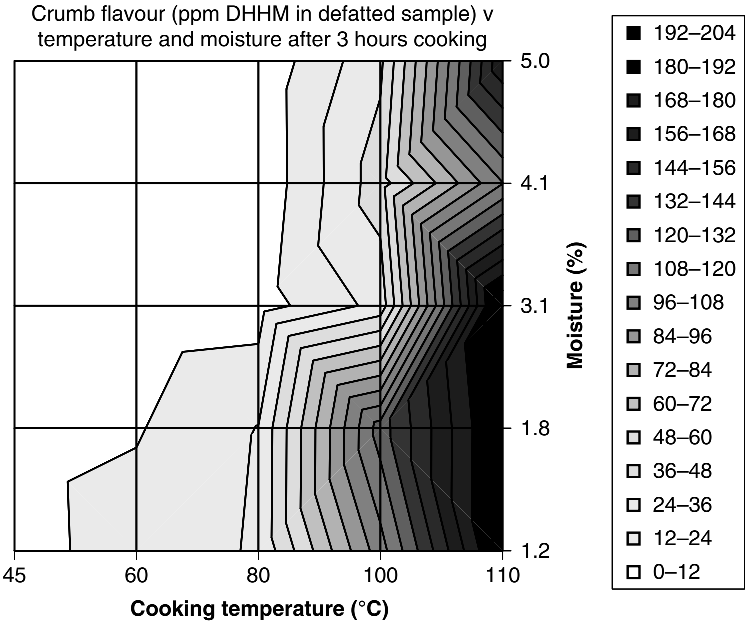

Figure 5.4 DHHM formation during crumb manufacture after 3 hours cooking. See Plate 3 for the colour image.

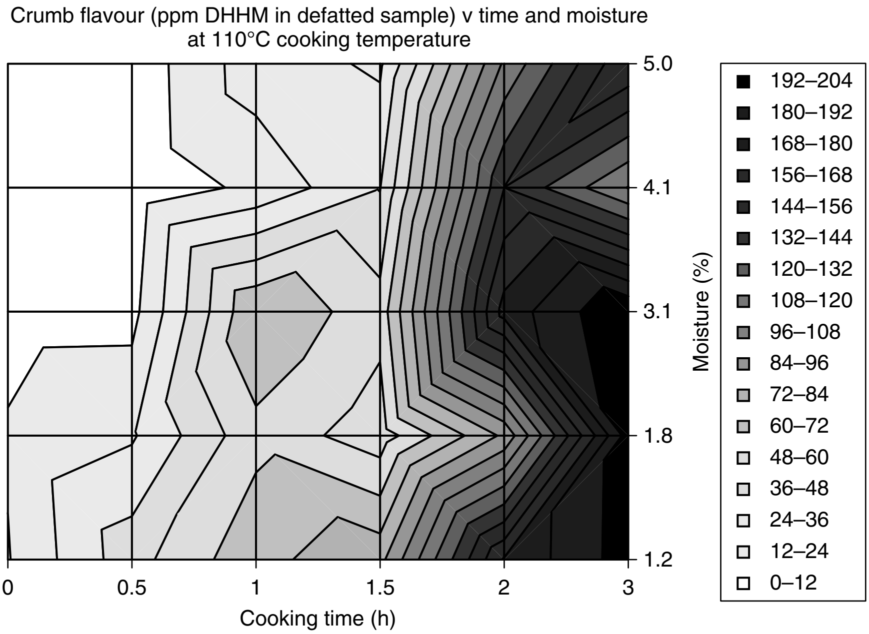

Figure 5.5 Effect of cooking time and temperature on the production of the flavour volatile DHHM. See Plate 4 for the colour image.

As expected, the cooking time was also significant as shown in Figure 5.5.

It can be seen, therefore, that a very wide range of flavours can be produced by the crumb manufacturer, depending particularly on the temperature and reaction times during the process.

5.5 Sugar crystallization during crumb manufacture

The state of crystallization of the sugars in the finished crumb is very important. The ultimate aim is to crystallize both the sucrose and lactose as fully as possible. The benefits of a highly crystalline crumb are as follows:

- It is less sticky and hygroscopic, so is more stable when stored and easier to handle.
- Very little amorphous glassy sugar remains to trap fat so that less fat needs to be used to make the correct finished chocolate viscosity.
- The finished chocolate dissolves more readily in the mouth, giving a cleaner and less sticky mouth feel.

The amount of fat trapped within the sugar varies according to crumb type. This is demonstrated in Table 5.2. Total fat in a recipe can be measured by nuclear magnetic resonance (NMR). Solvent extraction, however, will not dissolve fat which is trapped in amorphous sugar regions. Large differences can be seen from different crumb types. The glassy crumb contains a lot of trapped fat because there are significant quantities of glucose syrup in the recipe inhibiting sucrose crystallization. The difference between the Groen processed and roller-dried crumbs can be attributed to the higher processing temperature of the former crumb which slows down the crystallization rate.

Table 5.2 Extracted and bound fat within different types of crumb.

Recipe	Total fat (%)	Extracted fat (%)	Fat trapped within the crumb (%)
Plain chocolate	27.0	27.0	0.0
Crumb milk chocolate	30.0	29.5	1.7
Roller dried crumb	16.2	15.6	3.7
Groen process crumb	16.0	12.9	19.4
Glassy crumb	24.0	9.6	60.0

Whether sugars crystallize or not is largely dependent on the temperature conditions during the latter part of the process. This can be summarized as shown in Figure 5.6, which shows the relationship of temperature and sugar concentration to crystallization.

- The upper continuous line defines the maximum solubility of sucrose in water at different temperatures. When processing above this line, all sucrose will be in solution and no crystallization can occur.

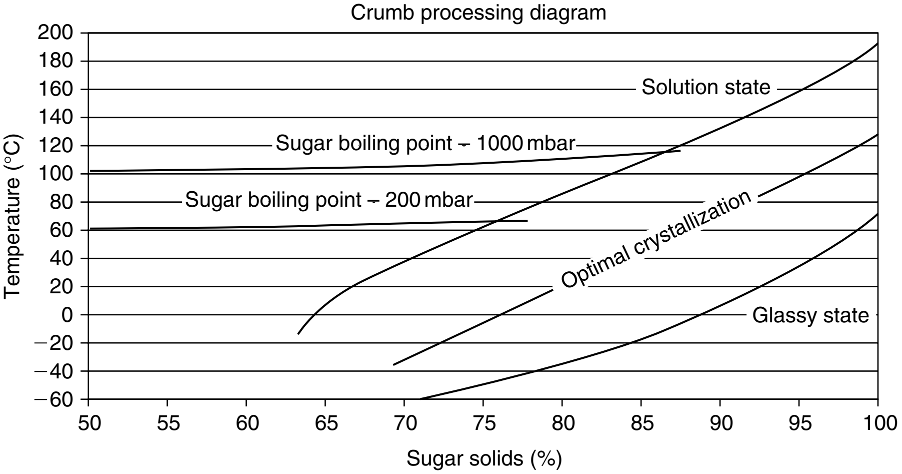

Figure 5.6 The effect of temperature and sugar concentration on crystallization.

- The lower continuous line refers to the glass transition temperature for sucrose in water. Below this line the viscosity is so high that though there are many crystal nuclei they are unable to grow.
- Optimal crystallization occurs roughly half way between these two lines as outlined in the diagram.
- To arrive in this area we need to evaporate moisture from the mixture. This can be done by boiling under atmospheric conditions. In this case we would need to achieve a solids content of nearly 97% to reach the optimal crystallization temperature. Product viscosity is then very high and considerable shear is needed to achieve high levels of crystallinity. In addition the high process temperature will lead to high flavour development.
- Alternatively it is possible to evaporate under reduced pressure. If this is around 200 mbar, optimal crystallization begins at around 90% solids, at a temperature of about 80°C (176°F) and with a manageable product viscosity. Crumb flavour is less pronounced at this temperature and high levels of sucrose crystallinity can be routinely achieved.

To achieve high sugar crystallinity it is helpful also to apply shear while the product is in the optimal region of the processing window just described. In the original batch oven process this was achieved by mixing the sweetened condensed milk and the cocoa liquor in a melangeur pan (see Chapter 1) until the correct crystal size was achieved according to optical microscope measurements. Modern continuous crumb processes are careful to build in shear steps before the crumb paste becomes too viscous.

Many early batch crumb processes did not incorporate shear during the final production stages and the product was highly amorphous (glassy). This produced a highly viscous chocolate when it was freshly made, so the crumb was 'matured' in hessian sacks in a humid atmosphere for several months before it was used. This enabled the glassy particles to absorb moisture and become crystalline, before ejecting the moisture again. 'Matured' crumb produced chocolate with a similar viscosity to crystalline crumb, but had the big disadvantage of requiring long storage periods.

5.6 The structure of chocolate crumb

The way the crumb ingredients bind together on the micro and macro scale is crucial to the crumb's behaviour in subsequent handling and chocolate processing. This section deals with this topic.

5.6.1 Crystallinity

Figure 5.7 shows the microstructure of a typical highly crystalline chocolate particle obtained from crumb. It is evident that a composite crumb particle is present where sugar crystals are surrounded by milk protein particles at the edge with randomly positioned cocoa fragments.

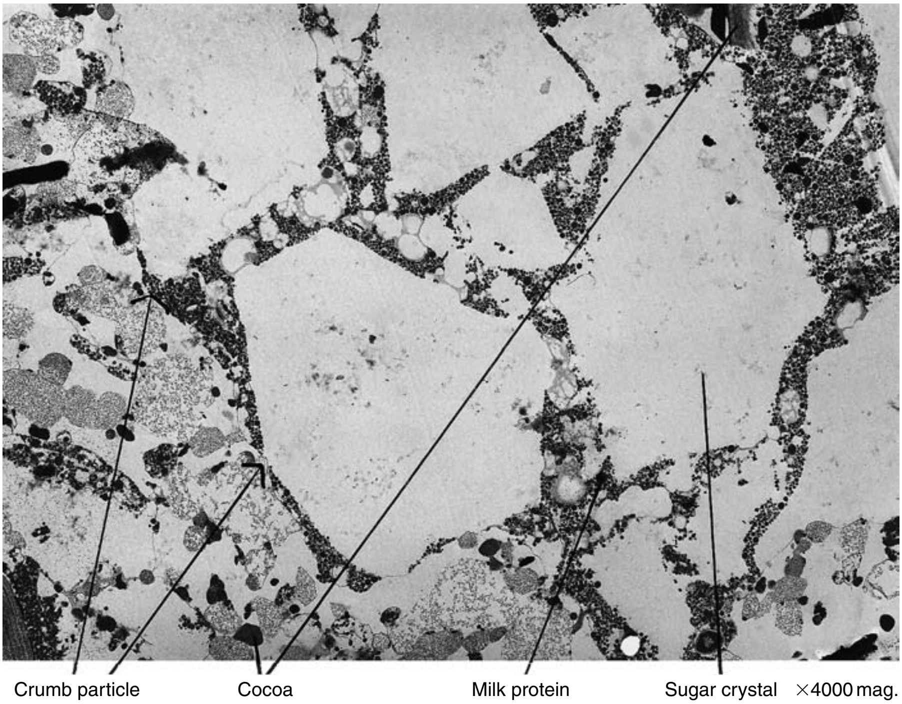

Figure 5.7 Ultra-thin section of crystalline crumb chocolate.

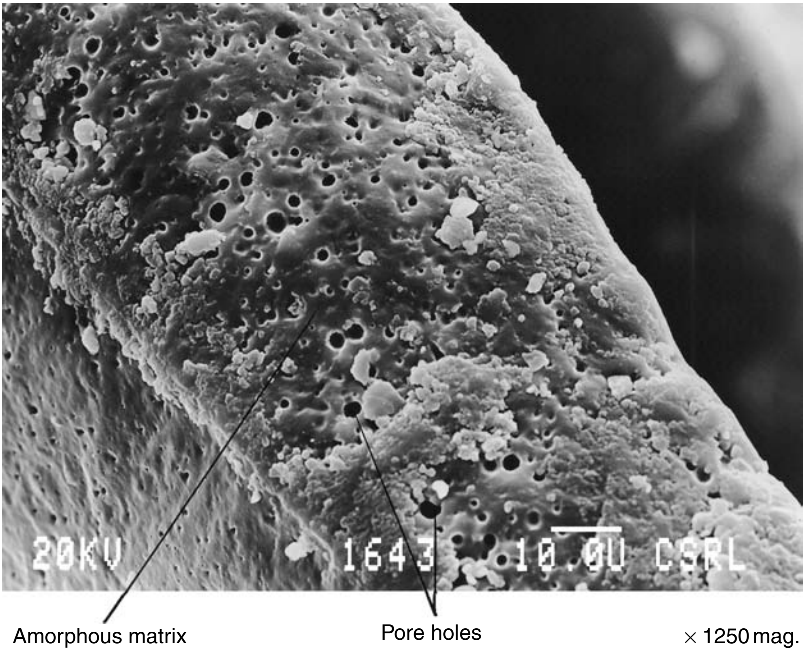

Figure 5.8 Section of amorphous (glassy) crumb.

When significant quantities of glucose syrup are present in the formulation before going through the drying process, a highly amorphous crumb is the result. The structure of such a crumb is depicted in Figure 5.8.

5.6.2 Fat availability

If a freeze etch picture is taken of a fracture through such an amorphous crumb, trapped fat globules can be seen within the amorphous sugar matrix (Figure 5.9). This would not be seen in a significant amount in a highly crystalline crumb.

5.6.3 Fat droplet size

Another significant structural factor affected by crumb processing is the size of the fat globules. The original batch oven process added cocoa liquor at a late stage, i.e. after making sweetened condensed milk. The degree of mixing did not disperse the cocoa butter from the liquor very finely so that during later chocolate refining, size reduction to about 25μm was able to release the fat fairly readily (see also Chapter 7). If, however, cocoa liquor is added to the original milk and sugar before evaporation, its cocoa butter is finely

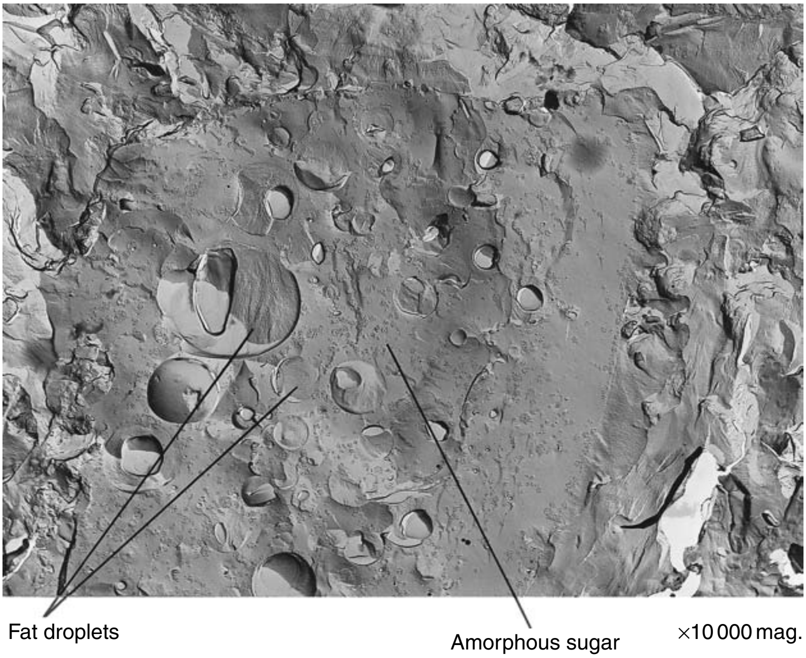

Figure 5.9 Scanning electron microscope picture of freeze etch fracture through amorphous crumb.

dispersed within the crumb structure and is not so easy to release in refining. This is even more the case in a process where a spray nozzle is used to disperse the liquor/sweetened condensed milk into a drying chamber.

5.6.4 Aeration

Original batch oven crumb had a honeycomb texture created by the evaporation of moisture from the stiff kneader paste under vacuum. This made the crumb easy to fracture and easy to mill and refine. This structure is harder to produce in a continuous process unless significant vacuum is used and the crumb is left static during the last stages of drying. This has the disadvantage that it makes the mixture less likely to crystallize.

5.6.5 Overall particle size distribution

The final structural element of crumb that is vitally important is the particles size distribution. The earliest batch oven crumb was composed largely of 1–2.5 cm (0.5–1 in.) lumps with a minimal amount of dust. This is very important to the crumb's handling characteristics. Very dusty crumb cannot be stored in large bulk without severe compaction problems, which lead to bridging in hoppers, build up in conveyors etc. One of the great difficulties with newer continuous processes has been their tendency to create too much dust.

The most successful crumb processes create lumpy product just prior to the final drying stage and preserve it through drying as well. Vigorous tumbling action during drying creates very dusty crumb, which is hard to handle.

One option to eliminate dust problems is to form the finished crumb into uniform sized 'briquettes' in a high pressure forming device. Processes to do this are described in the patent literature (Nestec S.A., 1978; Mars Inc., 2000).

5.7 Typical crumb processes and equipment

The different stages of a typical milk crumb process are listed in Table 5.3.

Table 5.3 Crumb processing stages.

Material	Process	Solids (%)	Water (%)
Full cream milk	Pasteurizing/evaporating	12.5	87.5
Concentrated milk	Sugar dissolving	50.0	50.0
Sweetened condensed milk (SCM)	Air/vacuum cooking	72.0	28.0
Cooked SCM	Cocoa liquor addition	88.0	12.0
Crumb paste	Kneading/mixing	90.0	10.0
Kneader paste	Air/vacuum drying	90.0	10.0
Dried crumb		99.0	1.0

The first stage of the crumb process involving pasteurizing and evaporating the milk is exactly the same as in other dairy processes. Pasteurization is ensured by keeping the milk at 72°C (162°F) for at least 15 s. Evaporation is carried out in multiple effect evaporators to the solid content required. Granulated sugar is then dissolved in the condensed milk according to the recipe. Treatment of the SCM from this point onwards varies substantially, the more modern continuous processes having, to differing degrees, all tried to mimic the original batch oven process which will be described first.

5.7.1 Batch oven process

- *Cooking* of the sweetened condensed milk was done in large pans under partial vacuum at around 75°C (167°F) with rapid boiling.

When the solids reached about 88%, signs of crystallization could be recognised by a skilled operator through an inspection window. At this point cocoa liquor was put into a heavy duty melangeur pan (Chapter 1) again according to recipe and the crystallizing SCM gradually discharged from the vacuum pans.

- *Kneading* of the stiff paste at this point was carried out for about 30 min. Samples of kneader paste were examined under the optical microscope to ensure that crystallization was extensive and that the sugar crystal size was less than 35 µm. It was believed that coarser particles than this could cause difficulties in later chocolate refining. When the operator was satisfied, the kneader paste was charged onto trays and placed on shelves in a vacuum oven.
- *Vacuum oven drying* reduced the crumb moisture content to around 1%. The drying temperature was varied from 75°C to 105°C (167°F to 221°F) depending on whether the shelves were heated with hot water or steam. The drying time was in the range 4–8 h. Virtually all the typical crumb flavours were developed during this last stage.
- *Crushing and storage.* The contents of the oven trays were put through a rotary crusher to reduce the crumb to pieces of 1–2.5 cm (0.5–1 in.) size with as little dust as possible. This material was then stored either in protectively lined bulk storage bags or in cylindrical silos of up to 500 tonnes capacity.

Because of the very large labour input into filling and emptying trays, much effort over the last 50 years has gone into developing continuous processes that can replicate the key steps of cooking, kneading and drying, while producing a similar flavour and texture. Some of the variants will now be described.

5.7.2 Continuous processes

A number of options have been used for continuous cooking of the sweetened condensed milk up to a solids content of around 88%. These include:

- Scraped surface evaporators
- Falling film evaporators.

These and other processes are critical to the whole crumb process. Many of them are proprietary, however, and so cannot be discussed in detail.

There is much more information on various whole, continuous processes and last stage drying steps from the 88% solids stage onwards. These will now be described.

5.7.2.1 Vacuum or air band dryer processes

This method of treating kneader paste is probably closest to the original batch oven process. The dryer consists of a continuous belt, as depicted in

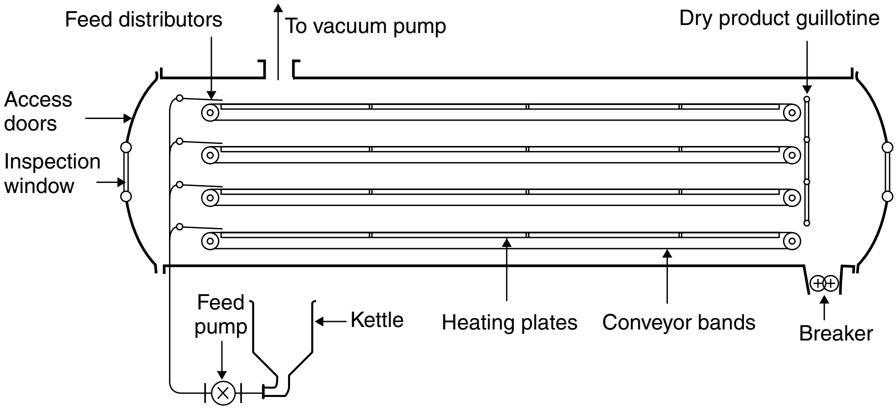

Figure 5.10 Schematic diagram of continuous vacuum band drier.

Figure 5.10, running in a long cylindrical vacuum chamber (Minifie, 1977a). The paste can then be extruded as ropes onto the moving belt. The belt may run over a 'bed', steam heated internally, or heat may be supplied by radiant heat above. The length and speed are such that drying is completed by the time the belt turns over a spindle for return. The dried crumb breaks off in pieces and falls via an air lock into a chamber from where it passes to storage.

When the drying process is carried out under atmospheric pressure conditions, the equipment is simpler to design, and drying can be carried out using co- or counter-current hot air.

5.7.2.2 Vacuum roll dryer process

This process takes approximately 90% solids kneader paste through two stages of drying (Powell, 1970). The first dryer consists of two internally steam heated rollers, counter rotating in a heavy gauge metal dome under partial vacuum. Partially dried crumb builds up and falls off as 'sausages' located by scrapers mounted at about 60 degrees from the top of both rolls. This material is mechanically conveyed from the base of the oven. The choice of partial vacuum, steam pressure and throughput is such that the paste can be aerated, dried and formed into pieces similar to the crumb obtained in the batch oven process, thus making it suitable for silo storage and bulk transport. The partially dried pieces discharge into air lock chambers and from there into hot air drying towers of large enough capacity to dry the crumb to 1% moisture after 5–8 h residence time. From these towers the finished crumb passes through a 2.5 cm (1 in.) breaker and is pneumatically conveyed into storage silos.

5.7.2.3 Atmospheric Groen process (scraped surface heat exchanger)

This process was developed in the late 1970s and has been disclosed in a number of papers (see e.g. Minifie, 1977b; Christiansen, 1983). It has two unusual features which make the final product rather different from batch oven crumb.

(1) All the ingredients, including the cocoa liquor, are dispersed in the concentrated milk before drying. This produces small droplets of fat.
(2) Drying takes place under atmospheric conditions so that process temperatures are much higher than in the processes just described.

The ingredient pre-mix, containing condensed milk, sugar and cocoa liquor is passed into the dual jacketed vertical scraped surface evaporator depicted in Figure 5.11.

The bulk of the water is removed at this stage and the crumb paste exits the top of the evaporator at a temperature of around 125°C (257°F) and a

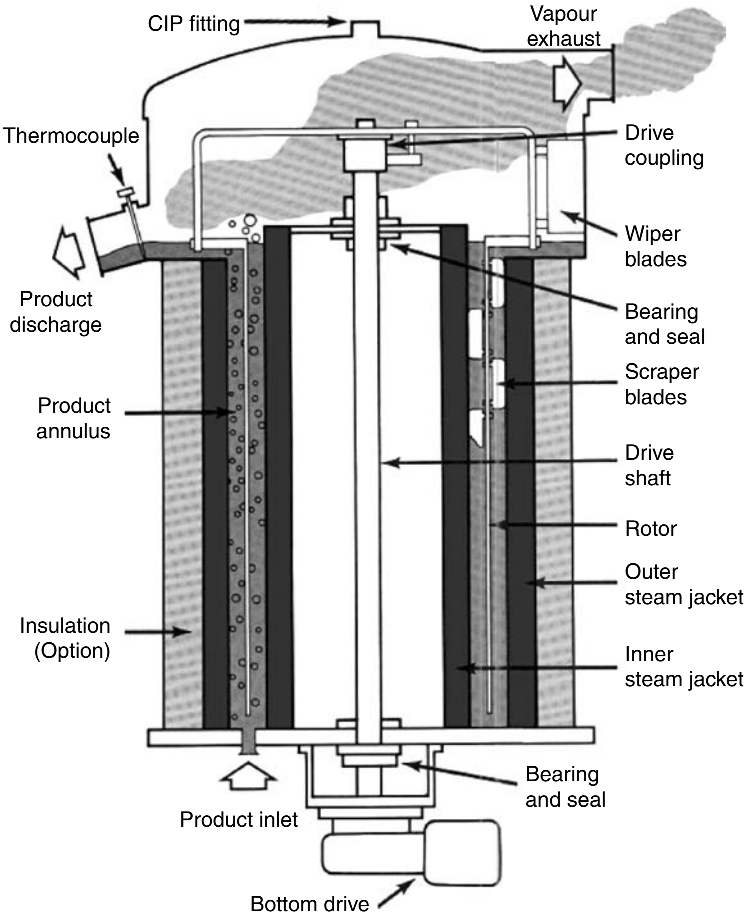

Figure 5.11 GROEN DR series scraped surface evaporator.

moisture content of around 5%. This stiff paste is starting to crystallise and its exit into the crystalliser is mechanically aided. The crystalliser is a water-jacketed vertical rotor stator arrangement of intermeshing blades in a progressively narrowing annular gap. Rapid cooling is encouraged by the dry ambient air that passes through the annulus and the water cooling. Sensible (specific) and latent heat of sugar crystallization are removed in this way and the crumb pieces drop at the base onto a continuous air band dryer.

Although the process described was developed for atmospheric pressure, the GROEN DR series of scraped surface evaporators are also available for vacuum operation. In addition crystallizers have been designed to operate with less viscous material out of the first dryer.

5.7.2.4 Stirred mixer vacuum process

A number of batch mixers have been designed to operate as semi-continuous crumb making machines. Typical of such processes is that offered by the company LIST AG. The process flow diagram is shown in Figure 5.12.

The core of the process is the second LIST dryer which is a heated single shaft mixer operating under vacuum and with sufficient power to convert an incoming paste of 88% solids, through the point of maximum viscosity and beyond to the point where the material becomes a flowing powder. At the correct flow rates it is possible to dry the final powder to around 1% moisture content. Figure 5.13 shows the LIST single shaft mixer/dryer.

In the early 1990s this type of equipment was being used to make white crumb in a number of companies. Vacuum mixer/dryers have been

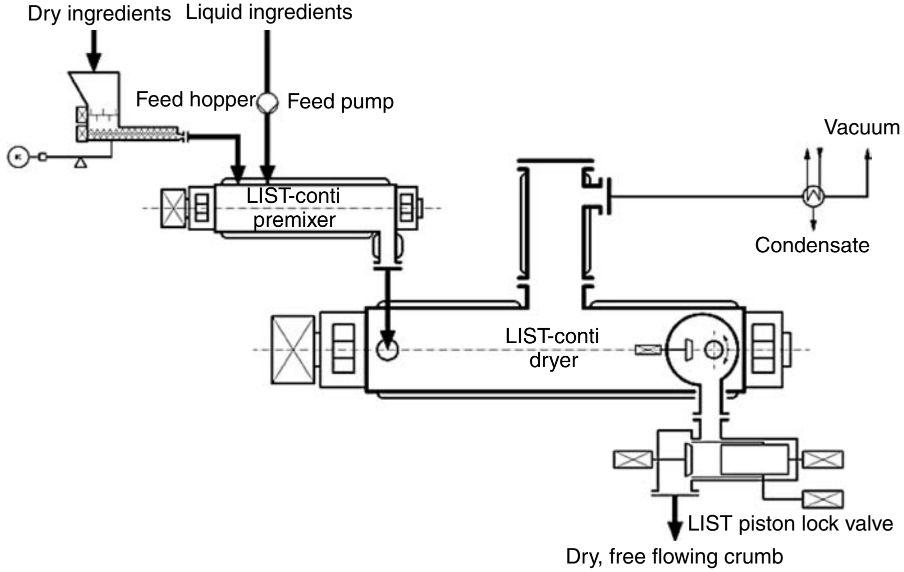

Figure 5.12 LIST crumb process flow diagram (courtesy of LIST AG, Switzerland).

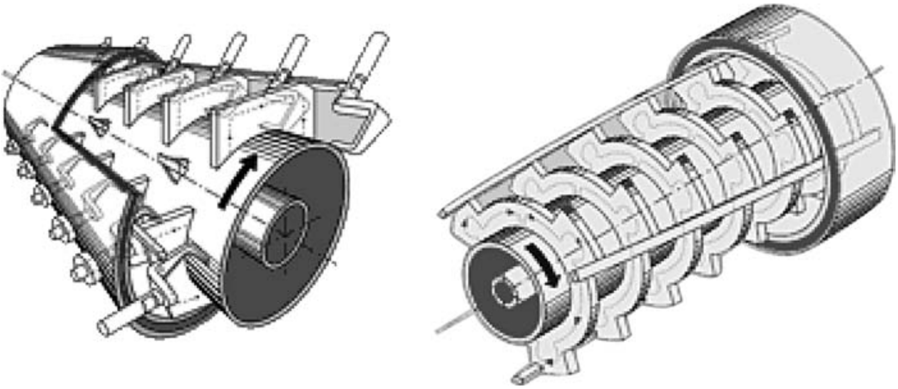

Figure 5.13 Illustration of LIST single shaft mixer/dryer (courtesy of LIST AG, Switzerland).

used to make milk crumb by one of the major confectionery companies throughout the world.

5.8 Effect of the crumb process upon the crumb properties

The choice of process has a major influence on the flavour and processing characteristics of the finished crumb. Table 5.4 summarizes the major differences.

Table 5.4 Effect of process upon crumb properties.

Process	Level of caramelization	Degree of crystallinity	Aeration	Fat availability	Lumps/dust
Groen	Very high	Med.–high	Low	Med.–high	Small lumps
Batch oven	Medium	Low–high	High	High	Large lumps
Vac. band dryer	Medium	High	High	High	Large lumps
Vac. roll oven	Low–med.	V. high	Med.	V. high	Lumps and dust
Stirred mixer	Med.–high	Med.–high	Low	High	Dust

5.9 Changes to crumb during storage

Although originally crumb was chosen as a stable alternative to milk powders, there are limits to its stability in certain aspects.

The fat system in crumb is not in its final stable form immediately after manufacture. Crystallization of the fats occurs slowly, with a tendency for

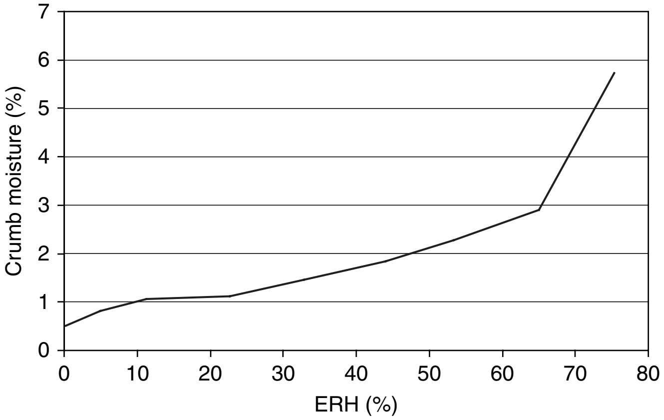

Figure 5.14 The relationship between the crumb moisture content and its equilibrium relative humidity.

the fat to migrate to the surface of the particles. It has been found that very fresh crumb requires more energy in later refining and conching and it is undoubtedly the slightly lower fat availability on particle surfaces which accounts for this.

Crumb has a very low equilibrium relative humidity (ERH, the relative humidity at which moisture is neither taken up nor given out) at normal moisture contents as Figure 5.14 demonstrates.

This means that crumb of say 1% moisture can readily pick up more moisture in contact with typical room air of 50% RH. This is unlikely to occur when the crumb is stored in large bulk containers (with a small amount of air), but it can be an issue when it is being transported.

Moisture pick up can cause changes in crumb which contains significant levels of amorphous sugar. At higher moisture contents the crumb may well be above the glass transition temperature described in Section 5.5. This means that sucrose and even lactose will be free to crystallize. The subsequent liberation of fat from amorphous sugar can lead to easier processing into chocolate with less total fat being used to reach the required chocolate viscosity.

Finally, care should be taken in storing warm crumb in large bulk for long periods. There are a number of reactions going on in crumb which are exothermic and can lead to crumb spoilage. The Maillard reaction itself is exothermic and when the crumb temperature builds up other reactions follow:

- The sucrose and lactose invert to monosaccharides (see Chapter 3).
- The monosaccharides can then dehydrate.

- Finally at temperatures of 120°C (248°F) or more, the remaining lactose and sucrose can also dehydrate.

Sucrose inversion is mildly exothermic, whereas dehydration reactions are highly exothermic. If these occur crumb will be seriously damaged. Crumb which is destined for long-term storage should be cooled to below 30°C (86°F).

Conclusions

There is very little to be found in the literature about chocolate crumb and its processing, indeed very few people outside of the industry know of its existence. It does however permit the manufacturer to make milk chocolate with a much wider variety of flavours. Many ‘house’ flavours are produced by special crumb processes, which make them very difficult to copy. It is interesting to note that the market leading milk chocolate tablets in the USA and UK are crumb chocolates, showing that the consumer appreciates their flavour and texture.

The dominance of Cadbury crumb chocolate bars in the UK in fact drove Rowntree to introduce innovative chocolate products such as Black Magic, Kit Kat, Aero and Smarties during the 1930s. Hershey’s similar success in the USA gave Mars the stimulus to develop new countlines such as Mars Bar, Milky Way and Snickers. Chocolate crumb can perhaps be thanked for providing much of the variety of chocolate products we now enjoy in developed markets.

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Chapter 6

PRODUCTION AND QUALITY STANDARDS OF COCOA MASS, COCOA BUTTER AND COCOA POWDER

H.J. Kamphuis

6.1 Introduction

Cocoa flavour is the most distinctive feature of chocolate and depends amongst other things upon the raw materials used, especially the cocoa beans. The processing, in particular roasting, is also very important in developing the desired chocolate flavour.

Following bean or nib roasting the cocoa nib is ground into cocoa mass, which is a liquid when hot, but solid at room temperature. How finely it is ground depends upon its subsequent use. When using the two- and five-roll refiner system to make chocolate (Chapter 7) the fineness of the cocoa mass is of less importance than when the mass is added directly into the conche, as is the case for the production of high cocoa content chocolates. The latter requires the cocoa nibs to be very finely ground.

Cocoa nibs must also be finely ground when making cocoa powder, otherwise the product may have a sandy mouthfeel or a poor visual appearance.

Cocoa butter is normally produced by pressing, which is often followed by steam treatment under vacuum conditions (deodorization). Cocoa butter is mainly used for the production of chocolate where taste and solidification characteristics are important. These can be influenced by the choice of raw materials and the processing applied.

6.2 Cleaning of cocoa beans

After harvesting, fermentation and drying, cocoa beans may be exported from the country of origin. Transport is in bags, bulk containers, or in ships' holds. For many years the latter has been very popular and is widely used.

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The grinding of cocoa in its country of origin has also expanded rapidly. Nowadays the production of cocoa mass, and even chocolate itself, is being increasingly outsourced by many manufacturers to a few specialist producer companies.

Before further processing, beans must always be cleaned to remove non-cocoa components for example stones and pieces of metal (Figure 6.1). Impurities may cause wear and damage to subsequent processing machinery. Cleaning is usually carried out in several stages:

- removal of coarse and fine impurities by sieving;
- removal of ferrous matter with magnets;
- destoning and removal of other high density particles; and
- dust collection during several cleaning steps.

A set of vibrating screens removes both very large and very small particles by sieving. Clustered beans, pieces of wood, strings and other large debris are collected by the coarse screens, whereas cocoa beans pass through. Smaller particles are then allowed to pass through finer screens.

Using counter air flow techniques, low density and dust particles are separated from the beans during the cleaning operation. Removal of dust and sand is very important, due to its abrasive nature, which will rapidly wear the balls in ball mills, or the surface of refiner rolls.

Ferrous material is removed by magnets, but metal detectors may still be used during further processing. Destoners remove stones and other heavy particles. They operate on the principle of a fluidized bed. The heavy particles, that is stones, are vibrated towards the top of the sloping screen with air passing through the screen. The lighter particles remain at the lower end of it.

6.3 Removal of shell

The removal of shell is an important step in the process of making cocoa mass. In the past it was a legal requirement in the European Union, but under the current directive 2000/36/EC, no maximum values are given. However, in the USA maximum values are still set (codex standard 141–1983, rev 1–2001). Apart from the legal requirements, proper removal of shell is a prerequisite for a good quality product:

- Shell, by its very nature, is exposed to external factors and will have picked up undesirable contaminants (Knezevic, 1983).
- Shell does not contribute positively to the flavour of the final product and may indeed produce off-flavours.
- Being a very fibrous material, it is extremely ‘hard’ and consequently difficult to grind which leads to abrasion of the grinding equipment.

Moreover, shell separation from the nib influences the yield, and the loss of small nib particles along with the shell is a particularly important financial

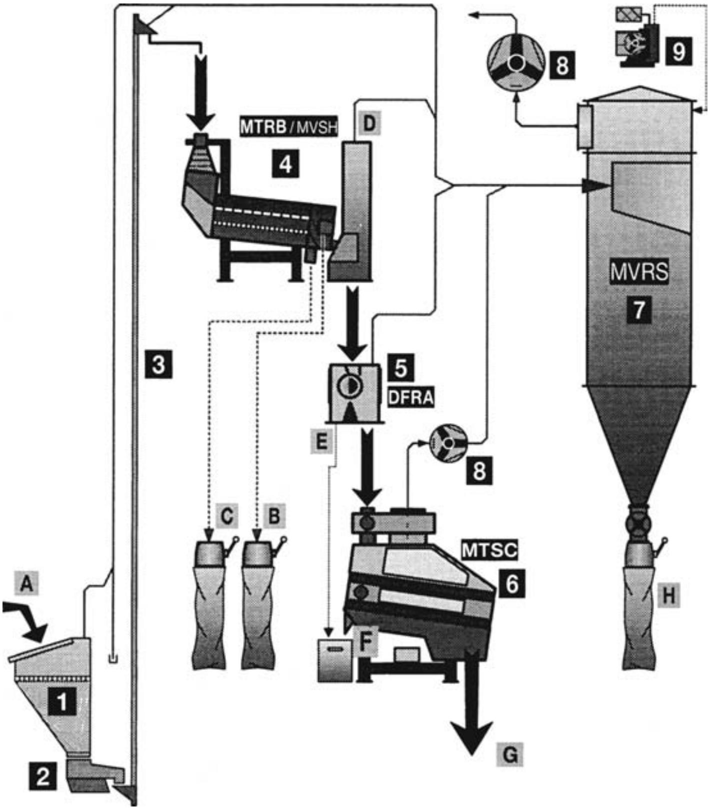


Figure 6.1 Schematic representation of a system for cleaning cocoa beans (Bühler AG, Switzerland, 1998). (1) Feed hopper; (2) vibratory feeder; (3) bucket elevator; (4) separator with aspiration system; (5) rotary magnet; (6) destoner; (7) aspiration filter; (8) suction fan; (9) air blower; (A) untreated beans; (B) coarse impurities (wood and string); (C) fine impurities (sand etc.); (D) light impurities (dust, shells etc.); (E) iron particles; (F) heavy impurities (stone and glass); (G) cleaned product; (H) filter dust.

factor. Ideally, the shell should separate perfectly leaving large pieces of shell and almost the intact nib. The shell around some beans cannot be removed easily however, with certain origins being particularly difficult for example Sulawesian and the so-called flat cocoa beans.

In practice, beans are usually subjected to surface heat treatments to facilitate shell release, that is fluid bed type of dryers, continuous air roasters, infra-red dryers or moistening/pre-drying systems produced by companies such as Bühler, Bauermeister, Barth and the Micronizing Company etc.

The principle of infra-red radiation is based on the idea of puffing the shell from the nib (Figure 6.2). It consists of infra-red radiators and a vibrating conveyor belt underneath. The beans rotate on the belt, where they are dried. The moisture in the bean evaporates giving a puffing effect and the heat increases the brittleness of the shell, facilitating easy removal of the shell

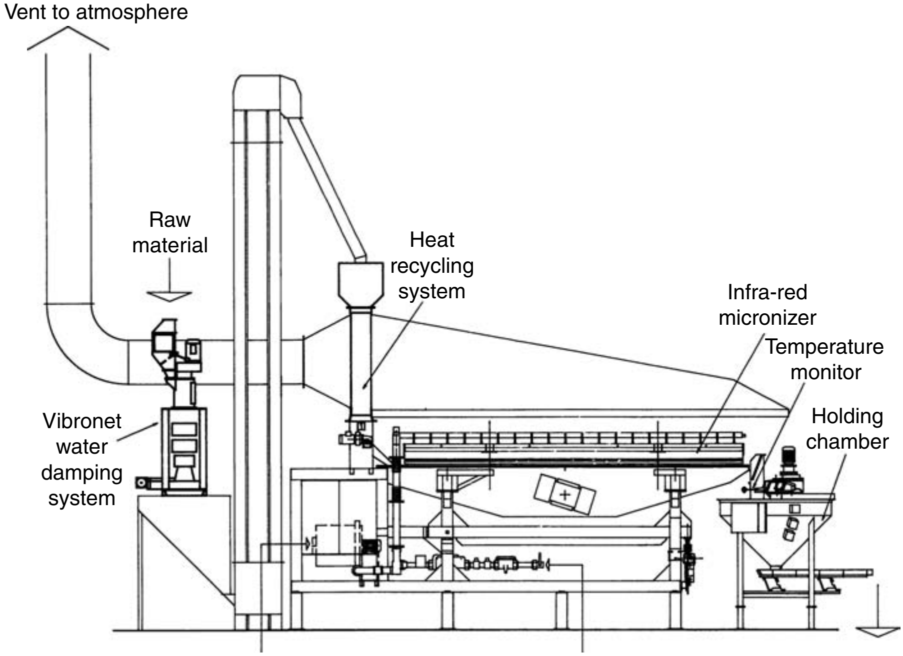


Figure 6.2 Schematic representation of the operating principles of the flat bed micronizing unit (Micronizing Company (UK)).

afterwards. Heat transfer is concentrated on the surface rather than on the inside and unwanted material such as rodent hairs and insect fragments are removed by burning.

A similar machine is the drum micronizer, which has a central infra-red radiator (see Figure 6.3).

An alternative system evenly wets the beans with steam in a screw conveyor and subsequently dries them using a fluidized bed dryer (see Figure 6.4).

6.4 Breaking and winnowing

Beans are generally broken by a swing-hammer type of breaker. Centrifugal force is used to break the beans against an impact plate from where they leave the breaker due to gravity (see Figure 6.5). The r.p.m. of the wheel providing the centrifugal force, together with the throughput, determine the particle size distribution for a given quality of beans. This distribution should be as homogeneous as possible for optimum separation of shell and nibs. After breaking, the shell and nibs are separated by winnowing and unbroken beans are returned for re-processing.

During winnowing the broken beans are divided into a number of fractions by means of sieves and an air classifier (or sifter) separates the shell

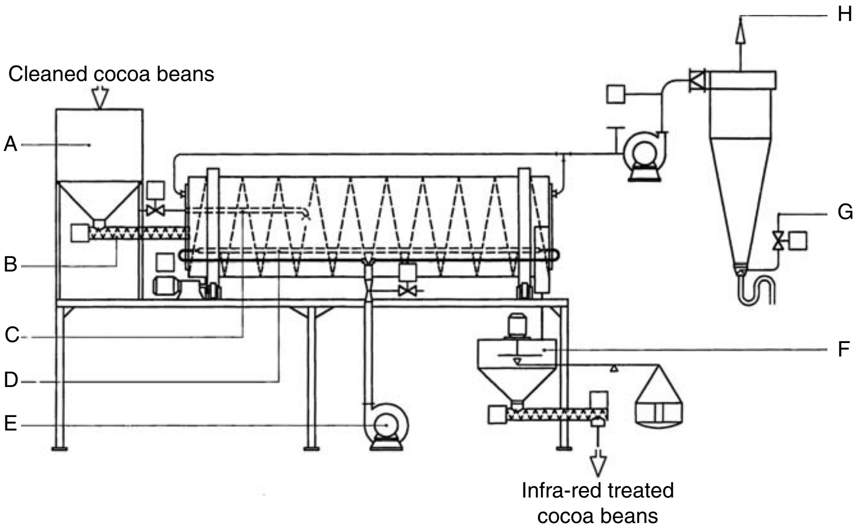


Figure 6.3 Schematic representation of the operating principles of the drum micronizing unit (Micronizing Company (UK), 1998 and Barth Ludwigsburg GmbH & Co., Germany, 1998). (A) Prehopper; (B) dosing screw; (C) water injection nozzle; (E) infrared radiator; (E) fan for combustion air; (F) spark arrestor; (G) cleaning water; (H) exhaust air.

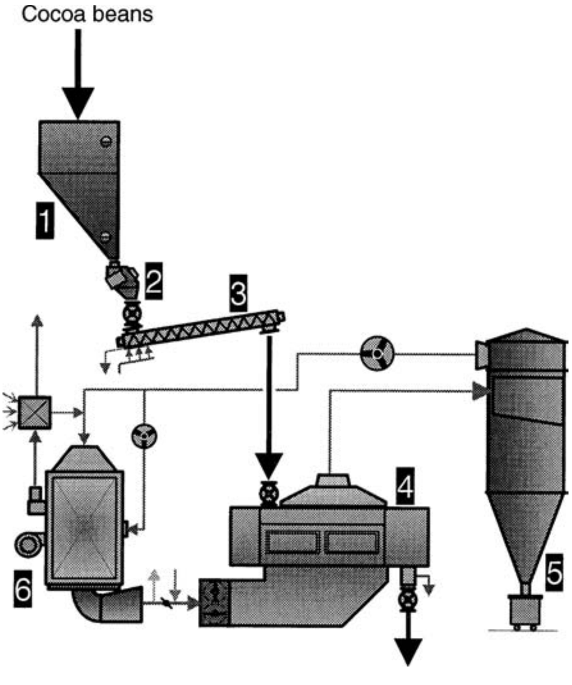


Figure 6.4 Bühler SCT steam puffing system (Bühler AG, Switzerland). (1) Cocoa bean silo; (2) flow balancer; (3) steam screw; (4) fluid bed dryer; (6) hot air generator.

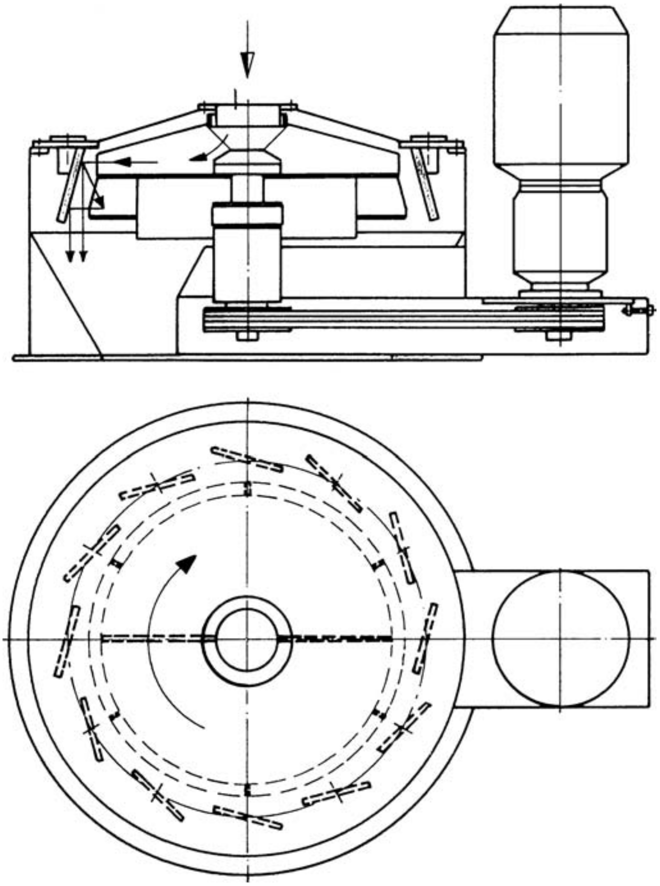


Figure 6.5 Diagram of rotating double disc breaker (Lehmann Maschinenfabrik GmbH, 1998, Germany).

from the nib particles. Each section (sifter) has its own optimal air flow, which depends upon the size fraction being treated (see Figures 6.6 and 6.7). The shell itself is used for animal feed, or horticultural or energy purposes.

6.5 Alkalization

Alkalization is predominantly used for the production of cocoa powder. Nevertheless, alkalized cocoa masses may be used in chocolates to introduce specific flavours.

Nib alkalization can be carried out in a drum, reaction vessel and/or in a screw conveyor. If appropriate the system can be pressurized. Basically, nibs are mixed with an alkaline solution for example potassium carbonate and water. This mixture is heated for sufficient time for colour changes to take place. Depending upon the cocoa beans used and the process conditions, that

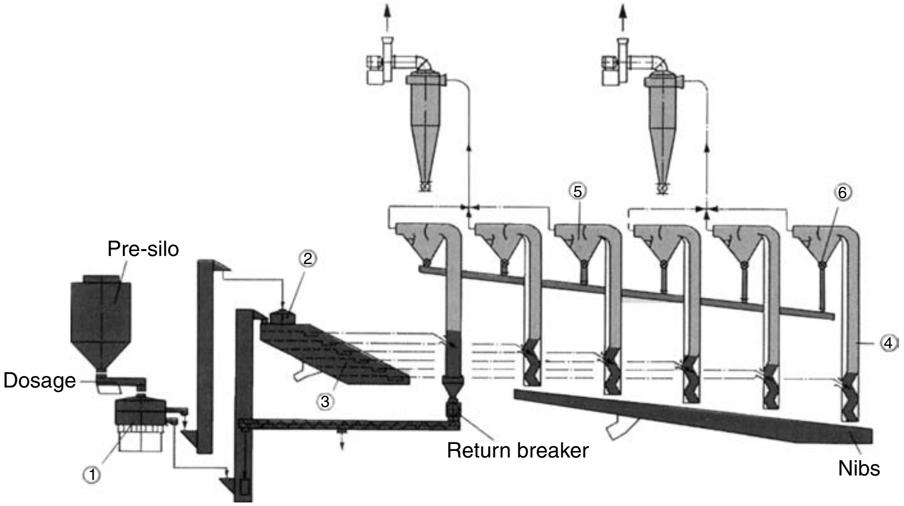


Figure 6.6 Schematic diagram of winnowing machine (Lehmann Maschinenfabrik GmbH, 1998, Germany). (1) Pre-screen; (2) main breaker; (3) main screen; (4) vertical sifter; (5) shell separator; (6) shell sluice.

is time, percentage alkaline solution, pressure etc., a specific colour will be produced. After alkalization the mixture is dried and subsequently roasted. It is also possible, however, to alkalize and roast in a roasting drum, although this may significantly increase the processing time.

Cocoa mass and cocoa cake can also be alkalized, but this is rather limited in terms of colour formation. The addition of the alkaline solution to cocoa mass may result in a high viscous (sticky) product, which is not easy to handle. In this case the removal of excess moisture is very difficult and needs specific equipment. Off-flavours can also easily be formed due to the long heating times required.

The pH of non-alkalized cocoa cake can also be increased by adding dry alkali to it. This results in a higher pH powder after pulverizing, but usually there is little effect on the colour and the intrinsic colour of the product is poor. This characteristic is better when alkaline solutions are used.

6.6 Bean and nib roasting

Roasting develops the flavour in the beans from the precursors formed during fermentation and drying. For example, the Amadori compounds, which are extremely reactive, produce a large number of flavours. This subject is dealt with in more detail in Chapter 8.

Ziegleder and Oberparleiter (1996) have proposed a moisture treatment prior to roasting. In this, steam is condensed on the nib, resulting in a water addition of about 15%. This moisture aids the formation of more flavour precursors during the 10–15 min processing time at 40–60°C (104–140°F).

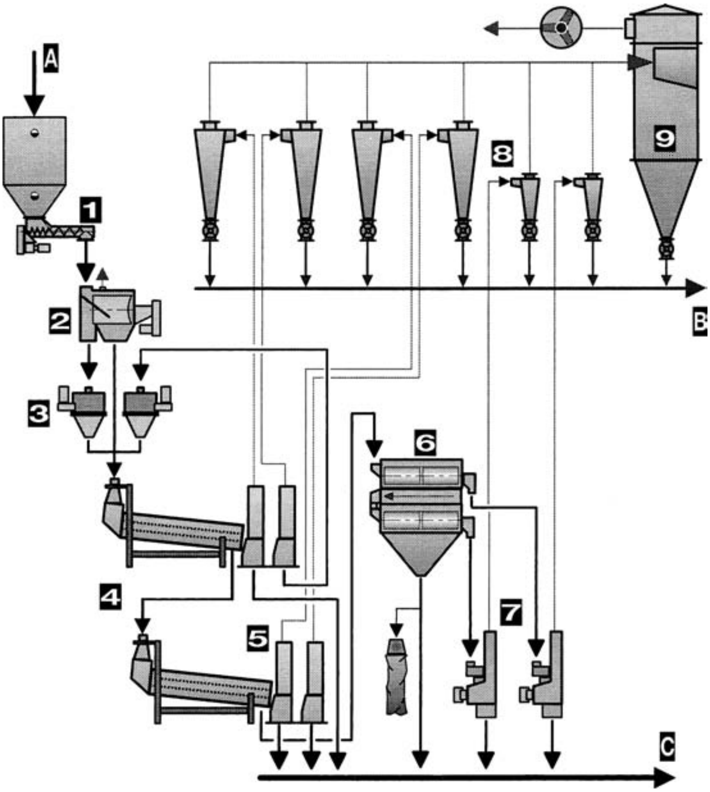


Figure 6.7 Schematic representation of breaking and winnowing system (Bühler AG, Switzerland). (1) Screw feeder; (2) drum sieve; (3) impact crushers; (4) classifying sieves; (5) air classifiers; (6) drum graders; (7) air classifiers; (8) shell separators; (9) aspiration filter; (A) cocoa beans; (B) cocoa shells; (C) cocoa nibs.

After drying to 3% moisture at 98–110°C (208–230°F) and roasting, this gives a product with a more intense flavour compared with normally roasted beans.

Mohr *et al.* (1978) have demonstrated that a slow reduction in moisture content to about 3% followed by a rapid heating to the final roast temperature is the optimal way of roasting. The highest roasting temperature depends upon the required roast intensity and the equipment used. All types of roaster can be operated over a wide range of roasting conditions.

Whole bean roasting was the original method and often used to produce cocoa masses with delicate flavours, due to the preservation of the volatile cocoa flavour notes within the shell during roasting. Also the removal of the shell after this type of roasting is relatively easy, as the shell becomes loose during the roasting. Currently, nib roasting is also widely used in part due to distinct improvements in the cocoa powder when alkalizing the nib before roasting.

Many different roasting systems are in the market place often using conduction and/or convection as the heat transfer mechanism.

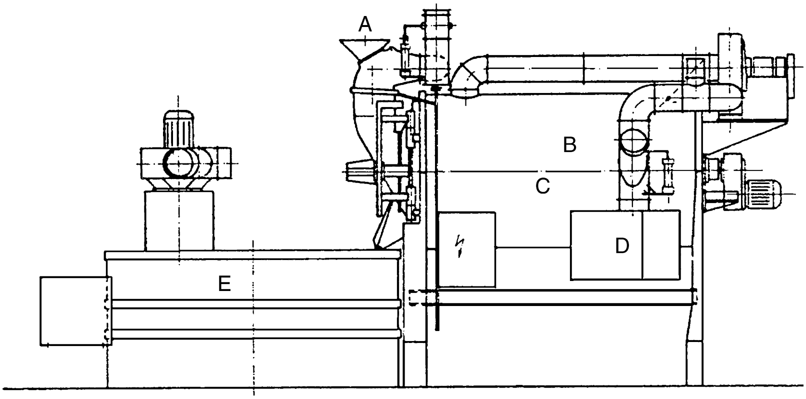


Figure 6.8 Schematic representation of a batch roasting unit (Barth Ludwigsburg GmbH & Co., Germany, 1998). (A) Funnel tube; (B) reaction drum; (C) perforated pipe to carry the reaction solution (for alkalising); (D) gas or oil heating; (E) cooling pan.

Batch drum roasters are frequently used in the cocoa industry for nib roasting (Figure 6.8). The principle of these roasters is generally the same. Nib is fed into the drum and depending on the taste requirements water can be added and a specific roasting profile will be applied. Roasting occurs by heat from the drum wall and the product tumbles in the drum, thus avoiding burning and localized overheating.

Effective debacterization can be carried out by adding water and assuring the presence of steam in the drum. Roasting temperatures, holding times and amount of water added vary according to the equipment being used and the desired flavour profile of the product. Generally, the final roasting temperature is between 110°C and 140°C (230°F and 284°F). Microbiological tests must be carried out for each specific roasting profile to ensure that it kills all pathogens for example *Salmonella* and reduces the total bacterial content (Brenner, 1991; Cerny, 1991).

After roasting, the product is cooled down in an external cooler. Using these types of drum roasters it is extremely important to maintain a strict separation between the raw and roasted nibs, because the loading and discharge may occur through the same door and cross contamination of microbiological material can easily take place.

Alternatively, continuous vertical air roasters can be used for cocoa beans or nibs (see for instance Figure 6.9). This type of shaft roaster is divided into a number of sections; the top sections are used to roast, the lower ones for cooling.

Lehmann manufactured a roaster using a shelf system. The roaster will be filled from the top and the product cascades down the roaster through a series of shelves. Each shelf tilts to discarge its load onto the one below, after a preset retention time. Hot air passes through special ventilation slots in the shelves, which ensures an even flow of the air in the roaster. The bottom shelves are used for cooling.

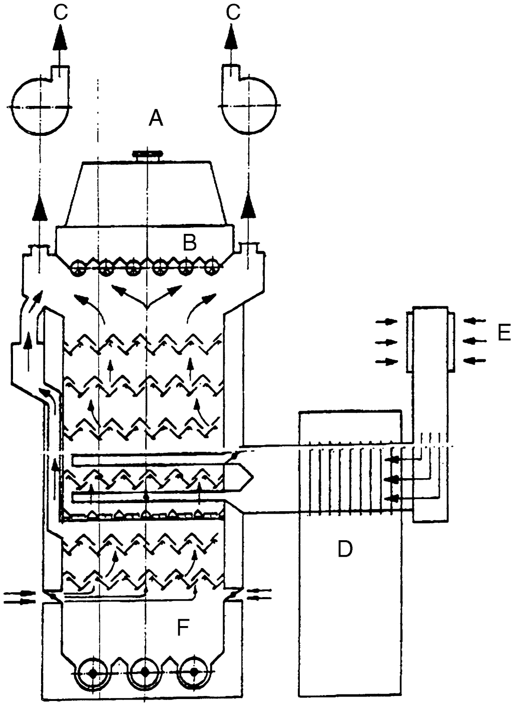


Figure 6.9 Diagram of continuous bean/nib roasting system (Lehmann Maschinenfabrik GmbH, 1998, Germany). (A) Product feed; (B) feed rollers; (C) exhaust air fan; (D) air heater; (E) air filter; (F) extraction screw.

Several suppliers also make continuous drum roasters. A continuous flow of nib or beans is fed into a drum, which is heated by a hot air flow. Air temperature and dwell time regulate the degree of roast. In the Newell Dunford roaster (Figure 6.10) the process air is typically heated by in-duct gas burners before being channelled through a stationary head plate. As the drum rotates this air is only allowed into those channels that are below the nibs. It then passes through louvres into the nibs and partially fluidizes them. Usually these type of roasters are divided into several sections and each section can be separately heated and by adjusting the (air) temperature different flavours can be developed. After roasting the product is cooled in a continuous device.

6.7 Cocoa mass (cocoa liquor)

6.7.1 Grinding cocoa nibs

Cocoa mass is produced by grinding cocoa nibs. As was noted earlier, the fineness to which the mass needs to be ground depends upon its final use.

Figure 6.10 Schematic diagram of the heated gas flow within a Newell Dunford continuous drum roaster. (JND Technologies Limited, Retford, UK).

There are many different mills that are available to carry out this process and the main types are described in Chapter 7.

6.7.2 Quality of cocoa mass for the chocolate industry

The microbiological quality of the cocoa mass is a key parameter for the industry. Owing to high total plate counts ($>1\times10^6$ cfu/g) and the presence of *Salmonella* in cocoa beans, heat treatment must be applied to obtain a product which meets the generally accepted cocoa mass specifications given in Table 6.1.

Bean blends are often used to obtain the desired flavour characteristics. Generally West African cocoa beans are used in Europe for the chocolate production, but due to the increased interest in high cocoa containing chocolates, South American and/or West Indian cocoa beans are also used in blends. Recently, the so-called single origin chocolates have also become very popular. The roasting conditions of the cocoa beans and/or nibs are of great importance to obtain the optimum delicate flavours. When manufacturing high cocoa containing chocolate, the cocoa masses are often added directly into the conche and these must be free from coarse particles to avoid the product tasting gritty. Preferably the particle size of this type of cocoa mass should be around 20 μm (measured by micrometer).

Table 6.1 Quality parameters for cocoa mass (*Source*: Cargill Cocoa, 2007).

Parameter	Value	Method
Fat content	Min 53%[a]	IOCCC 37, 1990
Moisture	Max 2.0%	IOCCC 26, 1988
Total plate count	Max 5000 cfu/g	IOCCC 39, 1990
Moulds	Max 50 cfu/g	IOCCC 39, 1990
Yeasts	Max 50 cfu/g	IOCCC 39, 1990
Enterobacteriaceae	Absent per gram	IOCCC 39, 1990
E. coli	Absent per gram	IOCCC 39, 1990
Salmonella	Absent per 750 g	IOCCC 39, 1990

[a] May vary due to bean origin and harvest.

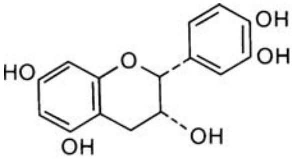
6.7.3 Quality of cocoa mass for the production of cocoa powder and butter

The cocoa pressing industry also selects beans on the basis of their colour forming characteristics, which is particularly important for the production of dark coloured cocoa powders. For cocoa powder production the nibs are normally treated with an alkaline solution. This alkalization process was developed in the nineteenth century in Holland and for this reason is also called the Dutching process. This results in darker products and depending on the processing condition, red and/or brown colours will be formed. It also has an impact on the cocoa flavour, and very often alkalized cocoa powders are preferred in many food/drink applications.

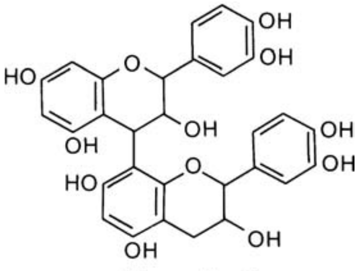
The effect on colour is very complicated (Kleinert, 1972; Schenkel, 1973; Taneri, 1977; Dimick and Hoskin, 1981; Richardson, 1982; Cook and Meursing, 1984). The chemistry of the formation of the cocoa colour is based on a class of components which is rather specific for cocoa: polyhydroxyphenols (Tannins). These are based on a basic molecular structure, i.e. epicatechin.

In the course of cocoa bean growing, fermenting, drying, alkalizing and roasting these compounds oxidize, polymerize (see Figure 6.11) and react with many other cocoa constituents. Thus, the number of chromophoric groups in the molecules is increased, resulting in darker colours but also in various colour hues, depending on the reaction conditions. The alkalization process requires a lot of experience and skill, in order to obtain end products with a consistent colour in combination with good flavour characteristics. Specifically for darker coloured cocoa powders, the so-called alkaline flavour should not be too strong.

The process is carried out by adding a solution of an alkali (mostly potassium carbonate) to cocoa nibs. This process can be batch (when pressurized conditions are required) or continuous (under atmospheric conditions) as was previously explained. Each process has it own (dis)advantages and will result in specific cocoa powders with individual flavour and colour characteristics.



Epicatechin



Epicatechin dimer

Figure 6.11 Epicatechin and dimeric form.

Cocoa mass can be transported and stored either in liquid or in solid form (as 25 kg (56 lb) block or as kibbled pieces) in 25 kg cardboard boxes with a polyethylene liner or a bag inside. Owing to the cocoa butter properties and the presence of natural anti-oxidants, cocoa mass has a very good shelf-life. As a result cocoa mass can be stored for several weeks in liquid form or for more than 12 months as a solid, providing that it is kept under suitable conditions.

6.8 Cocoa butter

Cocoa butter is clearly defined under EU law (Table 6.2 see also Chapter 25). Although the process used to separate the cocoa butter is no longer regulated, the Federation of Cocoa Commerce Market rules divide cocoa butter into press cocoa butter (fat obtained by pressing), expeller cocoa butter (fat obtained by physical removal using a so-called expeller from cocoa beans, nibs, mass, (reduced fat) press cake or any combination of these) and refined cocoa butter (FCC Market rules section 2). The latter includes press, expeller or solvent extracted cocoa butter that has been refined by neutralization with an alkaline solution and decoloured with for example bentonite, activated carbon etc. Subsequent deodorization can also be applied. In addition to these processes cocoa butter can also be obtained by extraction using solvent extraction.

The type of process used may affect the quality of the cocoa butter. For example, a too high deodorization temperature or a too severe alkalization can completely alter its setting (solidification) characteristics. High-quality raw materials are needed to make the best quality cocoa butter. Other

Table 6.2 Definitions and characteristics of cocoa products according to EU Directive 2000/36/EC and Codex standards.

EU Directive 2000/36/EC	
Cocoa butter	
Free fatty acids (expressed as oleic acid)	Max 1.75%
Unsaponifiable matter (determined using petroleum ether)	Max 0.5%
In case of press butter	Max 0.35%
Cocoa powder	
Cocoa butter content (on dry matter basis)	Min 20%
Moisture content	Max 9%
Fat reduced cocoa powder	
Cocoa butter content (on dry matter basis)	Max 20%
Codex Standards	
Cocoa mass (codex stan. 141-1983, rev. 1-2001)	
Cocoa butter content (AOAC 963.15, 1974 or IOCCC 14-1972)	47–60%
Cocoa shell and germ (AOAC 968.10, 1974 and 970.23, 1974)	Max 5% (on fat-free dry matter)
Cocoa shell (AOAC 968.10 and 970.23)	Max 4.5% (on fat-free dry matter)
Cocoa butter (codex stan. 86-1981, rev. 1-2001)	
Free fatty acids (method IUPAC (1987) 2.201)	Max 1.75%
Unsaponifiable matter (method IUPAC (1987) 2.401)	Max 0.7%
In case of press butter	Max 0.35%
Cocoa powder (codex stan. 105-1981, rev. 1-2001)	
Moisture content	Max 7%
Cocoa powder	Min 20% cocoa butter (on dry matter basis)
Fat reduced cocoa powder	Min 10% and <20% cocoa butter (on dry matter basis)
Highly fat reduced cocoa powder	<10% cocoa butter (on dry matter basis)

important factors for high quality are the origin of the beans and the processing conditions used. Press cocoa butter, which is most commonly used in the chocolate industry, is only filtered and (partly) deodorized to obtain the desired flavour. Table 6.3 lists the quality parameters for cocoa butter.

Owing to the characteristics of cocoa butter the shelf life in solid form is good; up to one year when stored under suitable conditions and in practice even up to two years. When cocoa butter has been refined the shelf life is reduced dramatically to a maximum of 6 months. For liquid cocoa butter the shelf life is up to one month. Nevertheless thin layers of liquid butter may oxidize quickly, so it should never be stored in this way. When liquid cocoa butter needs to be stored for longer periods, the use of nitrogen to prevent oxidation by air is recommended.

Table 6.3 Quality parameters for cocoa butter (*Source*: Cargill Cocoa, 2007).

Parameter	Value	Method
Free fatty acids	1.75%	IUPAC 2.201, 1987
Iodine value	33–42	IUPAC 2.205, 1987
Refractive index	1.456–1.459	IUPAC 2102, 1987
Moisture content	Max 0.1%	IOCCC 26, 1988
Unsaponifiable matter	Max 0.35%	IOCCC 23, 1988
Blue value	Max 0.05%	IOCCC 29, 1988

6.9 Cocoa powder

Currently both non-alkalized and alkalized cocoa masses are pressed using horizontal hydraulic presses (Figure 6.12). The pre-heated cocoa mass is transferred into the so-called pots (16–18 pots per machine) and when the pressure is increased the butter flows out of the press and inside the pots the cocoa press cake is formed. The remaining fat content of the cake (normally a minimum of 10% using horizontal presses) can be controlled and when this has been achieved the press opens and the cake falls out. Hydraulic pressures of up to 540 bar may be used. The pressing procedure is influenced by the previous processing for example the degree of alkalization and grinding. For the production of cocoa powders with fat contents of less than 10% further extraction is needed and CO_2 and/or other solvents can be used. Other techniques such as cryogenic grinding of cocoa mass are available to produce cocoa powders with fat contents exceeding 30%. Ideally, the cocoa cakes produced have residual fat contents of 10/12% and 22/24% and by blending the different cakes in any ratio any cocoa powder type with specific characteristics can be produced. An advantage of this appoach is that it is possible to standardize properties such as the colour of a powder.

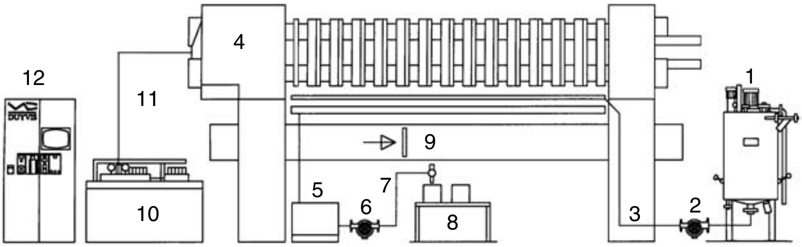


Figure 6.12 Schematic representation of the operating principles of a horizontal cocoa butter press. (1) Cocoa mass conditioning tank; (2) cocoa mass pump; (3) pipe for cocoa mass; (4) hydraulic cocoa press; (5) cocoa butter scales; (6) cocoa butter pump; (7) cocoa butter pipe; (8) cocoa butter blocking off; (9) cocoa cake pushing conveyor; (10) hydraulic pumping unit; (11) hydraulic pipe; (12) electric control with panel; (machinefabriek Duyvis).

It is also possible, however, to blend different cocoa masses before pressing to obtain cocoa cakes which can be pulverized without blending, but this is harder to standardize. During the cake mixing process, flavourings and/or lecithin can be added. The latter is added to increase the wettability of cocoa powder for specific applications for example (agglomerated) dry drink mixes. A wide variety of cocoa powders are indeed produced.

Usually pin or hammer mills (see Chapter 7 and Figure 6.13) are used to pulverize the cocoa cakes. Before pulverization the cake may be cooled. Preferably after pulverizing the cocoa powder is tempered to crystallize the cocoa butter into its stable forms. Incorrectly tempered cocoa powder may result in changes in its visual appearance, the so-called 'external' colour, and lumps may be formed. The visual appearance of powder will become lighter which is basically fat bloom. It should be noted that the so-called 'intrinsic' colour of the powder (colour following use for example in a drink or cake) will not change.

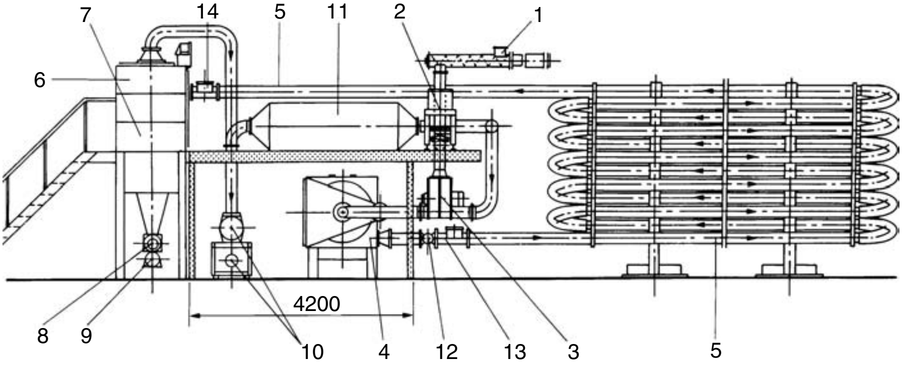


Figure 6.13 Operating procedure of a cocoa powder milling, sifting and cooling unit. (1) Dosing screw, adjustable for broken cocoa cake; (2) metal detector for broken cocoa cake; (3) rotary valve (blow-through-valve); (4) pin mill; (5) cooling tubes for cocoa powder; (6) cyclone preseparator for cocoa powder; (7) dust filter for fine cocoa powder; (8) rotary valve; (9) discharge screw for cocoa powder; (10) rotary piston blower; (11) air cooler and dehumidifier; (12) ball valve (cleaning system); (13) sending station for pig; (14) receiving station for pig.

6.9.1 Types of cocoa powder

As was mentioned above, a variety of cocoa powders can be produced and the final characteristics may vary in:

- Fat content: generally ranging from 10/12% towards 22/24%. The following reasons may determine the choice:
  - price: generally low fat cocoa powders are less expensive;
  - legal: in relation with the labelling. See also EU directive 2000/36;
  - taste: high fat powders give improved flavour characteristics in certain applications;

- colour: specifically when 'external' colour of powder is important. High fat powders are darker;
- Colour: the 'intrinsic' colour can vary from light brown–non-alkalized–towards dark brown and dark reddish colours. Even black colours can be produced.
- Flavour: depending on alkalization and roasting conditions, customized flavours can be developed. When needed flavours for example vanillin can be added.
- Physical behaviour: addition of lecithin to cocoa powder will increase the wettability properties. Also stabilizers can be added with other ingredients or flavour to produce the so-called premixes for the dairy industry.

6.9.2 Quality of cocoa powder

Table 6.4 gives a number of quality criteria for cocoa powder. These are generally accepted values, although other values may be used and/or added depending on the supplier and/or special requirements of the customers.

To produce products within the agreed specifications it is of great importance to start with good quality raw materials, followed by optimum processing conditions. When appropiate analysis and control schemes are implemented for the (semi-)finished products, a high-quality cocoa powder

Table 6.4 Quality parameters for cocoa powder (*Source*: Cargill Cocoa, 2007).

Parameter	Value (range)	Method	Remarks
Fat content	10–24%	IOCCC 37, 1990	Depending on cocoa powder type
pH	5.0–8.2	IOCCC 15, 1972	Depending on cocoa powder type
Moisture	Max 4.5%	IOCCC 26, 1988	
Fineness	Min 99.8% passing sieve	IOCCC 11, 1970	Wet sieving using 75 μm sieve
Colour	Conform to standard		
Flavour	Conform to standard		
Total plate count	Max 5000 cfu/g	IOCCC 39, 1990	
Moulds	Max 50 cfu/g	IOCCC 39, 1990	
Yeasts	Max 10 cfu/g	IOCCC 39, 1990	
Enterobacteriaceae	Absent per gram	IOCCC 39, 1990	
E. coli	Absent per gram	IOCCC 39, 1990	
Salmonella	Absent per 750 g	IOCCC 39, 1990	FDA sampling scheme
Contaminants	Conform EU legislation		Pesticides, heavy metals

can be produced. For final product approval it is recommended that relevant quality parameters are determined for example colour, pH, flavour, fat content, fineness and microbiology.

Salmonella analysis of the final product is of great importance. Owing to the nature of the harvest and subsequent fermentation in the country of origin and conditions in the supply chain, the presence of *Salmonella* cannot be excluded. The total bacterial load of cocoa beans can be up to $1\text{–}10 \times 10^6$ cfu/g. This can be reduced by roasting and/or nib treatment; both of which can also kill any *Salmonella* present. Besides validated processes it is also advisable to have robust sampling and analysis schemes on the final product for *Salmonella* (see Chapter 23). Unfortunately when cocoa powder is contaminated with *Salmonella* it is not homogeneously distributed therefore a sampling scheme proposed by the FDA is recommended. Details about *Salmonella* contaminated products have been published (Craven *et al*., 1975; D'Aoust *et al*., 1975; Gill *et al*., 1983) and it is known that *Salmonella* may survive for many months in chocolate. Additionally *Salmonella* is protected by the fat in chocolate against the acidity of gastric juice and consequently relatively lower levels of *Salmonella* may cause salmonellosis.

For specific applications, i.e. sterilized dairy products, other microbiological parameters, such as thermoresistant spores are important to be determined. The shell content of cocoa powder (as well of cocoa mass) is another important quality aspect. The shell, being the outer layer of the cocoa bean, can be contaminated with sand, pesticides, etc. The shell is very hard and causes wear to grinding equipment. It is technically impossible to produce a completely shell-free cocoa, but it should obviously be reduced to an acceptable level.

Cocoa powder is very sensitive to high temperature and to temperature fluctuations which may result in the melting and re-crystallization of the cocoa butter. This is visible as fat bloom, changing the 'external' colour of the powder. Melting and re-crystallization will also lead to lump formation, a common problem that causes difficulties in processing cocoa powder. Owing to the hygroscopicity of cocoa powder absorbance of moisture from its environment should also be avoided and appropriate packaging used. Multiply paper bags (with a inner polyethylene coating, liner or its equivalent) of 25 kg and/or 50 lbs are most commonly used to pack cocoa powder. Besides this supersacks/big bags (up to 1000 kg) and loose bulk deliveries in silotrucks (up to 20 000 kg) are used. Special skills and equipment are necessary when using this type of transport.

When cocoa powder is stored under proper conditions a shelf life of 3 years can be guaranteed. These conditions are:

- dry and clean warehouse.
- The relative humidity of the air should preferably not exceed 50%

- The temperature in the warehouse should consistently be between 18°C and 22°C (64°F and 72°F). Sharp fluctuations in temperature should be avoided.
- The warehouse needs to be free from any foreign odours, rodents, insects etc.
- Exposure to heat sources such as sunlight, lamps, and heating systems should be avoided.

Summary

The use of good raw material is essential for the production of high quality cocoa products. Many processes can be applied but experience and optimalization of the process conditions are needed to obtain a consistent final quality of the cocoa mass, cocoa butter and cocoa powder. Today cocoa products are available in a wide variety of colours, flavours and other important characteristics, which are then able to be used to produce unique cocoa and chocolate containing products.

Acknowledgements

This chapter is based on Chapter 5 (R.F.M. Heemskerk, Cleaning, Roasting and Winnowing) and Chapter 6 (E.H. Meursing, J.A. Zijderveld, Cocoa Mass, Cocoa Butter and Cocoa Powder) published in the third edition of *Industrial Chocolate Manufacture and Use* (Editor S.T. Beckett, 1999, Blackwell Science Ltd).

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Chapter 7

PARTICLE SIZE REDUCTION

G.R. Ziegler and R. Hogg

7.1 Introduction

Cocoa nib grinding, chocolate refining and kibble milling are all mechanical size reduction processes that may be seen in chocolate manufacturing factories. Grinding processes should not be considered in isolation, but evaluated in the context of the entire chocolate making system. Kuster (1991) considers the mixing, refining and conching stages of chocolate production as a single process with several steps.

Chocolate refining is affected by product type (milk, dark or compound) the process (crumb vs. milk powder) and the ingredients (granulated or powdered sugar). Ingredients may be mixed and then ground (combined grinding) or ground then mixed (separate grinding). The latter allows for the optimization of size reduction processes for each component individually, but may not produce the same flavour or texture as when the components are ground together. Nib grinding is influenced by pretreatment of the nibs, and the required end fineness is dependent on whether the liquor will be pressed or used in chocolate manufacture.

Grinding operations may be evaluated on the basis of their costs (capital, maintenance and energy) or by the product characteristics they produce (particle size distribution, particle shape and minimization of contamination). Fine grinding of cocoa nibs is used to produce an 'optimum' particle size distribution, which is commonly defined in terms of final product characteristics such as flavour, texture, appearance or flow properties. For chocolate, grinding operations may affect product cost through their influence on cocoa butter requirements. Very often the relationship between the size distribution of the ground material and the end product quality is poorly understood. The outcome of a grinding operation is a particle size distribution, while the real objective is to control the performance of downstream operations or final product quality. The importance of relating particle characteristics to product quality cannot be over-emphasized.

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7.2 Principles of fine grinding

7.2.1 Breakage mechanisms

Fine grinding is accomplished by breaking particles into smaller fragments. Contact forces (compressive or shear) deform particles and generate internal stresses which, when strong enough, bring about fractures. The number and direction of these fractures determine the size distribution, shape and surface characteristics of the fragments. For failure to occur, the strain energy released must exceed the surface energy generated. The magnitude, rate of application and frequency of application of contact forces determines the efficiency of the size reduction process.

How a particle responds to contact forces depends on its material characteristics. Most materials can be classified as either brittle or non-brittle. Brittle materials deform elastically in response to an applied stress, before failing suddenly at stress levels above some critical value. Brittle materials can be broken by simple stress application (usually compressive) and failure occurs as a catastrophic event resulting in a suite of fragments ranging in size from about 30% to 40% of that of the original down to submicron sizes (Figure 7.1). Internal stress concentrates at imperfections or microscopic flaws in the material such as cracks, air bubbles or foreign inclusions, increasing the probability of failure at these points. As the size is reduced a grindability

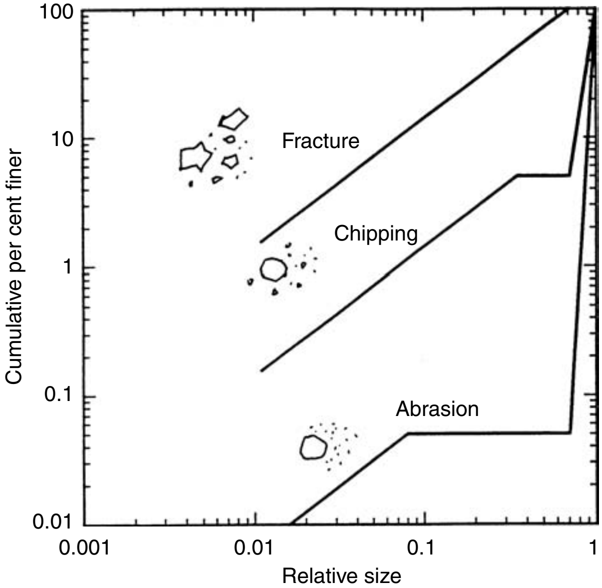

Figure 7.1 Fragment size distributions resulting from different breakage mechanisms (schematic).

limit may be reached because smaller particles contain fewer imperfections and the critical stress increases.

Breakage of brittle materials can occur at lower levels of stress application, if the stresses are localized for example at edges or corners of irregular particles. This kind of chipping action leads to gradual breakdown of the particle leaving a residual core only slightly smaller than the original and a suite of fragments of much finer size (Figure 7.1). Abrasion of particles, through surfaces rubbing together, should probably be considered as a limiting case of the chipping mechanism (Tangsripongkul, 1993). Brittle materials may exhibit plastic behaviour as the size of the particles becomes small.

Non-brittle materials, classified as either ductile or tough, are more difficult to grind than brittle materials. Ductile materials undergo substantial plastic deformation before simple failure occurs and tough materials relieve stresses through internal rearrangement. Tough materials, for example cocoa shell and germ, often possess a fibrous structure. Failure occurs as a gradual loss of integrity resulting from accumulated damage due to repeated deformation. The breakage of non-brittle materials often requires the application of shear, although some tough materials exhibit work hardening and can be broken down by repeated application of compressive stress. Cutting actions generally result in the production of relatively few (e.g. two) fragments from each breakage event. The relative size of these fragments may differ widely, so that a set of breakage events on many similar particles can lead to a fairly broad particle size distribution.

Temperature can affect a material's response to stress – tough materials may become brittle at low temperatures and amorphous materials are generally brittle below their glass transition temperature (Blanshard, 1995) – hence the application of cryogenic grinding. A sugar glass (amorphous sugar) may deform plastically above the glass transition temperature. However, brittle fracture may still occur if the critical stress is applied faster than the material can relax. Increasing moisture content generally reduces brittleness and may make some materials more difficult to grind. Temperature control is very important for heat-sensitive materials.

7.2.2 Grinding processes

The basic operation of any grinding device involves two aspects: placement or setting up of the particles to receive stress and the stress application itself. Particle placement can be direct (particles are brought to the stressing site) or random (particles arrive at stressing sites by chance). Single-pass devices such as a two-roll refiner involve direct placement, where the particles are provided with a single breakage opportunity before exiting. On the other hand, retention devices, such as media mills, mostly rely on random placement and a particle may be subjected to repeated stress application.

Direct placement systems make the most efficient use of input energy. Many nominally single-pass devices do include some degree of retention.

The effectiveness of a machine can be characterized, for the single-pass mills by a *breakage probability* that describes the fraction of particles actually broken during passage, or for retention mills by a *breakage rate* that describes the fraction broken during a given time period. For any mill, these quantities are determined by a combination of the effectiveness of the device in placing the particles to receive stress and their ability to provide sufficient stress for breakage to occur. These breakage parameters generally increase with particle size – larger particles are both weaker and easier to find.

Grinding systems that involve a significant contribution from the attrition (chipping or abrasion) mechanism produce quite different breakage rate and breakage distribution relationships. Rates appear to decrease with time, or perhaps more correctly, with the degree of attrition. The gradual removal of prominent protrusions leads to a rounding of particles and increased resistance to further attrition (Tangsripongkul, 1993). Breakage distributions show a bimodal character as illustrated in Figure 7.1. The bimodal form is also reflected in the product size distributions – the existence of such forms provides evidence that attrition plays a prominent role in the grinding process. Such distributions are shown for chocolate refining (Peter, 1994). Similar effects can occur due to variation in the relative strength of the feed particles, such that energy input is sufficient to break some, but not all, of the particles. Those particles that do break produce smaller fragments that are readily broken further, as is the case when sugar and milk powder are refined together.

Particle size reduction is very energy intensive, with the energy requirements increasing as the average size becomes smaller. Fritzsche (1994) in fact demonstrated an exponential increase in specific energy requirements for refining milk chocolate masse as the particle size was reduced. Kuster (1984) presented similar data for grinding cocoa liquor (mass), particularly in the size range below 20 μm (8×10^{-4} in.).

Breakage of brittle materials is essentially an irreversible process. However, in the case of softer, more plastic substances, agglomeration of the fragments can be significant. In contrast to breakage rates, which generally decrease with decreasing particle size, agglomeration rates and agglomerate strength tend to be higher for smaller particles (Rumpf, 1962). The net effect of simultaneous breakage and agglomeration is an approach to a limiting size at which the growth and breakage rates are equal. The structure of agglomerates differs from that of the original solid particles, so that breakage behaviour can also be expected to be different. In particular, agglomerates tend to be weaker and more plastic than the solid particles. An important consequence is that breakage rates decrease as the solid particles are broken down and then converted into agglomerates, which leads to a situation in which the average particle size first decreases and then begins to increase. At the same time, the size distribution becomes narrower as the fine particles are eliminated by agglomeration (Kaya *et al.*, 1997). It is likely that some agglomeration is taking place at the end stages of chocolate refining, and that conching, in part, disperses these agglomerates, although new agglomerates can also form due to moisture ‘sticking’ particles together (Chapter 9).

The physical and chemical environment in a grinding device is known to affect grinding. Wet grinding is often considered to be more ‘efficient’ than dry grinding (Bond, 1960). It seems that the primary effects are on agglomeration of fine particles, since the use of liquids permits greater control over particle dispersion. Chemical additives like surfactants, the so-called grinding aids, are believed to function largely through their effects on dispersion and rheology (Klimpel and Manfroy, 1978). Powder slurry rheology is clearly a critical factor in fine-grinding operations. Unfortunately, understanding of the relationship between particle dispersion and rheology, especially important in conching operations, is still rather limited.

7.3 Grinding equipment

The choice of equipment for size reduction depends on many factors including the feed particle size, the type of material being processed, the final particle size and as was discussed, the role the operation plays in the integrated system. It is not surprising that a wide variety of size reduction operations are in use in chocolate and cocoa processing plants. Despite wide differences in the nature and characteristics of the materials being ground, the types of equipment used in industrial applications are remarkably similar.

7.3.1 Crushers

Crushers apply direct mechanical force (primarily compressive) to individual particles or compacted beds. Roll refiners used in chocolate manufacture fall into this category. Machines of this type are relatively efficient in terms of utilization of energy input. However, their effectiveness tends to fall off drastically in applications to very fine grinding. Individual particle crushing becomes impractical at such sizes and energy is wasted in bed compaction. Disc mills and roll refiners incorporate shear as well as compression in the grinding action and are most effective for brittle materials.

7.3.2 Media mills

The grinding action in media mills is provided by the relative motion of individual loose elements, the grinding media, which may consist of balls, rods, or beads. Particle placement is essentially random; stress is applied only to those particles that happen to be caught in contact between media elements. In principle, a particle could remain in the mill for a substantial period of time without being subject to stress, while other particles may be subject to repeated stress. To some extent, the breakage probability can be maximized by appropriate control of the ratio of media to particles. A general guide is to maintain the volume of material being ground at about the void volume in the packed media bed.

Media size is an important variable in these mills; smaller media increase the frequency of media–media collisions, but reduce the energy associated with each impact. The result is that smaller media increase breakage rates for those particles that they are capable of breaking, but the limiting size that can be broken is reduced. As a rough guide, a media diameter to particle diameter of greater than about 20:1 seems appropriate. The decreased impact energy of smaller media can be offset by increased overall energy input by increasing impact velocity or media density.

Stirred media mills increase energy input through agitation by an impeller (see e.g. Chapter 9, Figure 9.23). They are typically vertical or horizontal cylinders, filled to as much as 90% of the available volume with grinding media (steel balls, ceramic beads, etc.). During wet processing in stirred media mills, the feed material in the form of a suspension is pumped into a grinding chamber and comminuted between the moving media, the stirrer and the grinding chamber by compression and shear. Relative media motion can be maintained throughout the charge and, with high-speed operation, energy input per unit volume can be very high. This leads to high grinding capacity, but can also introduce overheating problems. In many applications, it is necessary to use a combination of water jacketing and slurry recirculation for temperature control. Quite high pressures are sometimes required to achieve the necessary feed rates and contamination due to media wear can be a serious problem. The effects of media size and density appear to follow a very similar pattern to that observed in tumbling mills. Grinding efficiency, particle size distribution and suspension rheology are inter-related. The relatively large contribution from shear in the agitated media may make these devices especially suited to tough, non-brittle materials like cocoa nibs.

7.3.3 Impact mills

Hammer mills, pin mills and similar devices generally rely on impact with parts of the machine itself to induce particle breakage. Often particles are forced to exit the machine through a grate or screen that serves both as a built-in classifier and as an impact site. Such designs probably include a significant contribution from shear in addition to simple impact thus permitting their use for tough, non-brittle solids. Screen wear can become a serious problem in such applications. Since screen openings are limited to relatively large sizes and small-particle impacts tend to be reduced by their being drawn away in the air-stream passing through the mill, mechanical impact mills are not generally appropriate for very fine grinding (micron) applications. However, impact devices like pin-disc mills are ideal for pre-grinding of non-brittle material like cocoa nib.

7.3.4 Fluid energy mills

Often referred to as jet mills, the fluid energy devices use a high velocity fluid (usually air or steam) to accelerate particles. Breakage occurs through impact between individual particles (autogenous grinding) or with the walls of the grinding chamber. The absence of grinding media and other moving parts helps reduce product contamination and machine maintenance. It is claimed that these mills produce a relatively narrow product size distribution. This may be due in part to very low breakage rates for the finest particles, but may also reflect a loss of fines in the solid–fluid separation step required for collection of the product. Energy efficiency of these mills is relatively low. A schematic illustration of a fluid energy mill is given in Figure 7.2.

7.3.5 Guidelines for equipment selection

Different types of mills typically involve combinations of mechanisms for particle placement and stress application. While each type has certain advantages and disadvantages for any specific application, there is rarely one particular device that is ideal. Many factors contribute to the choice of an appropriate mill for a particular application. Primary considerations are

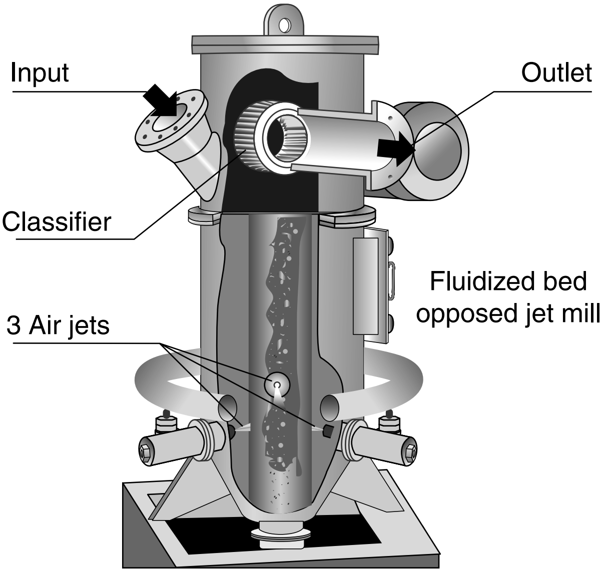

Figure 7.2 Schematic diagram of a fluid energy mill as manufactured by Hosakawa Micron.

material characteristics, product specifications and required throughput. In turn, the selection process requires the choice of mill type and mill size. Other features such as reliability and ease of maintenance also vary to some extent from type-to-type, and may also depend on the specific manufacturer.

The extent of size reduction required, i.e. the ratio of the feed size to the product size is also an important consideration for system design. Depending on the material, most mills are effective over a limited range of particle sizes; reduction ratios should rarely exceed 10–20, and 4–7 may be ideal. For this reason, grinding operations are usually accomplished in stages. Higher ratios require two or more mills, perhaps of the same type but different size, but often of different type. Size reduction in stages may help limit the excessive production of fines.

Batch grinding and open-circuit continuous grinding provide little control over product size distribution, other than the 'average' size. Closing a continuous grinding circuit with a classifier, or alternating stages of grinding and classification in a batch system, can provide additional control over the product size distribution by reducing over-grinding of product size material. This approach also increases mill capacity and reduces energy requirements and product contamination. Classifier mills have an integrated, internal grinding-classifying circuit. The aim is to prevent over-grinding by the continuous discharge, during grinding, of the product that has reached the desired final size. Larger particles are retained and ground further. Classifier mills are generally not as effective as separate mill and classifier circuits and are typically limited to dry grinding operations. As fat becomes liquid during grinding, this type of machine is typically used with material with a fat content of less than about 12%, unless cryogenic techniques are applied. A classifier mill which can be used to grind cocoa powder or other low fat ingredients is illustrated in Figure 7.3.

In the design of grinding systems, especially for complex materials and mixtures like chocolate, it is important to recognize that the process may actually serve to perform other functions besides size reduction, for example mixing or surface wetting. These may be deliberate or by accident and may not even be recognized or fully understood. Replacing a mill that is a good mixer with one that grinds more effectively, but provides less mixing action, could have important implications downstream. In other words, while grinding may be an important distinct step in the overall process, it should always be evaluated in the context of other processing steps.

7.4 Cocoa nib grinding

Cocoa nib is ground to cocoa liquor for the efficient removal of cocoa butter from within the cellular structure. Cocoa nib is approximately 55% cocoa butter, contained within cells of about 20–30 μm ($8–12 \times 10^{-4}$ in.) in size

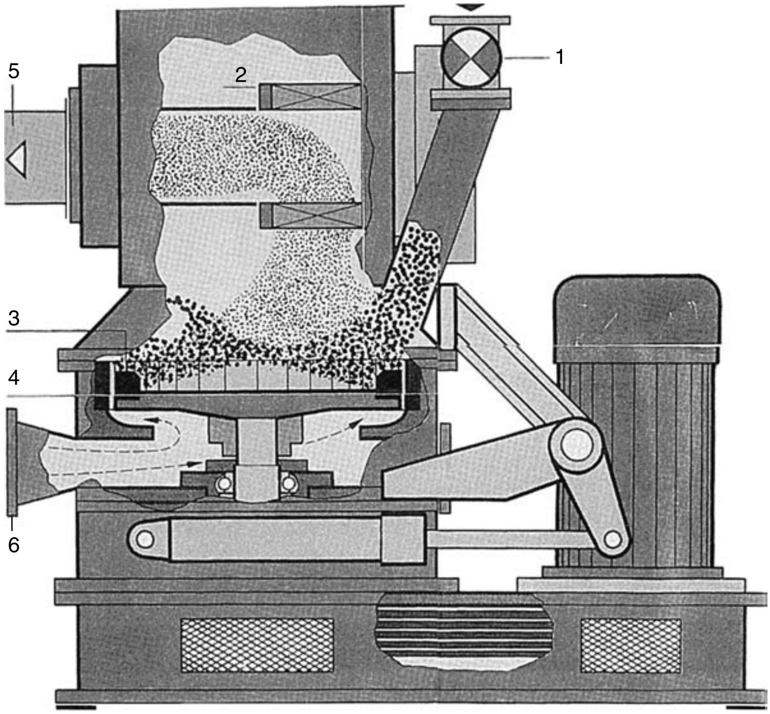

Figure 7.3 Schematic diagram of a classifier mill as manufactured by Hosakawa Micron. (1) Material inlet valve; (2) classifier; (3) milling hammers; (4) milling disc; (5) outlet to cyclones and filter bags; (6) air inlet.

(Beckett, 1994). It is the non-fat solids portion of the cocoa cell that must be broken to release the fat. This cell wall material, and more particularly cocoa shell and germ, are fibrous and tough, so shear is generally required. Final maximum particle size ranges from 15–50 μm (6–20 × 10^{-4} in.) (by micrometer) and is dictated by the requirements for subsequent use – finer for chocolate manufacture and coarser for pressing. Particles less than 20 μm (8 × 10^{-4} in.) will reduce pressing efficiency by plugging the filter, passing through the filter and absorbing excessive amounts of fat (Kuster, 1980).

When liquor is to be incorporated into chocolate, it is advisable to grind nib to the desired end fineness for organoleptic considerations. This assures maximum free fat, minimum viscosity, appropriate texture and flavour. It is difficult to overgrind nib (Niediek, 1994). Shell and germ are particularly difficult to grind and cause excessive wear in size reduction equipment. For this reason, effective winnowing is especially important (Chapter 6). If milling machines are set to adequately size the shell and germ, then the rest of the cocoa structure will be correctly ground (Niediek, 1994). Although higher temperatures can be tolerated for nib grinding than chocolate refining, colour and flavour are influenced by high grinding temperatures (Kuster, 1984). Kuster (1980) recommended milling nib to an end fineness 2–5 µm less than the end fineness of the finished chocolate. This is said to reduce subsequent refiner wear, increase refiner throughput and improve finished product flow properties, that is lower viscosity.

Cocoa nib grinding is usually accomplished in at least two steps. Impact mills, for example pin-disc or hammer mills, are typically employed for pre-grinding. The final fineness is achieved using a stirred media mill, corundum disc mill or a three-roll refiner. The high shear of the corundum disc mills and the repeated compressive stress of agitated ball mills makes them ideal for tough materials like cocoa nib. Milled cocoa particles appear as small platelets, but also include cocoa starch granules. The latter make up about 7% of the weight of the liquor and from 1% to 3% of chocolate depending on the liquor content (Schmieder and Keeney, 1980). Cocoa starch granule size varies from 2 to 12.5 µm ($0.8–4.8 \times 10^{-4}$ in.) (Schmieder and Keeney, 1980), so they could be expected to remain as intact, ellipsoidal particles after milling. The contribution of cocoa starch to the properties of chocolate is largely unknown.

The majority of the world's current cocoa harvest is milled using agitated ball mills (Niediek, 1994). Ball size, ball charge, agitator velocity, height-to-diameter ratio, feed rate and feed direction all have an effect on the mill efficiency and particle size distribution. Where large quantities of liquor are being processed, it may be more efficient to use a series of ball mills, each successive mill with a smaller ball size beginning with 15 mm (0.6 in.) and ending with 2–5 mm (0.1–0.2 in.). As ball size is reduced, agitator speed may also be increased (Niediek, 1994). Equipment wear of 20–100 g/1000 kg of cocoa mass can be expected in ball mills, but staging ball mills also tends to reduce contamination from the grinding media. Ferrous materials can be removed from the finished liquor by magnets located at the mill exit, but non-ferrous contaminants like ceramics are not easily removed. Contamination from grinding media increases subsequent chocolate refiner wear.

The triple mill employs three successive pairs of corundum discs for fine grinding cocoa nib. For each pair of discs, one rotates while the other is stationary. Their capacity is similar to commercial stirred media mills used for grinding cocoa nib, i.e. 1000–2000 kg (1–2 tonne) per hour. Although operating costs, such as energy and maintenance, may be lower than for agitated ball mills, capital costs are generally greater for disc mills (Niediek, 1994), and temperature control more difficult. Unlike the agitated ball mill, the feed material may be solid or liquid, although pre-grinding is customary. Figure 7.4 illustrates a typical triple disc mill.

Unroasted cocoa nib is more difficult to grind than roasted nib, due to a greater proportion of shell and a higher moisture content. This is related to the plasticizing effect of moisture on the cellular material. Alkalization of the nib usually makes it easier to grind (Niediek, 1994).

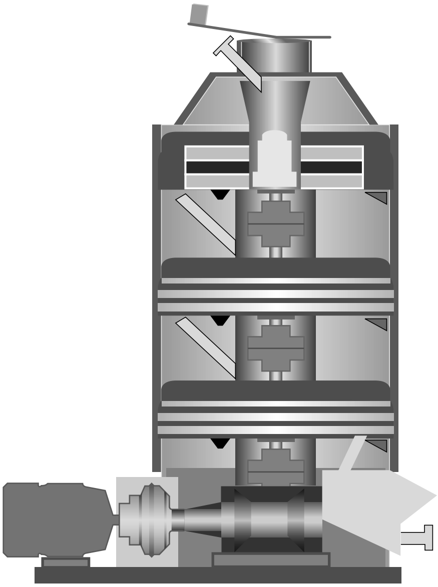

Figure 7.4 Schematic diagram of a triple disc mill (Lehmann).

7.5 Chocolate refining

The particle size of the dispersed (solid) phase of chocolate, particularly that of the largest particles, must be sufficiently small so that the chocolate does not feel gritty when eaten. Although traditionally continental European chocolate has been described as having a fineness of 15–22 μm (6–9 × 10^{-4} in.) and that in North America as being 20–30 μm (8–12 × 10^{-4} in.) (Jackson, 1994), with the increased globalization of the industry traditional differences begin to blur and specifications become much more product specific. For example, dark chocolate is generally ground finer than milk chocolate and chocolate for cookie drops can be coarser than solid eating chocolate, since the texture of the cookie will mask that of the chocolate. However, eating quality is not determined by particle size alone, and many other factors, such as fat content, determine the overall texture (see Chapter 20). In a comparative study of chocolates from the USA and continental Europe, it was found that the size of the larger particles (d_{90}, i.e. 90% finer than this size, as measured by laser light scattering, which approximates to a micrometer reading) to range from 20 to 37 μm. Unexpectedly, both the finest and the coarsest were from the United States.

Provided the cocoa liquor has been properly milled, the primary purpose of chocolate refining is to grind the sugar and, for milk chocolate, the solid milk particles. Crystalline sugars behave as brittle materials under mechanical stress. In studies where sucrose–cocoa butter mixtures have been

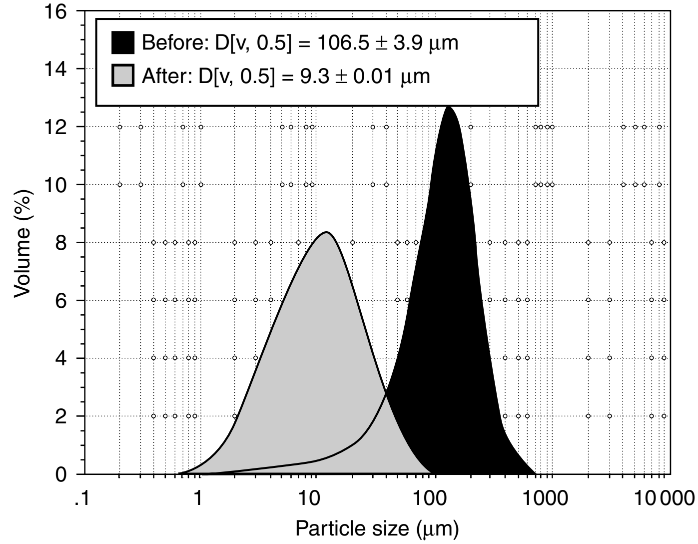

Figure 7.5 Particle size distribution before and after roll refining of spray-dried whole milk powder with an equal amount of cocoa butter.

roll refined, chipping and abrasion contributed significantly to the breakage pattern (Aguilar and Ziegler, 1992). This may not be surprising given the jagged, irregular shape of milled sugar. Whole milk powders (28% fat) roll refined with cocoa butter showed a log-normal breakage pattern, characteristic of brittle fracture when ground below their glass transition temperature (Figure 7.5).

Although spray-dried whole milk powder contains 25–29% fat, this fat is trapped in a matrix of glassy (amorphous) lactose as emulsified droplets (Figure 7.6). Milk protein is similarly distributed, principally as casein micelles. The glassy lactose matrix, like window glass, normally behaves as a brittle material during roll refining. This has been confirmed by Bouzas and Brown (1995). While the fat does not plasticize the lactose matrix, these inclusions, along with trapped air, do reduce the hardness of the particle, making milk powder easier to fracture in comparison to crystalline sugar. Therefore, when refined together, the milk powder is broken preferentially. Reducing the size of spray-dried whole milk particles liberates fat in a manner similar to reducing cocoa nib, but the effect this has on flow properties is not as obvious (Bouzas and Brown, 1995).

As the grinding temperature exceeds the glass transition temperature, either because the roll temperature increases or the glass transition temperature decreases, say because of an increase in moisture content, spray-dried whole milk particles deform plastically (Figure 7.7a). These highly asymmetric particles (Figure 7.7b) have a deleterious effect on product viscosity and sensory properties.

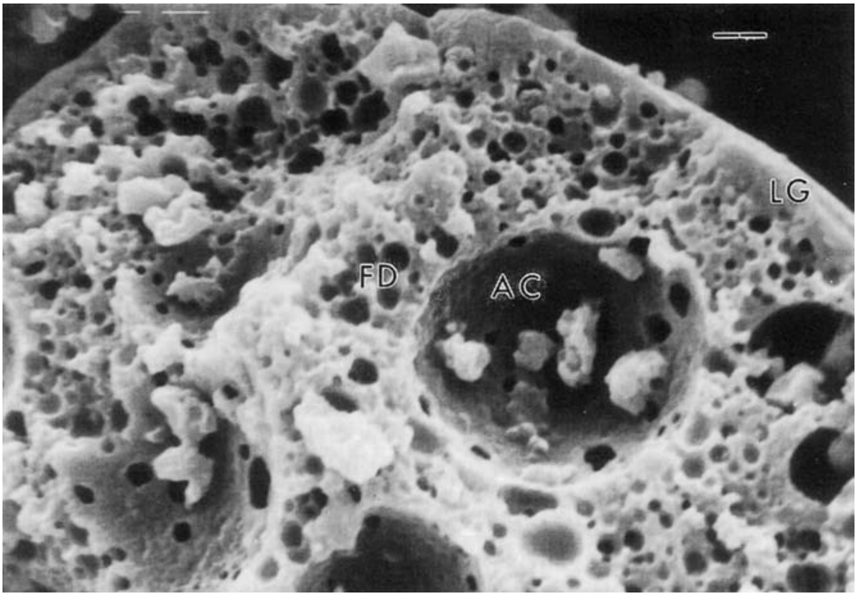

Figure 7.6 Interior surface of a milk powder particle fractured during roll refining. Bar equals 1 μm. AC = air cell, FD = fat droplet, LG = lactose glass.

Spray-dried skim milk powder, or non-fat dry milk (NFDM), behaves somewhat differently. As with whole milk powder, NFDM exhibits brittle fracture below the glass transition temperature, but requires greater force (more energy) to grind since it does not contain the defects introduced by the milk fat droplets (Figure 7.8). Above T_g, NFDM particles only slightly larger than the gap are distorted as they pass through the roll gap. However, they appear to recover their original shape to a greater extent than do particles of whole milk powder, that is they do not show the same degree of permanent plastic deformation that whole milk particles do. However, above T_g, the surface of NFDM becomes sticky and particles agglomerate. The end result is a particle size distribution that may contain agglomerates that are larger than the roll gap.

7.5.1 The five-roll refiner

The fine grinding of chocolate masse is most often carried out using a five-roll refiner. Four grinding rolls, up to 2.5 m (8 ft) in length and 400 mm (16 in.) in diameter, aligned vertically form a stack (Figure 7.9). The 'feed' roll (R1) is placed at an angle to the lowest stack roll (R2). The feed rate determines the throughput and end fineness of the chocolate and is adjusted by changing the feed roll gap at a constant roll speed or by changing the roll speed at a constant gap. At a constant gap, faster roll speeds mean greater

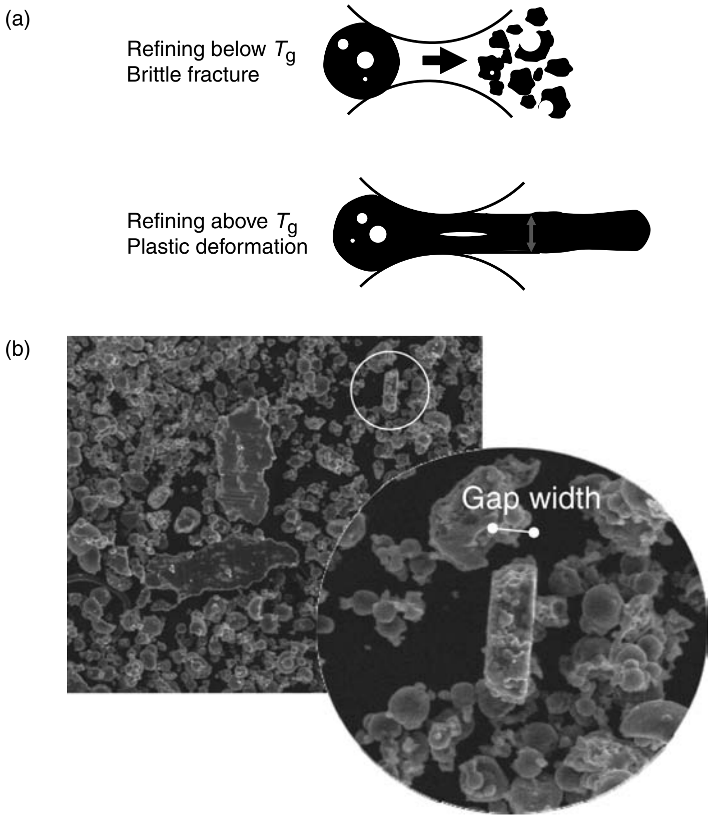

Figure 7.7 (a) Illustration of the effect of the glass transition temperature (T_g) upon the refining process. (b) Electron microscope picture showing asymmetric particles after refining at a temperature above the T_g.

product throughput and coarser chocolate. At 100–150 μm (0.004–0.006 in.), the feed gap does little grinding, instead forming an even film of chocolate masse across the length of the rolls. The rotational speed of the rolls gets progressively faster from the bottom (R2) to the top (R5), as the gap gets correspondingly narrower (Table 7.1). The roll-refiner is essentially a series of single-pass devices. The film of product exiting each gap is transferred to the faster roll, moving upwards, until it is scraped off the final roll by a stationary knife. Hydraulic pressure is applied to the roll stack to compress the camber (uncompressed the rolls are barrel shaped) and obtain an even coating across the roll length. Counter-pressure built up by the product ensures a stable roll gap, but alterations in pressure do little to affect the size reduction.

Size reduction occurs as a combined result of compression and shear. The *degree of reduction* in a five-roll refiner is generally 5–10, resulting in a final product with a maximum particle size in the range 15–35 μm

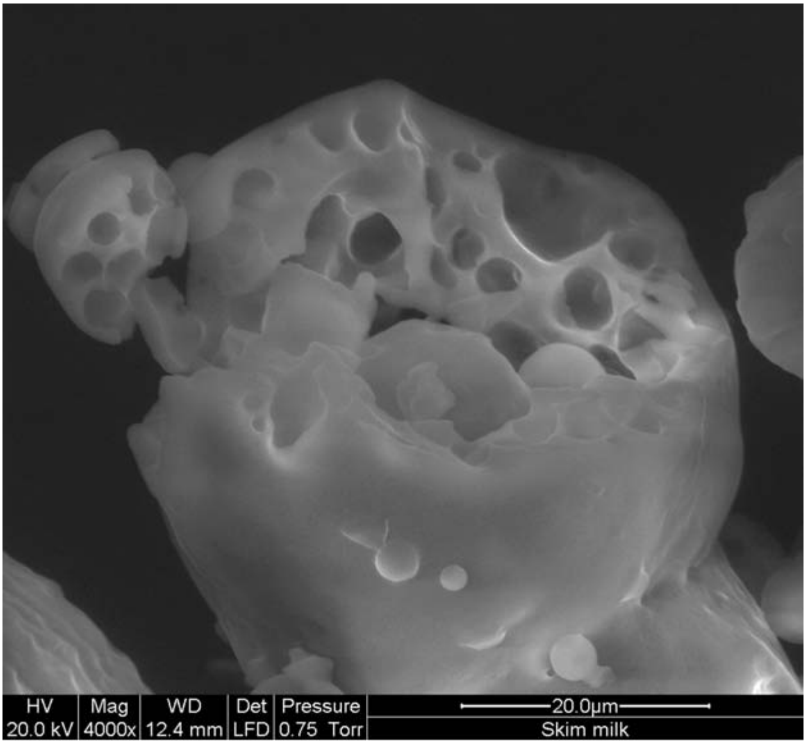

Figure 7.8 Fragment of refined spray-dried skim milk powder.

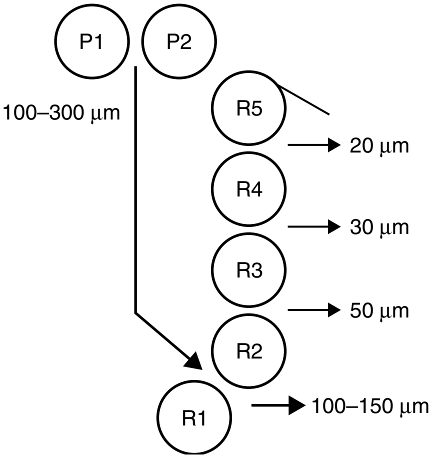

Figure 7.9 Schematic diagram of a five-roll refiner.

Table 7.1 Example of operating conditions for a five-roll refiner (Peter, 1994).

		Temperature[a]	
Roll	**RPM**	**°C**	**°F**
R1	<58	35–40	95–104
R2	58	35–40	95–104
R3	155	42–48	108–118
R4	268	50–60	122–140
R5	380	35–40	95–104

[a] Recommended for low-fat mixes, subtract 5–10°C (9–18°F) for high-fat mixes.

(6–14 × 10^{-4} in.). The relationship between final maximum particle size and specific flow rate (kg/h-m) is linear (Fritzsche, 1994), with the theoretical fineness being defined by

$$S_o = 2m'/\rho\ (\nu + \nu_{i+1})b \tag{7.1}$$

where S_o = theoretical maximum particle size equivalent to the film thickness or gap, m' = mass flow rate, ρ = chocolate density (approximately 1.2 kg/m^3), ν = speed of circumference for rolls i and i+1, and b = roll length. This equation has been used to predict actual particle size measured by micrometer with a relatively high degree of accuracy (Fritzsche, 1994), and can be rearranged and used to estimate throughput at a given particle size.

Temperature has a significant effect on the rheology of the chocolate film and thus influences the refining process. Temperature is maintained by circulating water in the interior of each roll. The relative size of the cooling zone (1/2 the circumference of the roll) compared to the gap width (a few µm) allows for effective temperature control. The properties of the material being broken may change substantially with temperature and thereby alter the milling process. The proper consistency for transfer of product from roll-to-roll is maintained by the appropriate fat content. It is normally advantageous to roll refine chocolate at the lowest fat content possible – in the range of 24–27%. It is said that ½ of all the fat conserved at the refining step is saved during conching (Kuster, 1991), i.e. if you reduce the fat at refining by 1%, you only need to put 0.5% into the masse at the end of conching to obtain the same viscosity. As stated earlier, a material's tendency to agglomerate rises with smaller particle size and moisture content. Refining a very low-fat mixture, especially under humid conditions, can result in particle agglomerates exiting the roll refiner.

For accurate particle size control it is necessary to produce consistent and uniform feed material, which can be produced by intense mixing prior to refining, or perhaps even better by the two-stage refining process. The two-stage refining system employs a two-roll pre-refiner to size the feed material for efficient five-roll operation. Separate sugar pulverization (as was previously needed with a single stage refining process) can be eliminated with two-stage refining, allowing for use of granulated sugar in the chocolate formulation. This improves mixing and permits refining at lower fat content. Ideally, the particle size exiting the pre-refiner should be slightly smaller than the feed gap of the five-roll machine, and in practice no more than 20% greater than the first five-roll gap (Kuster, 1991). Among the potential benefits of two-stage refining are a 10–25% increase in the throughput capacity of the five-roll machine and savings in cocoa butter needed to standardize the flow properties. The latter is probably due to a reduction in the proportion of very fine particles.

At least one roll refiner manufacturer has automated the milling process by incorporating on-line measurement of film thickness at the final roll (R5). The deviation of the measured value from a set point value is used to control the masse throughput by changing the gap setting at R2, as previously described. In addition, automated feed level control and dry running protection are also available (rolls become damaged very quickly if there is no material between them).

Refiner roll wear depends on the correct adjustment of the hydraulic roll stack pressure and the product recipe. The major contributors to roll wear are shell and silicates (sand) present in the cocoa liquor, so efficient cleaning and winnowing of cocoa beans are very important. In general, the greater the liquor content of the chocolate masse, the lower the anticipated service life of the rolls. Wear increases substantially with the silicate content of the liquor, the final degree of fineness of the chocolate and the contaminating shell content. The same could be expected to hold true for other chocolate refining devices.

7.5.2 Crumb chocolate

Refining of chocolate crumb is easier, i.e. requires less power and results in less wear, provided that the crystallization of sugars during the crumb making process is adequately controlled, since only loose agglomerates of sugar, milk solids and cocoa solids are being broken. If the agglomerates are less than about 125 μm (0.005 in.) then single-stage refining may be appropriate, otherwise two-stage refining may be necessary. Because fewer primary sugar crystals are being fractured, fewer fines (<5 μm) are present and particles are less jagged in refined crumb chocolate as compared with the milk powder process.

7.5.3 Sugar substitutes

Here we are principally talking about the growing number of alternatives to sucrose. Bouzas and Brown (1995) and Chapter 3 have reviewed the physical and chemical characteristics of sugars and sugar substitutes in relation to their usefulness in chocolate, so this discussion is restricted to the grinding of these materials. Fructose is particularly difficult to grind due to its hygroscopic nature (Niediek, 1994). Sugars that form crystal hydrates, for example glucose (dextrose) and maltose, may lose their water of hydration during roll refining, causing complications downstream (Hogenbirk, 1985). Anhydrous forms of glucose and maltose can be ground without difficulty, as can anhydrous or crystalline lactose monohydrate. Sucrose-free chocolates containing lactitol monohydrate must be roll refined at temperatures below 60°C (140°F), while those containing anhydrous lactitol or maltitol can be refined under standard conditions (Olinger, 1994). Isomalt, mannitol, sorbitol and xylitol sweetened chocolates should probably be refined at relatively low temperatures (<40°C, <104°F), and under dryer processing room conditions than sucrose-sweetened chocolates. Bulking agents like amorphous polydextrose can be roll refined, exhibiting brittle fracture below their glass transition temperature, but the fibrous structure of microcrystalline cellulose makes it difficult to grind.

7.5.4 The refiner-conche

The refiner-conche consists of a drum with a serrated internal surface. Particles are broken as they are forced between spring-loaded scrapers and the interior drum surface (see Chapter 9, Figure 9.24). Initially, this type of machine reduces particle size rapidly, but as the masse becomes liquid the few remaining large particles have a lower probability of being caught in the grinding gap and so the resultant particle size distributions are wide (Beckett, 1994). This can be improved by combining these systems with either a ball mill or roll refiner. Higher fat content during grinding is necessary since ball mills require a liquid feed. Ball mills and refiner-conches are both good mixers relative to roll refiners, and since both employ wet grinding, agglomeration may be lower, leading to potentially shorter conching times. Small-scale processors who wish to manufacturer their own chocolate or producers of high fat, chocolate-flavoured coatings may find the so-called 'universal' systems an acceptable alternative.

7.5.5 Refining in the presence of water

USA Patents 5,080,923 (Martin and Stumpf, 1992) and 5,464,649 (St. John *et al.*, 1995) describe a process for producing chocolate containing 20–24.5% fat, comprising the steps of mixing a small amount of water (1–3%) into a sugar–fat mixture, refining the mixture and then evaporating the moisture using heat and agitation. This sugar–fat mixture is then combined with cocoa liquor, milk solids and additional fat and lecithin to produce the finished product. It is claimed that the moisture added is sufficient to dissolve the very fine sugar crystals (<5 μm). Upon evaporation this dissolved sugar recrystallizes onto larger crystals, resulting in a chocolate or chocolate-like material with improved rheology, i.e. lower viscosity, and in particular a much lower yield value. It is further claimed that a chocolate of less than 25% fat with flow properties suitable for moulding, extruding or enrobing can be produced.

7.5.6 Milling cocoa powder

Cocoa press cake is first of all coarsely milled, generally in some sort of crusher, to cocoa kibble. These kibble particles are ductile and have the added problem of containing fat that can melt when heated. Furthermore, they are aggregates of smaller particles; cake pulverizers do not further reduce primary particle size, but break up particle agglomerates. Impact milling at low temperatures (5–10°C, 42–50°F) is appropriate for cocoa powder production. For grinding 10–12% fat cocoa powder, the air flowing through the mill is usually sufficient to cool it, whereas cryogenic grinding has been used for high fat content cocoa powders.

7.6 Particle size reduction and chocolate flow properties

As stated in the introduction, while the outcome of a grinding process is a particle size distribution, it is important to know the relationship between this distribution and finished product quality. For chocolate products, particle size distribution affects flow properties and sensory perception. The flow behaviour of molten chocolate is important in moulding and enrobing, for proper cookie drop formation and in the design of bulk handling systems. Size reduction operations influence product quality and cost through their impact on chocolate flow properties. It is often desirable for chocolate to have as low a viscosity as possible with a minimum addition of its most expensive bulk ingredient – cocoa butter. Chocolate flow properties are discussed in detail in Chapter 10 and Bouzas and Brown (1995) have published an excellent review of the literature on the effect of structure, including particle size, on chocolate rheology. In order to avoid duplication this chapter will focus on the influence of particle size distribution on flow properties of chocolate as described by the Casson parameters. As the preceding section has shown, there has been considerable attention given to reducing the proportion of fine particles in an effort to control chocolate rheology.

Conventional wisdom assumes that the presence of small particles is detrimental to chocolate ‘flow properties’, since smaller particles have a greater surface area that must be coated by fat. However, this is somewhat oversimplified. Typical flow curves for chocolate can be divided into three or four shear rate, or better shear stress, regimes (Windhab, 1995, 1997). At shear stresses near the yield value, particle–particle interactions – friction and adhesion – or ‘network’ effects dominate. The close-packed particles behave like a pile of powder and particle surface area and surface properties, for example roughness, become extremely important. Particle shape is also important in this low stress regime, and rounding of particles due to selective dissolution of protrusions and jagged edges by water, in the procedure described in the aforementioned patents (see Section 7.5.6), may be as important as reduction of fine particles. Once flow has been initiated, above shear rates of about $1\,s^{-1}$, hydrodynamic effects become significant and particle packed volume relevant. Although the Casson model has its limitations, it nonetheless gives a useful insight into the behaviour of chocolate in the first two stress regimes.

Several studies have been conducted at the Pennsylvania State University to try to understand the relative influence of particle surface area and packing ability (as affected by particle size distribution) on the Casson parameters for molten chocolate. In general, it is known that the viscosity of a particulate suspension like chocolate decreases as particle size increases, particles become more spherical, the particle size distribution broadens, and the solids loading is reduced (fat content increased). The competing effects of particle surface area and packing density on the Casson yield value and plastic viscosity were therefore evaluated for four sweet dark chocolates with distinct particle size distributions, but the same mean diameter (with respect to their volume distribution (mean diameter = 20.1 ± 0.5 µm)) (Fischer, 1994). The volume histograms for these distributions are presented in Figure 7.10. A bimodal distribution resulted in a much lower Casson plastic viscosity (Figure 7.11a) but higher yield value (Figure 7.11b) when compared with unimodal distributions at the same volume mean diameter. The effect was greater at lower the fat contents; little difference in plastic viscosity was observed above 34% fat, while differences in yield value persisted to 45% fat. Figure 7.12 shows the influence particle size distribution had on the apparent viscosity as a function of shear rate. One consequence is that, where polyglycerol polyricinoleate (PGPR) is permitted, it can be used to reduce the yield value and the particle size distribution can be manipulated to improve flow at higher shear rates.

Fat fills the spaces or voids between the solid particles in molten chocolate and reduces the resistance to flow. The void volume in a packed bed of solids depends on the particle shape, size distribution (especially the number of distinct sizes) and packing arrangement of the particles. The packing efficiency is defined as the ratio of the actual volume of solids to the volume occupied by the bed of solids (which includes the inter-particle spaces). For a given distribution of particles, the packing efficiency can be improved by adding solid particles of sizes corresponding to the size of the voids in a packed bed. Filling these voids with smaller solid particles allows for a higher amount of solids to be present per unit volume and reduces the amount of space to be filled by the fat (see Figure 10.16). The extent of reduction in the void volume depends on the ratio of the sizes, number of distinct sizes and the volume fractions of small and large components (McGeary, 1961;

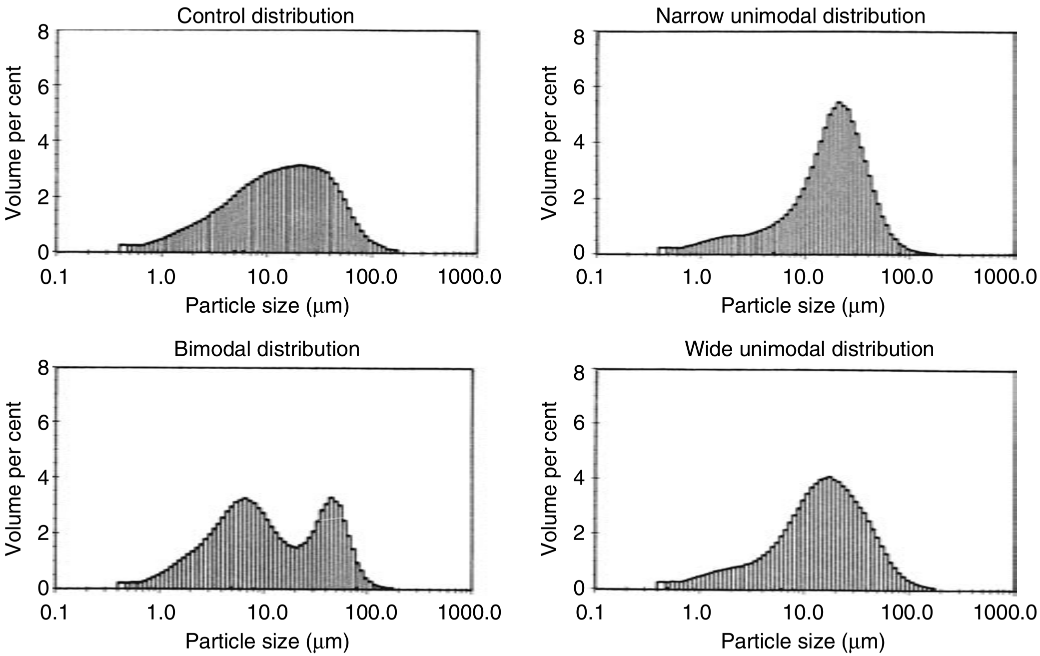

Figure 7.10 Volume histograms of four different dark chocolate samples. The specific surface areas as recorded by the Malvern Instrument were: ‘Control’ = 1.1696 m^2/g , ‘Bimodal’ = 1.2676 m^2/g , ‘Narrow’ = 0.9342 m^2/g and ‘Wide’ = 1.0512 m^2/g.

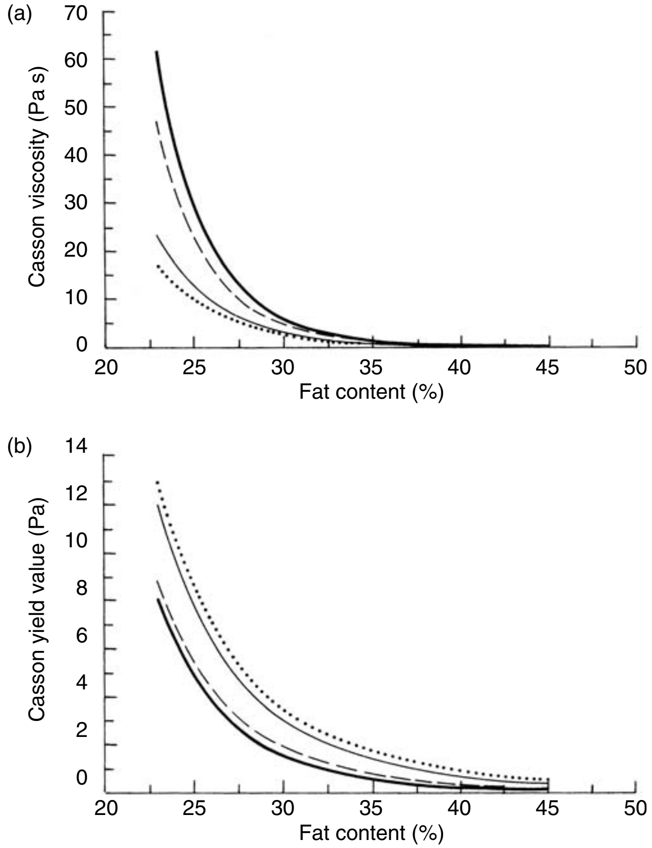

Figure 7.11 (a) The effect of the particle size distribution and the fat content of dark chocolates upon the Casson plastic viscosity. (b) The effect of the particle size distribution and the fat content of dark chocolates upon the Casson yield value. (——) narrow psd; (----) wide psd; (——) control distribution; (.....) bimodal psd.

Sudduth, 1993a–c). However, the addition of smaller particles increases surface–surface contacts.

Figure 7.13 illustrates the relationship between particle packing (bulk density) and the apparent viscosity for milk chocolates of equivalent composition, but different particle size distribution. As anticipated from theoretical treatments, the apparent viscosity decreases exponentially with increasing solids bed density. Again, this effect would be exaggerated at lower fat content. Particle packing becomes important once flow has been initiated and therefore affects the plastic viscosity component of the flow behaviour. Yield value is affected largely by inter-particle contacts and consequently shows a linear dependence on the mean particle size, or more accurately, on the specific surface area (Mongia, 1997; Mongia and Ziegler, 2000).

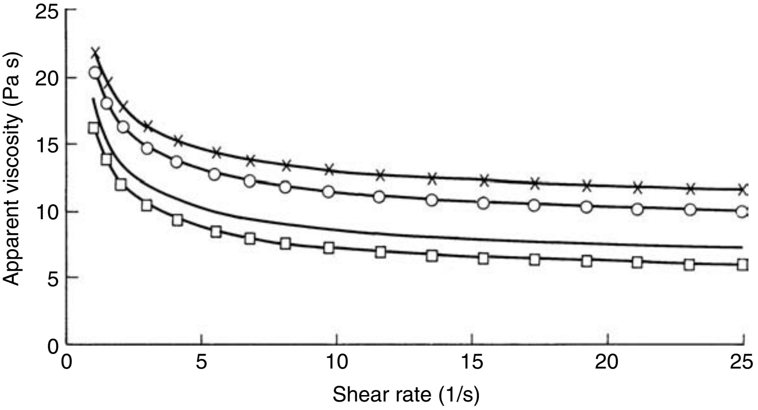

Figure 7.12 The effect of particle size distribution upon the apparent viscosity of a 28% fat dark chocolate. (—) Control; (□) bimodal; (x) narrow unimodal; (o) wide unimodal.

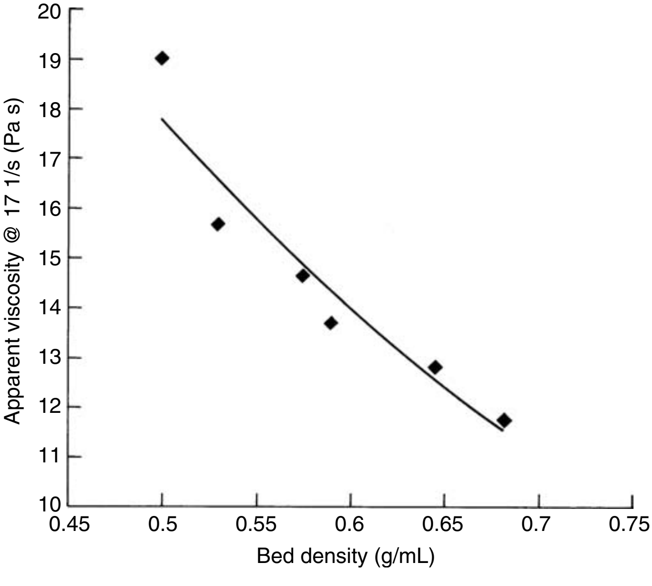

Figure 7.13 The apparent viscosity of a milk chocolate at a shear rate of 171 s^{-1} as a function of solids bed density.

Although these distributions were obtained through a combination of separate grinding and classification, they may be easily manufactured using conventional equipment like roll refiners. For example, a bimodal distribution containing a ratio of coarse fraction to fine fraction of 2:1 can be obtained by feeding a single conche from three refiners, two set coarse and one fine.

The overall throughput of the system is not much different than if all were set to an intermediate size. Alternatively, batches of coarse and fine chocolate could be mixed, in theory even after conching.

7.7 Particle size and sensory properties

Particle size not only influences the sensory perception of coarseness, but also melt, flavour, colour and gloss. According to Niediek (1994), there was no published systematic research on the effect of particle fineness on the flavour of chocolate masse. A study of the effects of particle size on the flavour of milk chocolate has, however, recently been carried out using time–intensity methods and a trained sensory panel (Mongia, 1997; Ziegler *et al.*, 2001).

Chocolate exhibits the unique property of melting from the solid state at room temperature to form a smooth dense suspension in the mouth at body temperature. The liquefaction of chocolate in the mouth is defined by the melting characteristics of the fat and facilitates the perception of taste and flavour attributes. The intensity of perceived taste and flavour changes dynamically over time as the chocolate is melted, manipulated and mixed with saliva. Time–intensity methods result in dynamic measurements of changes in sensory perception in the form of time–intensity curves, from which can be extracted attributes like maximum intensity, time to reach maximum intensity and the duration of the stimulus.

Sweetness, *chocolate* flavour and the *effort* required to melt, manipulate and swallow chocolate samples varying in particle size distribution and flow properties were measured using time–intensity procedures. *Thickness* and *coarseness* were measured using traditional descriptive analysis procedures (Mongia, 1997). The mean diameter of the volume distribution (as measured by laser light scattering) ranged from 8.50 to 16.95 μm (0.3–0.6 × 10^{-4} in.). This was achieved by varying the size of the sugar only; cocoa solids and non-fat milk solids were of consistent size in all samples. As the average particle size got finer and yield value increased, the time to maximum, intensity of maximum and duration of *effort* required to melt, manipulate and swallow the sample all increased, that is the finer chocolates had a greater residence time in the mouth. While the chocolates all had the same amount and size of cocoa solids, and therefore the *intensity* of *chocolate* flavour did not differ, the *duration* of *chocolate* flavour was influenced by the average particle size, with the *chocolate* flavour of finer samples persisting longer than that of coarser samples. This is directly related to the residence time of the sample in the mouth.

Kuster (1980) reported that cocoa liquor is sensed organoleptically earlier than sugar or milk powder, and presumed that with lower surface values (greater particle size), the sweetness of the sugar could be diminished. We originally hypothesized that the finer the chocolate, the sweeter the taste, since small crystals dissolve more rapidly that do larger ones. However, the maximum intensity for *sweetness* was greater for coarser samples. As with the *chocolate* flavour, the *sweetness* persisted longer in finer samples. Increasing viscosity is known to reduce the perception of sweetness in solutions and gel products, but not the perception of chocolate flavour in desserts (Pangborn and Kayasako, 1981).

Thickness scores were highly correlated to the Casson yield value ($r = 0.97$) and to the mean diameter over the volume distribution ($r = -0.99$). As expected, the chocolates became lighter in colour (tristimulus L value increased from 34 to 41) as the particle size became smaller. Multivariate regression analysis led us to conclude that yield value and mean particle size are more significant contributors to the sensory perception of chocolate products than, for example, plastic viscosity or the shape of the particle size distribution.

Conclusions

It has long been known that particle size reduction is critical to obtaining desirable liquid chocolate flow properties. However, as has been shown, the affects of particle size are much farther reaching and include influencing the taste and texture of the final product. Developments in engineering design and process control now enable chocolate manufacturers to manipulate the particle size and size distribution, should they wish to do so. However, it must also be remembered that size reduction is only one part of chocolate processing and that the choice of grinding equipment used must always take into account the ingredients being processed and downstream operations. The influence of particle size distribution on the flavour of chocolate suggests that deagglomeration occurring during conching may be as important to flavour development as it is to viscosity reduction.

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Chapter 8

FLAVOUR DEVELOPMENT IN COCOA AND CHOCOLATE

G. Ziegleder

8.1 Introduction

Owing to its unique taste, texture and aroma, chocolate is enjoyed by consumers all over the world. The flavour of cocoa and chocolate is generated by several processing steps, the most important being the post-harvest fermentation and drying of cocoa seeds, the roasting of raw cocoa and the chocolate conching process. To date, about 600 volatile and partly odour-active compounds have been found in cocoa and chocolate, following fermentation, drying, roasting and conching (Van Praag *et al.*, 1968; Keeney, 1972; Maniere and Dimick, 1979; Gill *et al.*, 1984; Hoskin and Dimick, 1984; Carlin *et al.*, 1986; Ziegleder and Biehl, 1988; Ziegleder, 1991a; Nijssen *et al.*, 1996; Schnermann and Schieberle, 1997). However, no unique 'chocolate compounds' have been identified and most of these substances are also found in other food. But these cocoa volatiles interact and enhance each other to develop a pleasant and unique sensory experience. In chocolate, the flavour/aroma volatiles are active supplementary to the pleasant taste of non-volatile constituents. These range from the typical astringent mouth-feel of cocoa polyphenols to the slight sour taste of cocoa acids and from the bitterness of theobromine to the sweetness of sugar. In addition there is the flavour and creaminess of milk components. The characteristic pleasant mouth-feel is produced by the melting behaviour of cocoa butter. Furthermore, the particle size distribution, the viscosity and the hardness of the chocolate dispersion determine the perceived taste of the final chocolate product (Beckett, 2000). A schematic overview of the various steps of the cocoa flavour development and its conversion into chocolate flavour is given in Figure 8.1.

There are obvious differences in the flavour of cocoa beans according to where they were grown in the world. Therefore, dark chocolate may show significant variations with respect to sour, bitter, astringent, chocolate, nutty, smoky and burnt flavours (Jinap *et al.*, 1995). Therefore recipes made with a single bean variety, or those using blends, may have dramatic differences in flavour. The Criollo- and Trinitario-based cocoa varieties are generally

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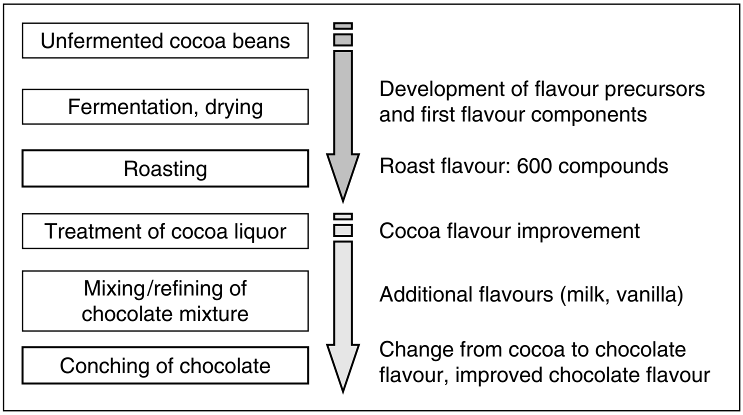


Figure 8.1 Steps of flavour development in cocoa and chocolate (schematic).

known to produce a fine chocolate flavour, often described as a mild nutty and a full flavour, respectively, and are considered 'fine grade'cocoas (Cook and Meursing, 1982). The 'bulk cocoas' which make up the vast majority of the world's production, are from Forastero varieties. Although they are of good quality and have intense cocoa flavour, they have less fine chocolate notes when compared to the Criollo type.

8.2 Fermentation

8.2.1 The fermentation process (see also Chapter 2)

Biochemical mechanisms that contribute precursors for flavour begin as soon as the cocoa is harvested. Even though the fermentation process facilitates the removal of the mucilaginous pulp and prevents germination of the beans, its primary importance is in the development of the chemical precursors, which will eventually be converted into the required chocolate flavours. However, the beans must have reached maturity, otherwise no amount of processing can produce the desired flavours (Dimick and Hoskin, 2002). Also, unfermented beans may only develop little cocoa flavour when roasted.

During this stage of processing, the mucilaginous pulp surrounding the beans undergoes an ethanolic, acetic and lactic fermentation. The acid and heat generated kills the beans, which also results in a change in the cell membranes. The different types of cocoa require different degrees of fermentation. For Criollo cocoa two or three days of fermentation are sufficient for full development of the flavour precursors. Forastero cocoas are fermented for between five and eight days with periodic mixing to homogenize the treatment and to aerate the fermenting mass. The fermentation together with the subsequent drying is important to ensure browning (Maillard reaction) of the beans and to generate flavour precursors (Lehrian and Patterson, 1983; Lopez and Dimick, 1991; Biehl and Ziegleder, 2003).

After the harvested pods have been cut and broken, the wet cocoa is infected by numerous types of spores from the surrounding airborne microorganisms. In the pulp an anaerobic (oxygen-free) break down of sugar starts. During the first two days, alcoholic fermentation is dominating over the lactic acid fermentation. Ethanol and carbon dioxide are produced, which displaces air from the fermentation box. At this stage the pulp is drained off and most seeds are still alive. With the decreasing rate of sugar break down and the loss of the pulp, more air is absorbed by the beans, giving rise to oxidative formation of acetic acid. Both the temperature increase to >45°C (113°F) and the uptake of acetic acid then kill the beans. The average pH value within the beans drops to about 4.5. A large amount of oxygen is consumed in the fermenting pulp, keeping the seeds under anaerobic conditions and allowing post-mortem reactions to take place. After 4 to 5 days the production of acetic acid slows down and temperature may drop. Now lactic acid is formed. Towards the end of the process, once the pulp has decomposed, air starts to flow from the bottom to the top of the hot cocoa and the beans come in contact with the oxygen in the air. During this aerobic phase, many oxygen-mediated reactions occur, one of the most important being the reduction of astringency by the conversion of soluble polyphenols into insoluble polymers.

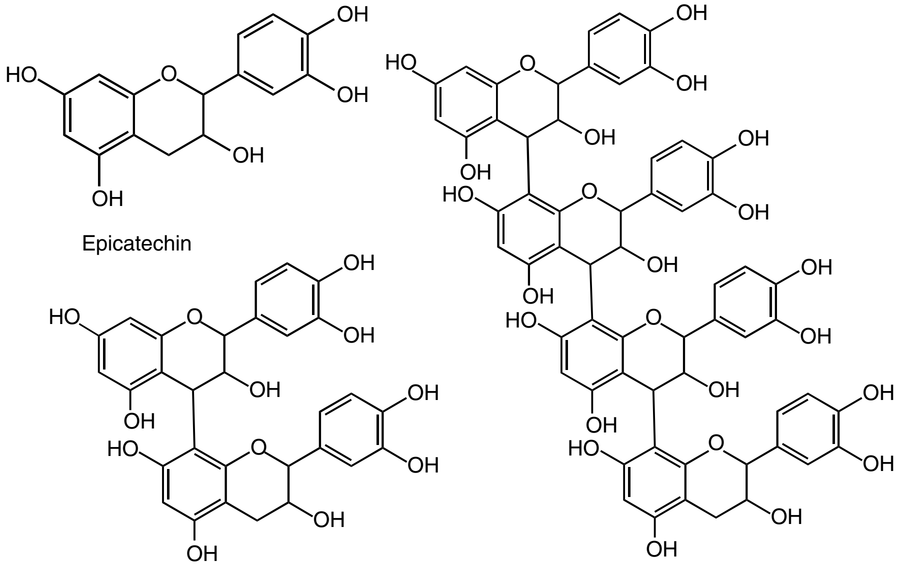
8.2.2 Chemical changes and development of flavour precursors

8.2.2.1 Polyphenols

Polyphenols, which cause the astringent flavour of cocoa, are a major group of cocoa components, making up about 10–20% (dry wt) of the cotyledon. They consist of anthocyanins, causing the characteristic purple colour of unfermented cocoas, colourless catechin and epicatechin, and their dimers, trimers, tetramers and higher oligomers, called procyanidins, as well as polymers. Epicatechin tends to polymerize under the influence of oxygen. Figure 8.2 shows the molecular structure of selected polyphenols, the monomer epicatechin, a dimer procyanidin built up of two epicatechin subunits and a tetramer procyanidin built up of four subunits. Epicatechin and the smaller procyanidins up to three subunits are soluble and therefore cause the astringent taste sensation of cocoa. Molecules, built up of more than three subunits, are insoluble and cause no astringency. During fermentation the concentration of soluble polyphenols is greatly reduced by oxidation and polymerization and due to exudation or enzymatic browning, respectively. So, astringency of cocoa is reduced and the colour changes from purple to brown. Besides procyanidins a series of different *N*-phenylpropenoyl amino acids appear to be key contributors to the astringency of non-fermented cocoa beans, as well as roasted cocoa nibs (Stark and Hofmann, 2005; Stark *et al.*, 2005, 2006).

8.2.2.2 Free amino acids

The major nitrogen-containing precursors are the numerous amino acids and peptides (Timbie and Keeney, 1997). Ripe cocoa seeds contain between 10% and 16% (dry wt) of protein and a low level of free amino acids.



Epicatechin

Procyanidin dimer

Procyanidin tetramer

Figure 8.2 Molecular structure of some selected polyphenols in cocoa.

During fermentation seed proteins are degraded by postmortem enzymatic hydrolysis giving rise to 1–2% of free amino acids (dry wt). Proteolysis in the seeds mainly takes place within about 24h after destruction of the cells and acidification by acetic acid. As mainly hydrophobic amino acids are set free, there is a clear difference between the compositions of the protein-bound free amino acids and resulting free amino acids (Kirchhoff *et al.*, 1989; Voigt *et al.*, 1994). Hydrophobic amino acids, especially leucine, valine, alanine, isoleucine, phenylalanine and hydrophobic peptides are of major importance as precursors for the formation of cocoa flavour (Biehl and Ziegleder, 2003). Table 8.1 shows some examples of volatile derivatives of hydrophobic amino acids.

8.2.2.3 Sugars

Fresh cocoa beans contain 5–9% (dry wt) of starch and 2–4% (dry wt) of free sugars. In early fermentation the major sugar is sucrose; however, it is soon hydrolysed into glucose and fructose as fermentation progresses (Berbert, 1978; Reineccius *et al.*, 1972a). In Sanchez or Arriba cocoa, which are traditionally weakly fermented, up to 1% sucrose was found (Keeney, 1972). The sucrose content in well-fermented raw cocoas, however, is near to zero, but fructose and glucose levels increase up to about 0.6% (dry wt). As the amount of fructose and glucose formed is considerably lower than the decrease of sucrose, it would appear that a substantial proportion must exude from the pulp.

8.2.2.4 Acids

Acetic acid and lactic acid, which are produced in the pulp during fermentation, are assumed to cause the acid and sour taste of raw cocoa. During

Table 8.1 Hydrophobic free amino acids (alanine, valine, leucine, isoleucine, phenyl alanine) as precursors of volatile aldehydes, acids, alcohols, esters.

Amino acid	Aldehydes	Acids	Alcohols	Esters
Ala	Acetaldehyde	Acetic acid	Ethanol	Ethyl acetate
Val	2-Methyl-propanal	2-Methyl-propanoic acid	2-Methyl-1-propanol	2-Methylpropyl acetate, ethyl 2-methylpropionate
Leu	3-Methyl-butanal	3-Methyl-butanoic acid	3-Methyl-1-butanol	3-Methylbutyl acetate, ethyl 3-methyl butanoate
Ile	2-Methyl-butanal	2-Methyl-butanoic acid	2-Methyl-1-butanol	2-Methylbutyl acetate, ethyl 2-methyl butanoate
Phe	Phenylacetaldehyde, benzaldehyde acetophenone[a]	Phenylacetic acid, benzoic acid	2-Phenylethanol, 1-phenylethanol, benzyl alcohol	Phenylethyl acetate, benzyl acetate, ethyl benzoate

[a] Ketone.

fermentation, acetic acid affects the nib pH value and consequently enzymatic reactions and flavour precursor formation. This means that the optimum condition for the enzymatic hydrolysis of sucrose and proteins in the beans is in the acid range (Biehl and Passern, 1982; Biehl *et al.*, 1985). According to Jinap and Dimick (1990) cocoa beans from Malaysia or Brazil (Bahia) have low pH (4.7–5.2), those from West Africa or Indonesia medium pH (5.2–5.5) and those from Ecuador, Venezuela or Guatemala high pH (5.5–5.8). The higher pH correlates to a lower fermentation degree. The concentrations of acetic acid and of lactic acid in Malaysian or Brazilian cocoas are 5.2–8.2 g/kg and 2.7–5 g/kg, respectively, and in the other cocoas 4.2–5.6 g/kg and 2.1–3 g/kg, respectively (Jinap and Dimick, 1990).

8.2.2.5 Alkaloids

Cocoa beans contain about 2–3% of theobromine, 0.2% of caffeine and traces of theophylline, with no quantitative change of the concentration being reported during fermentation and roasting. Owing to its low taste detection threshold of 10 mg/L, theobromine is believed to contribute to the bitter taste. After roasting, theobromine may form chemical adducts with diketopiperazines (Figure 8.6), which seem to have some connection with the characteristic bitter notes of roasted cocoa (Pickenhagen *et al.*, 1975).

8.2.3 Over-fermentation

A detrimental hammy off-flavour defect can arise due to a prolonged treatment after the optimum fermentation time. Over-fermentation is caused by a direct aerophilic microbial attack on the beans, destroying the cocoa flavour potential, increasing the pH value and blackening the beans. This process may arise especially in the wet, well-aerated mass. Aerophilic bacteria metabolize amino acids and peptides. The hammy off-flavour can be explained by the formation of a surplus of propionic acid, methyl propanoic acid and methyl butanoic acid (Lopez and Quesnel, 1973). Although these acids, in usual concentration levels, were postulated as important in cocoa flavour (Ziegleder, 1991a; Schnermann and Schieberle, 1997). In practice, it is often difficult to distinguish the 'hammy taste'and the 'smokiness flavour', which is caused by incorrect drying techniques.

8.3 Drying

After the fermentation the beans are dried and this process is also instrumental in flavour precursor development. Indicators of good drying practices, which also relate to the flavour quality of the beans, are a good brown colour and a low adstringency and bitterness. Flavour assessments of cocoa beans dried using different methods, i.e. sun drying, air-blowing, shade drying and oven drying, demonstrated that the sun-dried samples rated higher in chocolate flavour development and had fewer off-notes (Selamat *et al.*, 1991). For sun-drying, the beans are spread on the ground, on mats or on wooden floors raised from the ground and protected against rain. Five to seven days are usually necessary to reduce the water content to about 7%.

In artificial drying, wood fires or oil burners are connected to a flue under a floor of closely spaced slats. Hot air is passed through a layer of cocoa beans. Excessive heat and rapid drying may not allow for adequate loss of volatile acids for example acetic acid, and therefore have a detrimental effect on quality. If smoke, during oven-drying, comes in contact with the beans, an off-flavour known as smoky or hammy flavour can result, as cocoa easily absorbs volatile phenols from smoke. Figure 8.3 shows the total amount of volatile phenols in correlation with the sensorial intensity of smokiness (Lehrian *et al.*, 1978). In smoky cocoa beans phenol, methyl-phenols, dimethyl-phenols, 1,2-dihydroxy-benzene, dimethoxy-phenols and 3-methyl-gujacol have been identified via HPLC in combination with an electrochemical detection, whereas cocoas of good quality are mostly free of them (Sandmeier, 1987).

Incomplete drying or rain soaking may result in mould contamination. Heavy mould growth may produce high concentrations of methyl-ketones and volatile aldehydes, which have a very detrimental effect upon bean flavour (Hansen and Keeney, 1970).

During drying the Maillard reaction takes place, and Amadori compounds, the first intermediates of Maillard reaction, have been identified in dried, unroasted cocoa beans (Heinzler and Eichner, 1991; Oberparleiter and Ziegleder, 1997). They are the first intermediates of the reaction of free amino acid and glucose. Although the formation of these Amadori compounds is not detectable by colour or odour and may even be reversible at this stage, these initial reactions are important because Amadori intermediates will during subsequent roasting decompose into numerous volatile components.

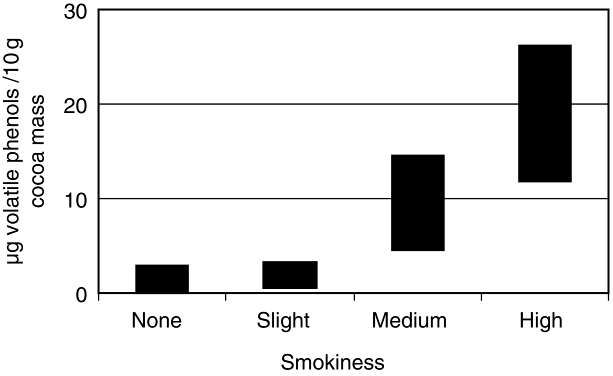


Figure 8.3 Correlation of the total amount of volatile phenols (μg/10 g cocoa) and sensorial smokiness of cocoa (according to Lehrian *et al.*, 1978).

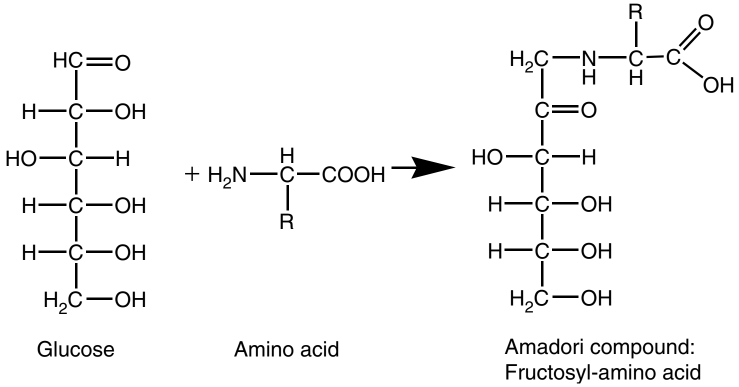


Figure 8.4 Formation of Amadori compounds from glucose and amino acids.

The reaction of Phenylalanine (Phe) and Glucose (Glc), as an example, delivers the Amadori compound Fructose-Phenylalanine (Fru-Phe). In course of the so-called Amadori rearrangement the structure of glucose is turned into fructose (see Figure 8.4). It was shown that Fru-Phe after heating produces much more cocoa-like flavour components than the simple mixture of Phe and Glc (Oberparleiter and Ziegleder, 1997). Currently, the Amadori compounds Fru-Thr, Fru-Ser, Fru-Gly, Fru-Ala, Fru-Val, Fru-Ile, Fru-Leu, Fru-Phe and Fru-Abu have been found in dried cocoa and were generated by the reaction of the amino acids threonine, serine, alanine, valine, i-leucine, leucine, phenylalanine and a-amino butyric acid with glucose. The concentrations of single Amadori compounds are between 20 and 70 mg/100 g (dry wt.) in dry raw cocoa, which means a conversion of about 10% of the single free amino acids into the corresponding Amadori compound. Owing to the high thermal reactivity of Amadori compounds, cocoa flavour may be generated at increased drying or low roasting temperatures.

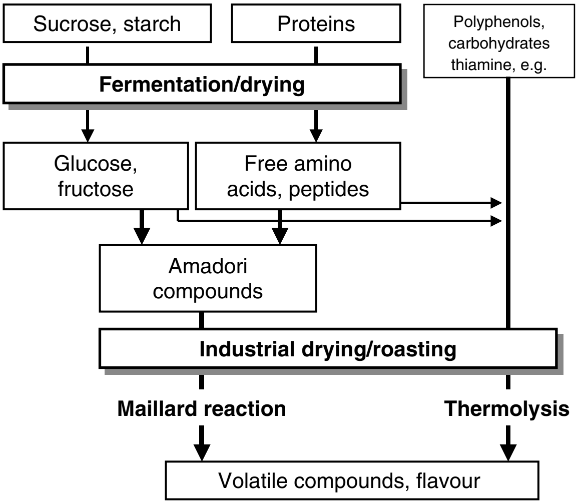


Figure 8.5 Influence of cocoa processing on development of flavour precursors and flavour compounds (schematic).

Figure 8.5 illustrates the formation of flavour precursors and flavour components during cocoa processing. In addition to the flavour precursors, the first aroma compounds are developed during fermentation and drying and are predominantly aldehydes, alcohols, acids and acetates. The main aldehydes in fermented cocoa (see Table 8.1) arise from Strecker degradation of hydrophobic amino acids such as alanine, valine, leucine, isoleucine, and phenylalanine and are partly converted into the corresponding alcohols and acids. During Strecker degradation amino acids react with the dicarbonyl part of sugars to form aldehydes and aminoketones (Figure 8.6). Several aromatic, odorous volatiles derive from phenylalanine. Alcohols were partly esterified by acetic acid to form acetates. In addition, methyl butanoic acids and benzoic acid are esterified by ethanol to form ethyl-methyl butanoates and ethyl benzoate.

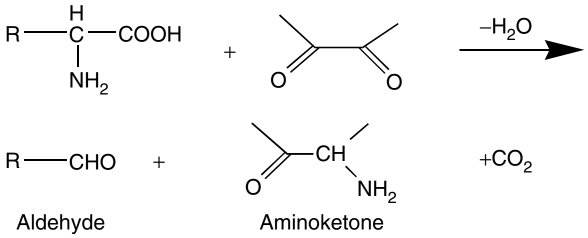
Special flavour grade cocoas, mainly harvested in Venezuela, Trinidad, and Ecuador (Arriba), reveal a flowery and tea-like aroma and contain significant concentrations (0.5–2 mg/kg) of linalool and further terpenoids, which contribute to this pleasant note (Ziegleder, 1990; Pino, 1992). Bulk cocoas from West Africa, Malaysia, or Bahia carry a fairly strong inherent flavour and have very low levels of linalool. Tetramethylpyrazin occurs in relatively high concentrations in fermented unroasted cocoa and is produced by microorganisms (Zak *et al.*, 1972).

8.4 Roasting

8.4.1 Roasting process and the further development of flavour precursors

The roasting of cocoa develops cocoa flavour, reduces moisture and acidity and releases the beans from the shell. Cocoa is normally roasted at

(a) Strecker degradation of amino acids



(b) Conversion of amino ketones into pyrazines

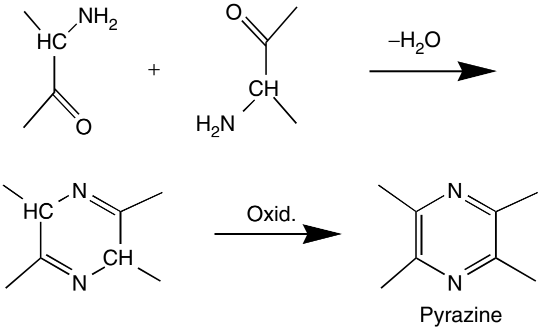


Figure 8.6 (a) Formation of aldehydes and aminoketones via Strecker degradation of amino acids. (b) Conversion of aminoketones into alkylpyrazines.

temperatures between 120°C and 140°C (248°F and 284°F), which is rather a low temperature in comparison to the roasting of nuts or coffee. Using modern equipment, cocoas can be roasted as whole beans (many different sizes), as nibs (broken beans), or as liquid cocoa mass, which is produced by a fine grinding of cocoa and liquefying within its own molten fat (see Chapter 6). Special thin-film techniques were developed for the roasting of cocoa liquor (Schmidt, 1978; Rapp, 1981). The roasting of smaller particles has the advantage of a better controlled and homogeneous roasting level, of a reduced roasting time and of the partial removal of any excess acetic acid. Although acetic acid remains unchanged during bean roasting, it is significantly reduced during the roasting of cocoa liquor (Nuyken-Hamelmann and Maier, 1987). Beans take about 30 min, nibs 12 min and liquor 2 min for roasting.

Prior to roasting, cocoa may taste astringent, bitter, sour, flat, musty or unclean. After roasting, cocoa possesses the typical intense aroma of cocoa and shows a reduced acidity. Roasting at temperatures higher than about 150°C (300°F), or for too long a roasting time, results in 'over-roasted' cocoas, which have a significant bitter and burnt, coffee-like taste. Before roasting, pre-drying is necessary to reduce water content below 4%, and during roasting the moisture level decreases to about 2%. In industrial roasters this pre-drying takes place as a separate processing stage. If roasted without pre-drying, cocoa would generate a cooked, flat aroma. As the formation of most flavour compounds is based on condensation or decomposition reactions, a surplus of moisture would hinder these reactions and furthermore evaporate volatile reaction products by steam distillation.

The flavour precursors interact in the roasting process to produce the desired cocoa flavour. Although the exact percentage of conversion depends upon the roasting parameters, there is a characteristic average for the utilization of the precursors: about 25% of free amino acids (fermented, unroasted: 1–2%, dry weight) are only used up, and about 70% of the glucose and fructose (fermented, unroasted: 0.6%, dry weight) (Pinto and Chichester, 1966; Rohan and Stewart, 1966; Reineccius *et al.*, 1972a; Mermet, 1989; Ziegleder, 1991b). Reducing sugars as the minor component within the mixture of aroma precursors are converted to a greater extent, while free amino acids, due to their surplus concentration, are consumed to a smaller extent and are partially recycled as part of the chemical reactions. The Amadori compounds (fermented, unroasted: 0.08–0.27%) are highly reactive intermediates and are totally utilized and rapidly decompose into numerous flavour volatiles (Heinzler and Eichner, 1991; Ziegleder and Oberparleiter, 1997).

When alkalization (for the production of cocoa powder) takes place as part of the roasting process, about 80% of free amino acids may be converted (Bonvehi and Coll, 2002). It has been speculated that a pre-treatment of unroasted cocoa nibs or liquor with water or aqueous precursor solutions might increase flavour development. As reducing sugars have been identified as the flavour precursors that are totally used up, the addition of sugar solutions might promote the formation of desirable flavour components. The preparation of unroasted cocoa liquor and the addition of sugar solutions to cocoa liquor before thin-film processing was therefore investigated (Rapp, 1981). When cocoa liquor is treated, however, the aqueous reagent solution must diffuse across the hydrophobic fat cover. Therefore, the treatment of cocoa nibs was recommended (Kleinert-Zollinger, 1986). After the infiltration of an aqueous solution of 1% glucose into cocoa nibs before roasting, an increased formation of volatile sugar degradation products was found within the roast flavour (Ziegleder, 1993). A pre-treatment of raw cocoa nibs with 15% of water for 15 min at 40°C (104°F), followed by drying at 98°C (208°F) to 3.5% water content and roasting, brought a more intense cocoa taste and an increased level of roast flavour components compared to cocoa which had been roasted without water pre-treatment. As a consequence of the pre-treatment with water, the consumption of amino acids and reducing sugars was increased, and an increased level of Amadori compounds was temporarily reached (Ziegleder and Oberparleiter, 1996). Probably the added water temporarily dissolves amino acids and sugars and so supports their reaction. In the case of cocoa powder production, where the nibs are treated with alkaline solutions, this type of reaction will already be occurring.

The temperature/time to which the cotyledons are roasted has an effect on the flavour balance of the final chocolate. As the roasting is increased, not surprisingly, the degree of roast flavour increases, but other factors are also affected. As is shown in Figure 8.7, the cocoa flavour intensity increases, but the acidity decreases (Lemmen, 2004; Beckett, 2006). While specific cocoa volatiles,

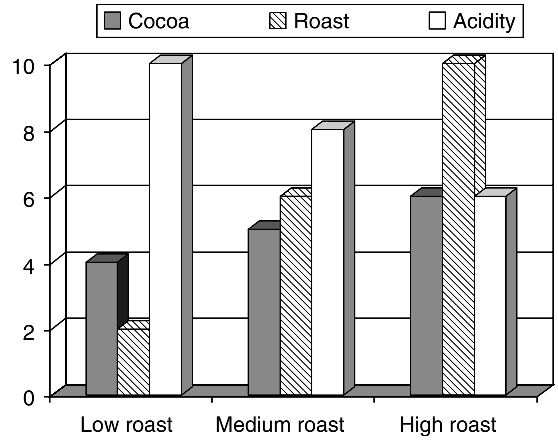


Figure 8.7 The effect of roasting conditions upon the taste of the final chocolate (according to Beckett, S.T. (2006) and Lemmen, E. (2004)). Partly reproduced from Beckett, S.T., *New Food*, **3**, 28–34, copyright 2006 with permission of Russell Publishing Ltd, Kent, UK.

such as phenylic or furylic compounds are already developed at low roasting temperatures, other volatiles, like pyrazines need higher roasting intensity.

8.4.2 Roast flavour

The pioneer work on cocoa flavour analysis was performed by Bainbrigde and Davies (1912), who isolated about 20 g of an aroma oil by steam distillation of 2000 kg of cocoa beans. Since then several groups have analysed cocoa flavour volatiles and, to date, about 600 components have been found (Van Praag *et al.*, 1968; Maniere and Dimick, 1979; Gill *et al.*, 1984; Carlin *et al.*, 1986; Ziegleder, 1991a; Nijssen *et al.*, 1996; Schnermann and Schieberle, 1997). These flavour components occur only in traces, mainly at levels of few µg/kg or not more than few mg/kg. Among them, about 100 different pyrazines represent the predominant flavour fraction. Other significant flavour fractions are hydrocarbons, alcohols, aldehydes and ketones, esters, sulphur compounds, acids, phenols, pyrrols, pyridines, furanes, pyrones, lactones, chinolines, chinoxalines, thiazoles and oxazoles.

Pyrazines are heterocyclic compounds with two nitrogen atoms in a six-membered ring. Cocoa pyrazines have many different substitutes for example methyl-, ethyl-, propyl-, butyl-, 2-methyl-butyl-, isopropyl-, isobutyl-, vinyl-, isopropenyl-, isobutenyl-, furyl-, methoxy- and acetyl-groups. These alkyl pyrazines are generally considered to be important components contributing to the flavour of roasted cocoa. The odour threshold values of different pyrazines range from 10 to 0.000002 mg/kg depending upon the substitution. The mechanism usually postulated for pyrazine formation is dimerization of ketoamines to dihydropyrazines with a subsequent oxidation step (Figure 8.6b). The variety and quantity of the alkylpyrazine formation depends on the reactivity of amino acids present, pH and roasting procedure

(Hwang *et al.*, 1995; Cremer and Eichner, 2000; Bonvehi and Coll, 2002). The total concentration of pyrazines in roasted beans varies according to variety. Ghanaian beans may have about 7 mg/kg, whereas Mexican beans may contain as little as 1.4 mg/kg (Reineccius *et al.*, 1972b). Only tetramethylpyrazine (TMP) occurs in large amounts (0.5–2 mg/kg) in fermented unroasted cocoa and during roasting soon reaches its maximum level at medium roasting levels. At higher roasting intensities tetramethylpyrazine is expelled to some extent with the roasting gases and decreases because its precursors are no longer available. The concentration of other pyrazines rises with increasing roasting time or temperature. Major quantitative differences involve primarily the dimethyl-, trimethyl-, and tetramethylpyrazines whereas other alkylpyrazines appear only at minor level. While the trimethylpyrazine (TrMP) increases steadily, the 2,3-, 2,6- and 2,5-dimethylpyrazines do not increase until strong roasting conditions occur (Figure 8.8). This enables a correlation to be established between the sensorially perceptible roasting degree of cocoa and selected components of the methylpyrazine fraction (Ziegleder, 1982; Ziegleder and Sandmeier, 1983). The sensory evaluation of different roasted cocoa beans showed that a concentration ratio of TMP/TrMP between about 1.5 and 2.5 was obtained when the degree of roasting was normal. Overroasted samples have a burnt, coffee-like taste and show significant concentration levels of 2,5-dimethylpyrazine and have TMP/TrMP ratios below 1.0 (Ziegleder, 1982). For alkalized cocoa powders a TMP/TrMP ratio of about 1.0 appears to correlate with normal levels of roasting (Bonvehi and Coll, 2002).

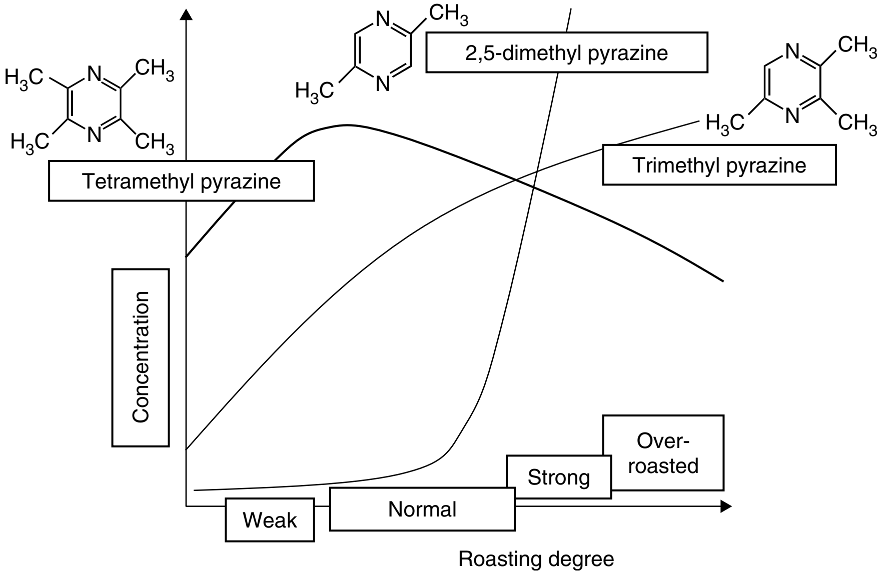


Figure 8.8 Influence of roasting on the formation of selected alkylpyrazines and on the sensorial roasting degree (according to Ziegleder, G., 1982).

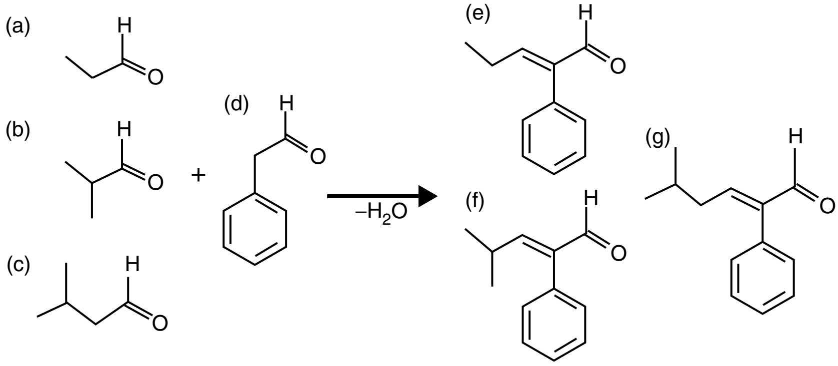


Figure 8.9 Aldol condensation of aldehydes with phenylacetaldehyde to form 2-phenyl-alk-2--enals: acetaldehyde (a), 2-methyl-propanal (b), 3-methyl-butanal (c), phenylacetaldehyde (d), 2-phenyl-but-2-enal (e), 2-phenyl-4-methyl-pent-2-enal (f), 2-phenyl-5-methyl-hex-2-enal (g).

Another predominant fraction of cocoa flavour are aldehydes, which are formed via Strecker degradation of amino acids (Figure 8.6a and Table 8.1). Their concentration greatly exceeds the threshold values (e.g. concentration for 3-methyl-butanal 4 mg/kg, threshold value 0.008 mg/kg). The concentration of 3-methyl-butanal strongly increases during roasting, and may be decreased to some extent due to evaporation together with the roasting gases or due to thin-layer treatment of cocoa liquor (Mohr *et al.*, 1968; Ziegleder, 1981). In addition, aldehydes may be converted during certain secondary reactions. In this way acetaldehyde, 3-methyl-butanal and 2-methyl-propanal undergo aldol condensation with phenylacetaldehyde to form 2-phenyl-but-2-enal, 2-phenyl-4-methyl-pent-2-enal and 2-phenyl-5-methyl-hex-2-enal (Figure 8.9), which carry a flowery odour faintly reminiscent of chocolate (Van Praag *et al.*, 1968) and which significantly increase with roasting time (Meili, 1985; Ziegleder and Biehl, 1988). As intermediates, aldehydes are involved in the formation of pyrazines and further heterocyclic compounds, which are dominant in the flavour of cocoa. By utilizing what is known about Strecker degradation during the roasting process, methods for evaluating cocoa bean quality by comparison of headspace volatiles have been suggested (Keeney, 1972; Ziegleder, 1981). In these 3-methyl-butanal and 2-methyl-butanal (Strecker degradation products of leucine and isoleucine) and 2-methyl-propanal (from valine) are used as indicators of highly volatile compounds.

Besides amino acids and sugars, other compounds such as peptides, proteins, vitamins, polyphenols, lipids and their oxidation products can enter the roasting reactions and influence the final flavour. In this way heat treatment may generate specific flavour compounds: 1,2-Benzendiol (pyrocatechol) is formed in cocoa by thermal decomposition of catechine, as well as thiazoles by thermal decomposition of the vitamin thiamine. Several pyrones, such as maltol, dihydro-hydroxymaltol, hydroxymethylfurfural, and furaneol stem from the degradation of sugar precursors in cocoa (Ziegleder, 1991a). Some of the furaneol and 2,3-dihydro-6-methyl-4H-pyran-4-on has already been formed

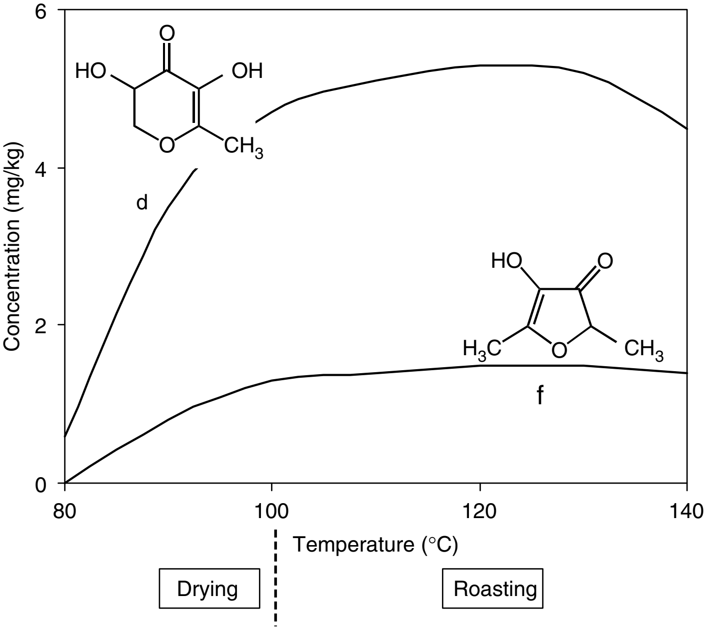


Figure 8.10 Influence of processing temperature on the formation of the sugar degradation products dihydro-hydroxy-maltol (d) and furaneol (f) (according to Ziegleder, G., 1991b).

at earlier moderate temperatures and relatively high humidities (Figure 8.10). This makes these volatiles a useful indicator, whose level can be used for monitoring drying processes or the early stages of roasting (Schnee and Eichner, 1985; Ziegleder, 1991a,b). These compounds decrease slightly during extended roasting, probably as a result of their chemical reactivity. Furaneol has a pleasant caramel taste and may also have a flavour enhancing effect.

Diketopiperazines, cyclic dipeptides, are generated by the intramolecular breakdown of peptides (Figure 8.11). In cocoa several diketopiperazines (e.g. Cyclo(ALA-VAL), Cyclo(ALA-Gly), Cyclo(LEU-PRO), Cyclo(ALA-LEU), Cyclo(ALA-PHE), Cyclo(PRO-GLY)) have been identified (Pickenhagen *et al.*, 1975; Rizzi, 1988; Bonvehi and Coll, 2000). Model experiments demonstrated that these diketopiperazines, when mixed with theobromine in a 2:1 mole ratio, induce a bitter taste sensation similar to that perceived from an aqueous suspension of cocoa powder (Pickenhagen *et al.*, 1975). Comparison of quantitative data of diketopiperazines and the sensorially perceived bitter intensity, however, led to the conclusion that further studies are necessary to understand the typical bitter taste of roasted cocoa (Bonvehi and Coll, 2000). Application of chromatographic separation and taste dilution analyses of cocoa extracts recently revealed *N*-phenylpropenoyl amino acids as powerful astringent components in cocoa. Besides procyanidins a series of different *N*-phenylpropenoyl amino acids seem to be key contributors to the astringent and bitter taste of non-fermented cocoa beans as well as roasted cocoa nibs (Stark *et al.*, 2005, 2006; Stark and Hofmann, 2005).

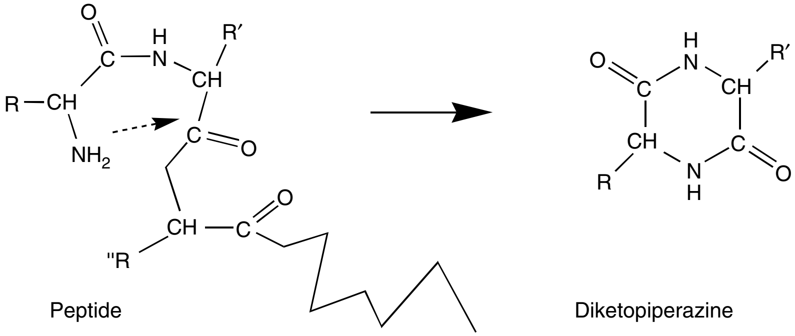


Figure 8.11 Heat-induced formation of diketopiperazines from peptides.

Table 8.2 Some selected compounds of the most odour-active volatiles in cocoa mass, their odour quality and FD factors. According to source: Schnermann, P. and Schieberle, P. (1997).

Odorant	Odour quality	FD factor
2- and 3-Methylbutanoic acid	Sweaty	2048
3-Methylbutanal	Malty	1024
Ethyl 2-methylbutanoate	Fruity	1024
2-Methoxy-isoproyplpyrazine	Earthy, beany	512
Hexanal	Green	512
2-Methyl-3-(methyldithio)furan	Cooked meat-like	512
2-Octenal	Fatty, waxy	512
2-Ethyl-3,5-dimethylpyrazine	Potato chip-like	256
2,3-Diethyl-5-methylpyrazine	Potato chip-like	256
2-Nonenal	Green, fatty	256
Phenylacetaldehyde	Sweet, honey-like	64
4-Heptenal	Sweet, biscuit-like	64
δ-Octenolactone,	Sweet, cocoanut-like	64
γ-Decalactone	Sweet, peach-like	64
Dimethyl trisulphide	Sulphurous	32
Nonanal	Soapy	32
Trimethylpyrazine	Earthy, potato-like	32
2-Ethyl-3,6-dimethylpyrazine	Nutty, earthy	32
2-Phenylethanol	Sweet, yeast-like	32
Ethyl 2-methylpropionate	Fruity	32
2-Decenal	Fatty, green	32
2,4-Nonadienal	Fatty, waxy	32
Ethyl cinnamate	Sweet, cinnamon-like	32
3-Hydroxy-4,5-dimethyl-2(5H)-furanone	Seasoning-like, spicy	32
3-Hydroxy-5-ethyl-4-methyl-2(5H)-furanone	Seasoning-like, spicy	32

The predominant odour-active compounds in cocoa liquor and their odour notes (FD factors 32 and higher) as found by aroma extract dilution analysis (AEDA) (Schnermann and Schieberle, 1997) are shown in Table 8.2. AEDA is a very good method of screening the most odour-active volatiles in food. It is based on the extraction of flavour components from food, separation by means of capillary gas chromatography, identification via mass spectrometry coupled with a so-called 'sniffing port' to characterize odorants. After several extract dilution steps, only the most potent odorants may be detected at the sniffing port. The number of dilution steps to reach the odour threshold is defined as the FD-factor. In general, the odour efficacy of a flavour component is dependent on the ratio of concentration level and specific odour threshold values. Several constituents, that have been previously mentioned, have very significant odours: 3-methylbutanal with malty odour, ethyl-2-methylbutanoate (fruity), 2- and 3-methylbutanoic acid (sweaty) and different pyrazines (earthy, potato-like, nutty, beany) (Table 8.2). Although trimethyl pyrazine contributes medium odour intensity, it is relatively less than that provided by other pyrazines with mixed substitutes. The majority of the potent odorants seem to arise from lipid precursors (hexanal, 2-octenal, 2-nonenal, nonanal, 4-heptenal, nonalactone, octenolactone, 2-decenal, 2,4-nonadienal) and carry green, fatty, tallowy, biscuit-like or waxy notes (Schnermann and Schieberle, 1997).

8.5 Conching

8.5.1 Thin-film-treatment of roasted cocoa liquor

The thin-film treatment of roasted cocoa liquor was developed around 1975, largely in order to reduce conching times. During this thin-film degassing, the cocoa liquor is spread to a thin layer and thermally treated at 70–90°C (158–195°F) for about one minute (Mohr, 1978; Schmidt, 1978; Kleinert-Zollinger, 1986). The major aim is to reduce acetic acid, because its flavour would otherwise mask the more valuable chocolate notes. Acetic acid and a portion of highly volatile substances may be reduced by about 20–40%, which enables the subsequent conching times to be shortened by about 30%. The degassing is more effective from liquid cocoa mass than from liquid chocolate masse, because the cocoa mass can be treated at higher temperatures without introducing burnt notes and it also has better flow properties, due to its lower viscosity.

8.5.2 Effect of conching on aroma development

Conching can be described as the working of chocolate flake and crumb into a fluid paste, coupled with flavour modification. Typically, conched chocolate is described as having a mellow flavour compared to an unconched one. The bitterness is reduced, perhaps allowing other flavour notes to be more pronounced. The nature of the flavour change during conching has not been completely explained at the chemical level (Dimick and Hoskin, 1999). Prior to conching, the basic chocolate masse is normally milled to the required final particle size in a five-roll refiner (see Chapter 7). This produces a dry, flaky chocolate powder. Most of particles have to be smaller than 30 μm (1.2×10^{-3} in.), otherwise grittiness will be felt in the mouth (Beckett, 2000). Although many particles are broken under the shear of the refiner gaps, others stick together to form porous agglomerates, which trap and enclose fat. Following refining, the chocolate masse is directly conveyed to a conche, where it is turned into a flowing melt that has an intense, harmonious and long-lasting taste of chocolate.

At the start of conching the masse usually contains between 2% and 5% less fat than the final chocolate. Inner friction raises the temperature steadily, which then causes the evaporation of steam-volatile components. The physical changes brought about by plastification consist of the breakage of any agglomerates and the coating of the non-fat particles by a film of fat. The temperature can rise to 80°C (176°F) for plain chocolate, but should not exceed 55°C (95°F) for milk chocolate. After plastification, the chocolate masse is liquefied by the gradual addition of the residual cocoa butter under continuous mechanical work. After the addition of an emulsifier (usually lecithin) a chocolate masse with good flow properties is produced (Kleinert-Zollinger, 1988). Good flow properties are a prerequisite for optimum manufacturing performance and also for good flavour perception, coupled with a pleasant and smooth mouthfeel (Beckett, 2000). Although conching requires about 6–24 h in modern high-efficiency conches, it often took 72 h in the traditional long-conche.

For decades, there have been many theories about the causes of chocolate flavour improvement during conching. One important factor is the degassing effect, which can be carried out in the conche or, more economically, by means of a pre-treatment of the cocoa liquor. Highly steam-volatile compounds and low boiling short-chain fatty acids are reduced by about 30%, allowing other flavour notes to be more pronounced and thus provide a more mellow chocolate after conching (Mohr *et al.*, 1968; Mohr, 1978; Maniere and Dimick, 1979; Ziegleder, 1997). The air space immediately surrounding an operating conche smells of acetic acid. It is also known that the moisture is reduced by about 30%. Flavour components such as 3-methyl-butanal, ethyl-2-methylbutanoate, dimethyl disulphide and hexanal are evaporated and reduced to some extent, which may have influence on the character of chocolate aroma (Schnermann and Schieberle, 1997). Although there could be small changes in the levels of amino acids or polyphenols, it is unlikely that chemical reactions play an important role during conching, other than where very high temperatures are deliberately used to introduce a cooked flavour.

Recent findings have shown however that conching results in a re-distribution of the flavour components within the chocolate masse (Ziegleder *et al.*, 2003, 2005). At the start of the conching process the chocolate flavours exist only in the cocoa components, i.e. cocoa particles and cocoa butter, whereas the granulated sugar only has sweet flavours. During conching cocoa flavour components, together with fat, are partially transferred to the sugar surface. This coating of the sugar surfaces results in a more uniform aroma perception and in a reduction of the penetrating sweetness of the roll-refined sugar. The diffusion of flavour is a result of the initial flavour concentration gradient between the different particles or phases; in addition, the increased porosity of the sugar surfaces, of which a very thin layer has been turned amorphous during roll refining (Niediek, 1981), may help flavour absorption. This means that sugar now acts as a flavour carrier. Figure 8.12 illustrates the process schematically, whilst Figure 8.13 shows the different flavour distributions before

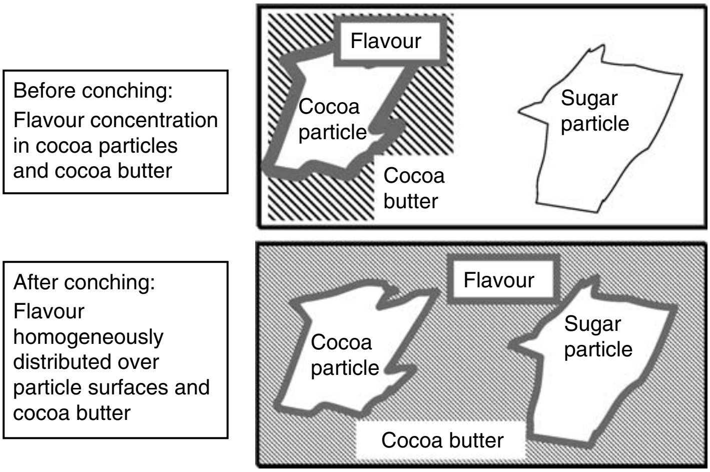


Figure 8.12 Redistribution of flavour within the chocolate masse (between cocoa particles, sugar particle surfaces and cocoa butter) during conching time. Flavour intensity demonstrated by hatching.

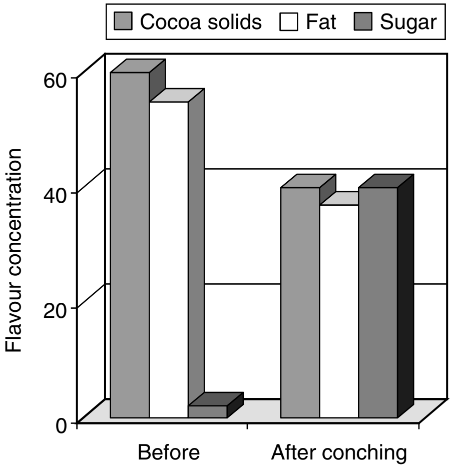


Figure 8.13 Flavour distribution between cocoa solids, sugar particle surfaces and the fat phase before and after conching.

and after conching. After conching the flavour components in the cocoa solids, fat and at the sugar surfaces have all been evened out.

Through flavour redistribution and absorption by the sugar surface, the flavour concentration in the fat phase decreases during conching (Ziegleder *et al.*, 2003). This was proved by separating a representative part of the fat from the finished, melted chocolate masse by centrifugation. The volatile compounds were then identified and quantified by GC–MS using internal standards. It was found that there was a very significant decrease of flavour in the fat during conching , even though the whole chocolate masse lost only a low portion of flavour due to evaporation. Using this method, conches and conching parameters could be evaluated objectively and an analytical 'conching degree' could be defined for the first time and a good correlation of analytical values and sensory results was achieved. Conching time and energy input showed the biggest influence on conching degree and sensory quality (Ziegleder *et al.*, 2003, 2005). The main factors affecting the flavour change were found to be the dry conching time, total energy/average power, type and rotation speed of shafts, starting fat level, viscosity of chocolate mass, flavour of cocoa mass, temperature, ventilation, humidity and particle size distribution. This mechanism of flavour redistribution during conching has been found to apply to both milk and plain chocolates.

8.6 Plain chocolate and milk chocolate

Owing to their higher proportion of cocoa liquor, plain chocolates have a more intense and bitter taste in comparison to milk chocolate. Factors such as the type of cocoa bean, where it is grown and how it is treated, will all affect the quality of plain chocolate. This is very pronounced with the so-called 'origin chocolates', which only contain cocoa liquor of one defined country of origin. As an example, a plain Arriba chocolate will have the typical taste of the mild, floral and earthy notes of Arriba cocoa. Some consumers prefer premium chocolates with high cocoa content, and plain chocolates with about 70% of cocoa and a high portion of flavour cocoa have an increasing market. These chocolates need specific manufacturing techniques, as their high fat level, due to the high portion of cocoa liquor and cocoa butter, causes difficulties during roller refining. They may be produced by the five-roller refining of a chocolate mixture with a reduced portion of the cocoa liquor and the later addition of the remaining cocoa liquor during conching. Alternatively cocoa powder can be used in the recipe, or the chocolate mixture can be processed in a ball mill (Ziegleder, 2006).

In milk chocolate there is a balance between milky/creamy flavours and the cocoa ones (Beckett, 2006), and in comparison to plain chocolates they are softer due to their portion of lower melting milk fat. Different forms of milk powder are used in milk chocolates and their influence on flavour have recently been described (Beckett, 2006, see also Chapters 4 and 5). Roller-dried milk forms platelet-like particles with most of the fat outside. This helps the chocolate flow properties and the temperatures used create a small amount of cooked flavour. Spray-dried milk has spherical particles, and most of the fat is trapped within the particle and so is unable to aid the viscosity of the chocolate. Milk chocolate crumb for the production of milk chocolate is made from milk, sucrose, and finely ground cocoa mass or cocoa powder. After being dried to a residual moisture of 2%, the crumb is pulverized (Kleinert-Zollinger, 1988). A typical caramel taste and an increased level of furfuryl compounds from sucrose degradation was found in milk crumb

(Ziegleder and Stojacic, 1988). It was shown that the important flavour compounds in milk chocolate stem from cocoa mass, but some additional volatiles were found in milk chocolate which may be sensorially relevant. For example, several δ-lactones and further volatiles such as 2,3-butandione, 1-octen-3-one, and 5-methyl-2-hepten-4-one are present, which probably stem from milk powder or may be generated at the higher temperatures during conching (Schnermann and Schieberle, 1997). In addition, short-chain free fatty acids appear to have some influence on the sensory properties of milk chocolate (Ziegleder, 1997). Milk chocolates have shorter shelf life when compared to plain chocolates. In stale milk chocolates an increased level of short-chain free fatty acids and volatile lipid oxidation products, 3,5-octadien-2-ones, were found (Ziegleder and Stojacic, 1988). As these compounds are formed under the influence of lipases and lipoxidases, there appears to be a residual enzymatic activity, even though the water activity of milk chocolate is very low.

Conclusions

Modern analytical techniques have provided a much greater understanding of the chemical changes that are occurring during cocoa and chocolate processing. They are also able to help the manufacture to optimize chocolate production and quality control.

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Chapter 9

CONCHING

S.T. Beckett

9.1 Introduction: The reason for conching

9.1.1 Flavour development

The flavour of a piece of chocolate depends upon a series of processes being carried out correctly. Conching is the final one of these and is the last opportunity for a manufacturer to obtain the taste required for a particular product. It cannot, however, correct previous errors for example off-flavours from smoke or mould due to poor drying, nor can it make an inferior cocoa taste like a perfect one.

This leaves us to look at what a conche actually does. Cocoa mass, even when the beans have been fermented, dried and roasted correctly, has a very acidic flavour which most people find objectionable. It is the function of conching to remove the more distasteful of these flavours and yet retain the more desirable ones. It is possible to 'over conche' and produce a very bland product. The actual required flavour, and hence the conching time, will depend upon the initial cocoa flavour intensity and the product in which it is being used. In order to shorten conching times the cocoa mass may be pre-treated to remove some of the acidic components (see Section 9.4.5), which leaves the conching process essentially to one of liquefying the material from the previous milling procedure. Alternatively, if the chocolate is being used in a product containing a strong flavour, such as peppermint, it may be necessary to retain some of the acidic notes so that the chocolate flavour is not completely overwhelmed.

The actual physico-chemical changes which take place, as described in Chapter 8, are very complicated and not fully understood. However, the objective of conching is essentially the removal of undesirable flavours, the transfer of flavour components between the ingredients and in certain circumstances the development of more desirable ones to match the final product. The former is particularly important for dark chocolate and is largely dependent upon conche ventilation and conching time. The development of flavour in milk chocolate, will also depend upon the ingredients being used. Those manufactured from milk powder may be heated to obtain

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a more cooked flavour, whereas those starting from crumb (see Chapter 5) already contain a cooked note, although this can be strengthened during conching. This type of flavour development is largely related to conching temperature.

9.1.2 Flow property optimization

In the majority of chocolate manufacturing plants the conche is preceded by a roll refiner or a hammer mill. These grind the chocolate masse to produce a crumbly paste or powder. It is the function of the conche to treat this and turn it into a flowable liquid, which can be poured into a mould or over the product centre.

Fat (both cocoa and cow's butter) makes up less than one third of the weight of the chocolate in a majority of recipes. It is this fat that melts when warm and enables the chocolate to flow into moulds or through an enrober and to have a smooth texture in the mouth. The ground chocolate masse, although containing the majority of this fat, cannot flow as most of the surfaces of the sugar (and non-fat milk solids, when present) are freshly broken and uncoated by fat. The conching process is required to smear the fat over these surfaces, so that the particles can flow past one another. In addition some of the particle form loosely connected agglomerates, perhaps due to the presence of moisture or amorphous sugar on the sugar surface (Niediek, 1970). These too must be broken up by the mixing action of the conche. Some of these agglomerates contain droplets of fat, which must be freed from the surrounding particles and smeared thinly over their surface.

9.2 The principles of conching

9.2.1 Removal of volatiles and temperature control

As was explained in Section 9.1.1 it is necessary to remove some of the undesirable acidic flavours from the cocoa during conching. It has been shown (Dimick and Hoskin, 1999) that the boiling point of many of these components is very much higher than the temperature of the conche, so what is actually happening is very hard to fully explain.

Another volatile that is necessary to reduce during conching is moisture. Water has a severe thickening effect upon chocolate, and very approximately, for every 0.3% of moisture left in the masse (above a level of 1%) a further 1% of fat must be added to compensate for it in viscosity terms. Therefore although water may at first sight appear as a 'free' ingredient, in actual practice, because of the relatively high cost of fat, its removal is often economically very worthwhile. Much of the moisture, below the 1% level, however, is bound into the ingredients for example as water of crystallization in lactose, and so is much less likely to affect the flow properties.

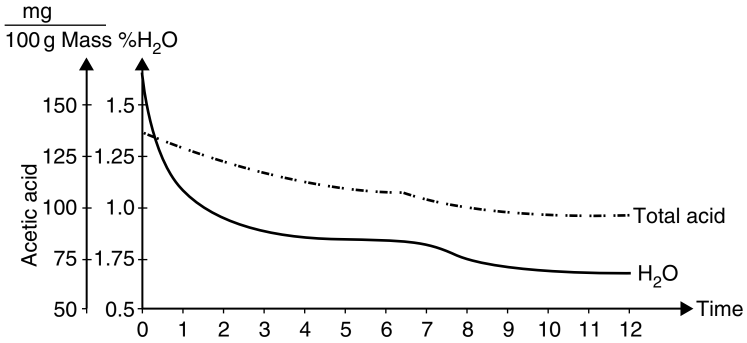

Figure 9.1 Graph showing the changes in moisture and acidity during a conche cycle (time in hours).

Figure 9.1 shows the changes in moisture and total acid during a 12h conching cycle. As can be seen, the majority of the moisture is removed very early on in the conching cycle. This is because much of the moisture comes from the milk components, and once these have been coated with fat, it is much harder for the water molecules to reach the surface of the masse and be extracted from the conche. It is very likely that this moisture removal also has a major effect upon the chocolate taste by 'steam distilling' some of the flavour components. The acidic components however, continue to decrease throughout the conching time and it is possible to over-conche and produce too bland a chocolate.

Adequate ventilation is of paramount importance during conching to enable the moisture and other volatiles to escape. Conche filling is a very dusty and dirty operation and may partially block some of the ventilation ports on a conche. Not only is this a hygiene hazard, but it can also reduce the conches efficiency and may lead to increased conching times. Forced ventilation, using fans to blow or suck air through conches can effectively shorten conching times, when the ventilation area is small relative to the amount of chocolate inside the conche.

The rate of moisture removal will depend upon the temperature of the chocolate masse. A higher temperature not only makes the water molecules in the masse more mobile, but also lowers the relative humidity in the conche for a given air moisture content, thus in turn speeding up the rate of evaporation. It would appear, therefore that a high initial temperature would be beneficial to the conching process. This is not the case, however, as this frequently leads to very high free moisture levels in the conche, which is unable to escape into the room atmosphere. This is instead absorbed by the hydrophilic (water attracting) sugar particles, which will stick together to form large agglomerates (grit). This means that even when a chocolate has been correctly refined/milled the chocolate tastes rough to the pallet. This is especially likely to happen when the air in the conche room itself is very humid or when there are cold, unheated metal parts near the top of the conche, on which the moisture can condense and then fall back into it. Gritty chocolate can best be avoided by having the masse temperature high enough to melt the fat, but not so high as to rapidly evaporate the water at the beginning of the conching cycle. This should be coupled with a high ventilation rate, forced by fans if necessary. The temperature should then be raised once the majority of the moisture has been removed (see Figure 9.1).

The actual maximum temperature used depends upon the ingredients used and the type of taste required for the final product (Chapter 20). If cooked (Maillard) flavours are desired temperatures above 100°C (212°F) may be used. The actual flavour depending upon a combination of time and temperature, i.e. a higher temperature can be used for a shorter time and vice versa. Crumb chocolates frequently contain some of these flavours from their drying process, so may require shorter conching times. For the more milky chocolates, Maillard flavours must be avoided, and the temperature must be kept lower, usually below 50°C (122°F). Some sucrose-free recipes containing sugar alcohols require lower temperatures still, to avoid melting and agglomeration of the particles (Chapter 3).

9.2.2 Fat and emulsifier additions

As was mentioned previously, one of the main aims of conching is to produce the optimum viscosity for the subsequent processing. The actual viscosity can be reduced by adding more fat (Chapter 10), but as the price of the fat is frequently several times that of the other ingredients in the chocolate, this in turn increases the cost of the product. The aim, therefore, becomes one of obtaining the optimum viscosity at the lowest practical/legal fat content. It thus becomes necessary not only to remove the excess water content, but also to ensure that the fats and emulsifiers that are used, have their maximum effect upon the flow properties.

The most commonly used emulsifier is lecithin (Chapter 10), which is hydrophilic (that is it can attract and hold in moisture). In Figure 9.1 it was shown that the majority of moisture evaporates from the chocolate masse during the early part of conching. If a large amount of lecithin is present at this stage it will hold in the moisture and make the chocolate thicker. Similarly excess fat, present in the early stages of conching, will coat the solid particles, making the removal of moisture more difficult.

The actual amount of fat present at the beginning of conching is to a certain extent determined by the previous milling procedure. If the dry milling method is used (Chapter 7), very little fat is present. When a five-roll refiner is used, however, enough fat must be in the masse to prevent the particles being thrown from the rolls and consequently the majority of the fat is already present. In both cases, however, fat is normally added at the beginning of conching. As a general rule, this should be kept to a minimum, but must obviously be sufficient to make the masse thin enough not to stall the conche motor. Fat and emulsifiers added towards the end of conching normally have a much bigger effect on the final viscosity than that added at the beginning. The introduction of the two-roll and five-roll refiner system was frequently able to produce a thinner chocolate than the previous single five-roll system, because the masse being refined had a lower fat content and so more fat could be added later in the process.

The emulsifier used, whether it is lecithin, YN or polyglycerol polyricinoleate (see Chapter 10) should also be added towards the end of the conching process. Some authors (Ley, 1994) believe that high temperatures are detrimental to the effectiveness of lecithin, and that, when conching at high temperatures, additions should only be made when the chocolate has been cooled. Lecithin is also very effective in reducing chocolate viscosity, being approximately ten times as efficient as cocoa butter. Consequently, additions of it into the conche have to be made very accurately. This is often helped by adding it as a mixture with cocoa butter, so that small weighing errors have less effect. Recently, however, metering pumps have become more accurate and suppliers have produced lecithin in a more liquid form, which designed for pumping directly into the conche.

Not only must the fat and emulsifiers be present in the chocolate, they must also coat the sugar and other solid particles uniformly. The efficiency of this coating action depends upon the mixing action of the conche.

9.2.3 The degree of mixing

In order to coat the particles with fat, the conche must move the particles relative to one another within the liquid fat. There are two different types of mixing (Windhab, 1995) (see Figure 9.2):

(1) shear mixing, where the chocolate is between two surfaces moving relatively to one another;
(2) elongational mixing, in which the material is squeezed through or spread over a surface.

Failure to mix the chocolate satisfactorily may not only result in a chocolate which is relatively thick for its fat content, but can also produce an unstable viscosity. This can be the cause of chocolate thickening in storage tanks and giving viscosity readings which change as the chocolate is sheared by the viscometer during the measuring cycle.

9.2.3.1 Shear mixing

In conching this takes place between a moving rotor and the outside walls of the machine. The intensity of the mixing can be quantified by a factor known as the shear rate. In Figure 9.2(a) the two surfaces are moving at a relative velocity of $v_1 + v_2$ and they are separated by a distance h. The shear rate is then defined by

$$\text{Shear rate} = (v_1 + v_2)/h \qquad (9.1)$$

This has the units 1/time and is normally expressed in seconds –1.

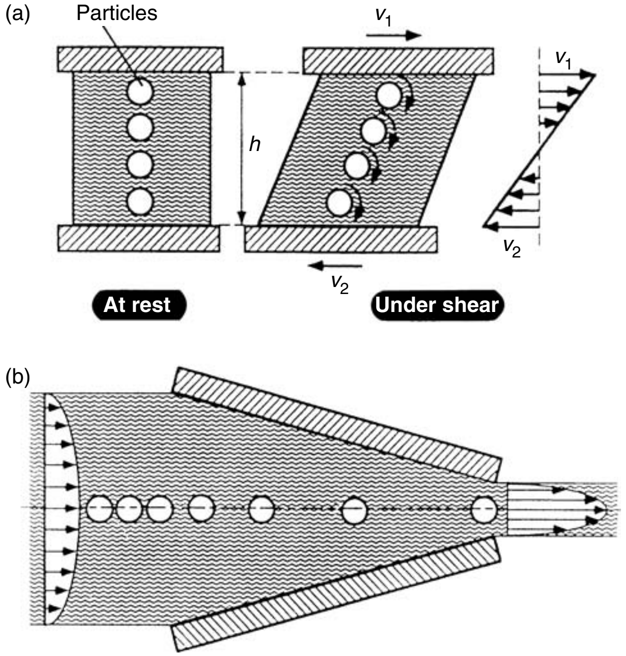

Figure 9.2 Representations of simple shear and elongational flow.

If a chocolate is mixed at a slow shear rate for a long time, the viscosity will come to an equilibrium level and remain there, so any further conching is not worthwhile, other than to bring about flavour changes. If the shear rate is increased this equilibrium viscosity is at a lower value and tends to be reached more quickly (Figure 9.3). Even higher shear rates may produce even thinner chocolate.

What this means for conche design is that higher shear rates, i.e. more work input into the chocolate, produces thinner chocolates. This can be achieved by making the arms of the conche rotate faster or by decreasing the gap between the rotor blades and the conche wall. The former is obviously limited by the size of the motor, especially in the early stages of conching. The latter is limited by engineering precision and the need for a significant amount of the chocolate to be between the rotor and wall. The actual amount of chocolate being sheared by the rotors at any one time, will, to a large extent, determine the conching time. Thus a narrow gap will produce a thin chocolate, but will take a relatively longer time in doing so. There is also little point in having a very large conche when only a very small proportion of the chocolate masse is being sheared at any one time. The ratio of the masse of material being conched to the surface area being sheared is therefore important.

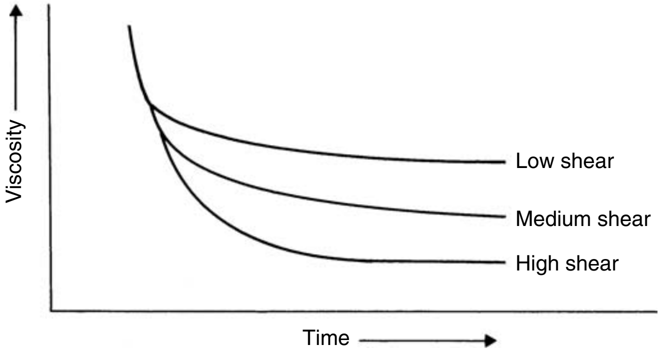

Figure 9.3 Illustration of the change of viscosity with time for conches with different energy inputs.

Another property of high shearing systems is that they produce a lot of frictional heat within the material being mixed. This means that the temperature control system on the high shearing conches becomes more critical, especially if a low-temperature conching is needed for flavour reasons. In this case the ratio of the masse of the chocolate to the area of the conche wall being covered by it, becomes important.

9.2.3.2 Elongational shearing

This action, which is a bit like buttering bread, is also important in that the particles are treated in a different way to that during the simple shearing (Figure 9.2). Some conches are designed to produce this type of shearing during the early part of conching in that they have wedge-shaped ends to their rotors (see Figure 9.4). At the beginning of conching the wedge cuts into the powdery material and smears it along the wall. Once the chocolate has become liquid the rotor is reversed thus producing a higher shearing action within the masse. Other conches (Figure 9.10) use extruder-type screw elements to smear out the chocolate across the conche base.

9.3 The three phases of conching

Traditionally, conching is said to take place in three stages or phases, although not all occur for every recipes and all types of conche. The three phases are:

Dry phase: chocolate masse is crumbly, moisture is removed.
Pasty phase: chocolate is a thick paste, high work input required by the conche.
Liquid phase: high-speed stirring to mix in the final fat and emulsifier additions.

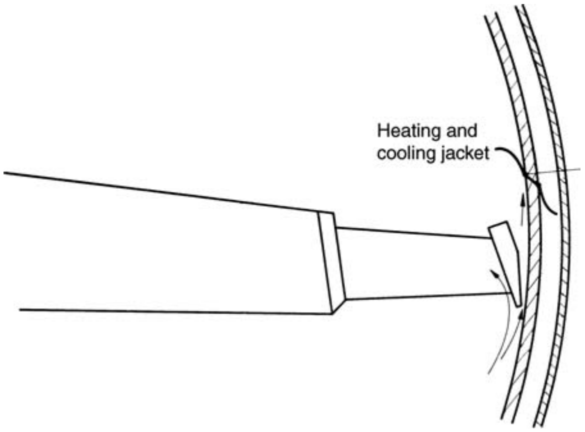

Figure 9.4 The chocolate masse being sheared by rotor arm wedge element against the conche wall.

The power and temperature curves of a traditional conching cycle are shown in Figure 9.5 together with the approximate times of the three phases.

9.3.1 Dry phase conching

The feed material normally enters the conche as a powdery material. Frequently a small amount of fat (approximately 1%) is placed in the conche at the beginning of filling. This together with the mixing action and rising temperature soon turn it into a crumbly masse.

At this stage it is relatively easy for moisture to escape provided that the conche is well ventilated. The initial moisture content of many milk chocolates is about 1.6% and if possible this must be lowered to less than 1%. Some authors (Ley, 1994) suggest that the viscosity continues to reduce even to a moisture content of 0.6%. Below about 0.8% however, the moisture becomes very much harder to remove, and it may not be economically viable to do so.

As was mentioned earlier this moisture takes with it many of the unwanted flavour compounds. For dark chocolate, however, the initial moisture may already be below 1% and care most be taken to avoid the chocolate picking up moisture and becoming thicker. It is very undesirable to conche dark and milk chocolate in the same room in open conches, as the transfer of moisture and flavour volatiles between the two can give rise to unpleasant flavours and thicker dark chocolate. The temperature must, of course, be increased slowly to enable the moisture to escape and minimise the risk of the formation of agglomerates.

As can be seen in Figure 9.5, as the filling progresses the electrical current drawn by the conche increases and it, in fact, continues to do so throughout

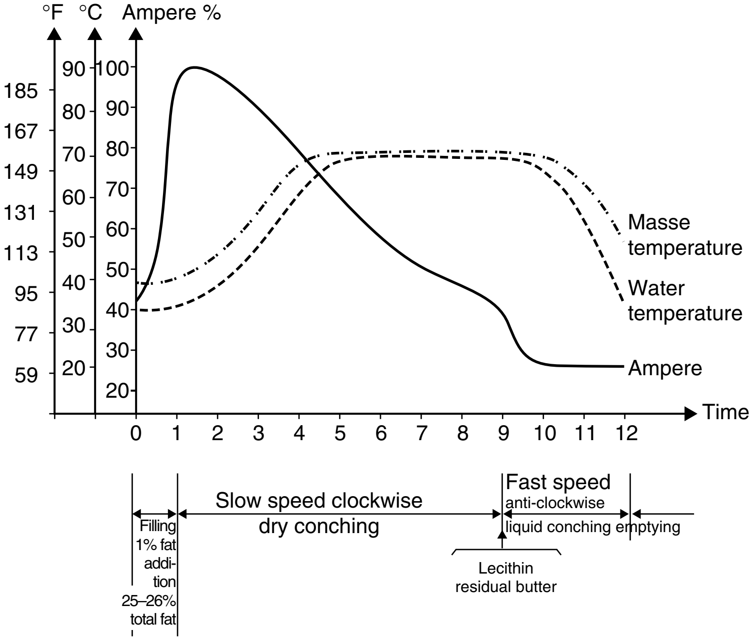

Figure 9.5 Graph showing the changes in conche amperage and water and chocolate masse temperature during a conche cycle (time in hours).

the dry conching phase. This is because the crumbly chocolate is becoming more pasty. This often starts with the formation of small balls 1–4 cm in diameter (0.5–2 in.) on top of the masse. Sometimes large lumps attach themselves to the mixing elements as the masse becomes more pasty, and in exceptional circumstances the whole masse can turn with the elements, resulting in no mixing taking place. This can be off-set by changes to the temperature and/or fat content.

With certain conches the motors are not sufficiently strong to continue operating as the power increases and fat and emulsifier additions are made very early on in the conching cycle to turn the chocolate masse into a thin paste or liquid. In this case there is little or no dry conching, normally, however, this results in a relatively high viscosity chocolate at the end of processing.

9.3.2 Pasty phase conching

The energy put into the chocolate by the mixing action towards the end of the dry conching and at the beginning of the pasty phase is often so high that the temperature rises rapidly. The water jacket temperature, therefore, has to be several degrees lower than the chocolate, in order to maintain a steady increase to the required conching temperature. The latter has a large effect on the final chocolate flavour, and so must be controlled carefully in

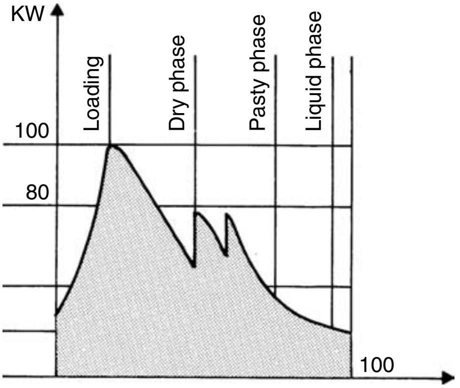

Figure 9.6 A graph illustrating a typical conche power amperage during the three stages of conching (conche with two speeds and reverse direction operation).

order to manufacture a reproducible product. This is particularly critical during the pasty phase, when thermostatic water jacket controls, capable of reacting to sudden temperature changes, should be used.

Once the chocolate has become pasty, the viscosity starts to fall, in part due to continued moisture removal and also because many of the solid particles are now being coated with fat. The actual final viscosity, however, is partly dependent upon the amount of shear/work that can be put into the chocolate (see Section 9.2). In traditional conching however, such as is illustrated in Figure 9.6, this shear energy input (as denoted by the conche amperage) falls steeply as the chocolate becomes thinner. This can only be off-set by increasing the shear rate. This can be done by increasing the speed of the mixing elements or changing the elements themselves. Figure 9.7 shows the power curves of a conche which has been fitted with a servo-mechanism which changes the speed as the viscosity changes to give a uniform power input.

In order to develop a cooked flavour within a chocolate it is necessary to reach a certain temperature for a given time. Within limits it is possible to raise the temperature and shorten the time and vice versa. The same is true for conche power input, and if the power is increased, shorter conching times are possible (Figure 9.7). Once the final additions of fat and emulsifier have been made, however, the chocolate becomes very thin and it is very difficult to put a significant further amount of shearing energy into the chocolate.

9.3.3 Liquid phase conching

This phase can be very short and is required to mix in the final recipe additions. Sufficient time must be allowed for the viscosity to reach an

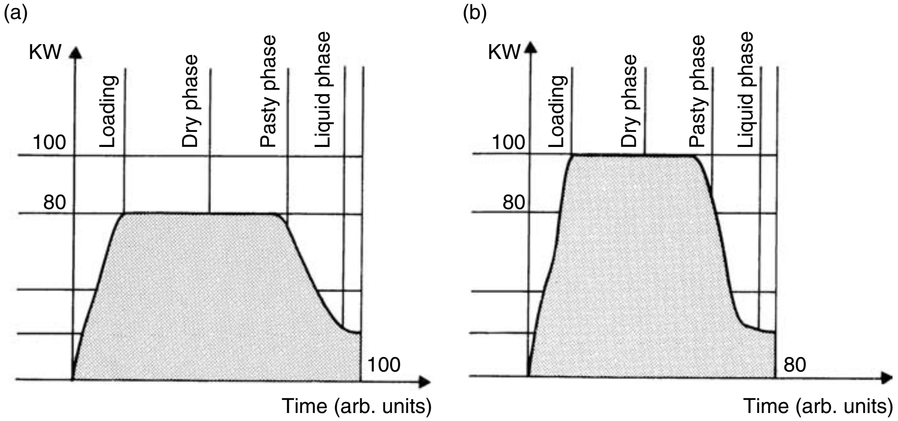

Figure 9.7 A graph illustrating the conche power amperage during the three stages of conching, when the motor speed is continuously adjusted according to the chocolate viscosity. (a) Lower power motor; (b) higher power motor.

equilibrium. As there is little change in flavour or additional work input, however, there is little reason for extending this stage. Recent research has shown a very big consumer preference for chocolates processed with a long dry conching phase compared with ones which were conched for a similar length of time, but with a long liquid phase (Beckett, 2006).

When conching at a high temperature, additional time may be required to enable the chocolate to cool before the emulsifier is added, as some authors have found that lecithin is less efficient when added to chocolate hotter than about 60°C (140°F).

The conche is the last major processing stage before the chocolate is used for moulding or enrobing etc. These processes require a consistent viscosity and some adjustment may be required. One approach is to place a viscometer in the discharge pipe from the conche, and then make the necessary fat or emulsifier additions in the storage tanks. An alternative solution is to monitor the conche electrical power curves and use these to make fat adjustments into the conche during the liquid phase (Mars, Incorporated, 1994). Frisse provides a viscometer, which can be fitted inside a conche. This operates by measuring the damping of mechanical oscillations and can give continuous readings, which are recorded by the PC control system.

9.4 Conching machines

9.4.1 History

Although the Mexican grinding stones were used to mix the cocoa, the first real conche can be attributed to Rudi Lindt who invented the longitudinal

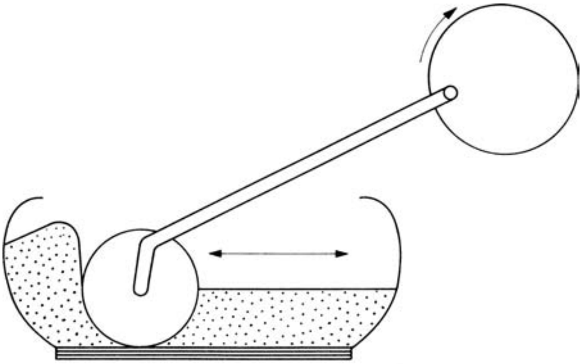

Figure 9.8 Longitudinal conche.

in Switzerland in 1878. The machine getting its name from the shell, whose shape it resembled. Lindt noted that continuous movement by the granite rolls (Figure 9.8) pushing the chocolate backwards and forwards, over very long periods, produced a smoother chocolate with a modified flavour. The smoothness may have been in part due to particle breakage, given the poorer milling equipment that then existed. Current conching is almost entirely chemical change and liquefying, with any particle size change being restricted to the breaking or formation of agglomerates.

The longitudinal conches were normally constructed of granite, and were capable of producing a very good chocolate flavour. So much so, in fact, that for many years some producers would not use metal processing machinery for fear of spoiling the flavour. Normally these machines are made up of four connected troughs each capable of holding 100–1000 kg (220 lb^{-1} tonne). The rollers are driven by connecting rods at a frequency of 20–40 rpm, during conching times of up to 96 h.

The longitudinal conche has several disadvantages, one of the main ones being that it is unable to dry conche. Because of the large angle between the trough and the grinding roll, only pasty and semi-liquid masses can be fed into the conche. Powdery flake compacts and would probably damage the machine. The lack of dry conching means that the particles are already largely coated with fat and so the removal of moisture and other volatile flavour components is relatively slow, leading to the long conching times. Recently, conching trials were performed, which included a longitudinal conche, in a Swiss museum. The dark chocolate refiner flake was produced at a chocolate company and divided into two parts, with one part being transported to this museum. The remaining half was conched in a modern high-performance conche in a chocolate factory. The degree of conching of the finished chocolates was estimated via flavour analysis using the methods described in Chapter 8 (Ziegleder *et al.*, 2003). With a total conching time of 24 h the longitudinal conche showed a very low conching degree in comparison to the modern conche (Balimann *et al.*, 2006). These results were confirmed by the sensory tests on the finished products using coded chocolate bars. The average of the twelve industrial panels showed a clear preference of the chocolate produced in the modern conche. Generally, the degree of conching seems to correlate with the energy input (Ziegleder *et al.*, 2005). As energy input into the historical longitudinal conche was relatively low, long conching durations of about 72 h were often used in former times.

Although the energy input into the chocolate is low, these conches have a very high energy consumption, relatively small filling capacity and poor temperature control, and so have normally been replaced, often by a batch rotary conche (Section 9.4.2).

With the increasing demand for chocolate there has been many developments to try to reduce conching times. As grinding is a continuous operation, as are most chocolate usage processes, some conches have also been designed to operate continuously (Section 9.4.3). Where a single formulation is being used, this can have advantages, but difficulties can be encountered with frequent recipe changes, unless the conching time is very short (when the amount of partially conched masse is therefore also very small).

Another method of reducing conching times involves separating the flavour development and the liquefying parts of the process. Usually this involves pre-treating the cocoa mass in what is sometimes known as a mass or liquor conche (Section 9.4.4) followed by a machine capable of producing an intense shearing action (Section 9.4.5).

Chocolate manufacturing machinery is expensive, and this has led to the construction of large high throughput plants (as with cocoa liquor, Chapter 6), often supplying a number of factories. An alternative approach, often used when smaller amounts of certain types of chocolate are needed, is to use a single stage chocolate making plant which combines both grinding and conching (Section 9.4.6).

9.4.2 Batch conches

Historically there have been a large number of conche designs, and because of their robust construction many conches several decades old are still operational today. In fact even in the mid-1990s only about 100 new conches were installed world-wide each year (Müntener, 1996). It is, however, impossible to describe all the conches in detail and this chapter will be restricted to reviewing the different common types of design found in many factories.

9.4.2.1 Horizontally stirred rotary conches

Many of the conches, which replaced the original longitudinal conches, had round chambers inside of which paddles or scrapers turned around a vertical shaft. Hence the name rotary conche. This design became more complicated with Bauermeister producing a conche with two troughs inclined at an angle of 45° and HMS adding a series of rotating mixers to each rotating shaft.

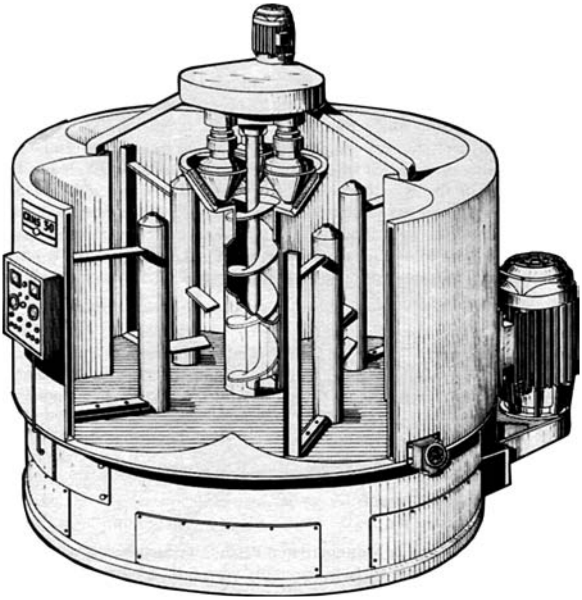

Figure 9.9 Carle–Montanari Clover conche (Carle & Montanari SpA).

One of the most widely used conches, which was developed on this principle, was the Carle–Montanari Clover conche shown in Figure 9.9. This consists of a clover leaf shaped, heatable outer container and a conical inner trough. The chocolate masse is initially mixed in the outer container until it becomes sufficiently pasty to be able to be transported into the conical inner trough by a conveying worm. Here the tapered granite rollers provide an intensive shearing action by running against the conical inner wall and throwing the masse against the wall of the outer container, where scrapers provide further shearing and viscosity reduction. As the chocolate is thrown between the two containers it has a large surface area exposed to the air. This means that, provided there is a good airflow in the conche vicinity, moisture and flavour volatiles are readily removed. This type of conche is able to carry out all three phases of the conching process and models with capacities of up to 6 tonnes have been produced.

In Section 9.2.3, it was noted that there are two very different types of mixing action, i.e. shear and elongational. One machine, which exploits this, in order to reduce the mixing time, is the Petzholdt model PIV-HLC conche. (Figure 9.10). The previous PVS design had the traditional circular container and horizontal mixers. This was supplemented by a homogenizing spraying arrangement, which operates during the pasty phase. By spraying the chocolate in a thin film, it was possible to greatly increase the surface area and increase the removal of volatiles. In the PIV-HLC model the traditional stirrer mixing is added to by inter-leaving mixer worm screws which act in

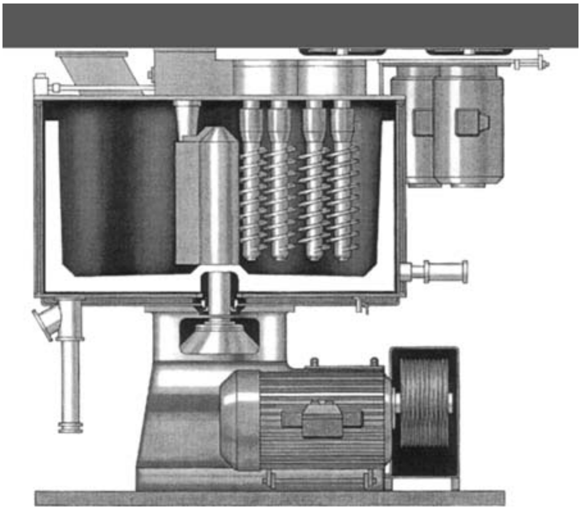

Figure 9.10 Petzholdt PIV-HLC conche.

the manner of an extruder (Chapter 17). These are suspended in the vessel from above and set up parallel to, but off-centre with respect to the central axis of the conche chamber. The main shearing elements force the masse at right angles into the worm screws. These then force the masse downwards where it is subjected to a smearing shearing action against the base of the conche. The chocolate is therefore subjected to two very different types of shearing action.

The processing cost per tonne of chocolate has been shown to depend upon conche size. The smaller conches tend to be relatively more expensive in terms of machinery price, whereas the larger ones require a longer conching time. For this type of conche, Petzholdt have calculated the optimum capacity to be between 4 tonnes and 6 tonnes (Holzhäuser, 1992).

Although both the Carle–Montanari and Petzholdt conches exist with capacities up to 6 tonnes, many of the early horizontally stirred rotary conches were of low capacity (in general up to 1 tonne) and had poor temperature control, so most conche manufactures changed their designs to produce vertically stirred models.

9.4.2.2 Vertically stirred rotary conches

Once again many different designs exist, most having two or three chambers containing mixer/scraper arms rotating about horizontal shafts (Figures 9.11 and 9.12). These arms can be overlapping or separate, and can be the same or of differing sizes.

As the arms turn, they lift the powdery chocolate masse into the air. It then drops under a combination of centrifugal force and gravity back

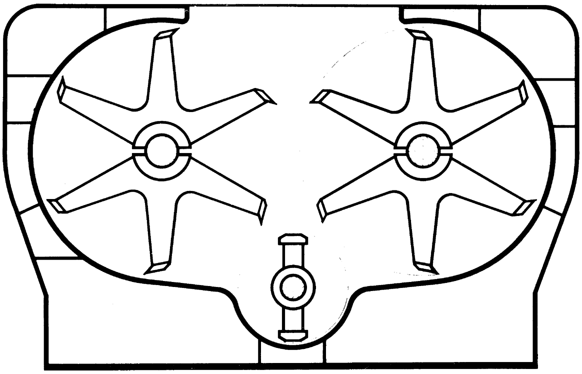

Figure 9.11 Thouet DRC conche (Thouet KG Maschinenbau).

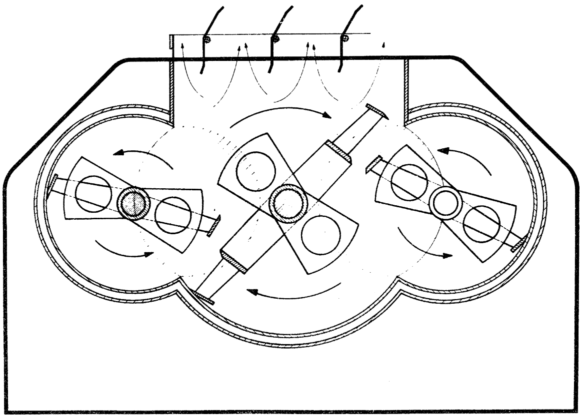

Figure 9.12 The Frisse conche (Richard Frisse GmbH).

into the bottom of the conche, from where it is moved back around by the mixing arms again. At this stage the masse is well aerated and so it is easy for the moisture and volatile flavour components to escape, provided that the conche is well ventilated with low relative humidity air.

The early part of conching is critical in obtaining a low viscosity chocolate. Because the masse from the refiner or mill has a density which is very much lower than that of the finished chocolate (approximately half (Anon., 1997)) the chocolate masse tends to build up within the conche and reduce the ventilation. In addition the power on the motor increases as the chocolate becomes more and more pasty. In many modern conches the motor has multiple or continuously variable speeds, which enables the rotors to slow down to avoid overload. In older models it is often necessary to add some fat or lecithin to reduce this peak, or to decrease the rate of filling.

The former tends to produce a thicker chocolate, owing to the increased difficulty in removing moisture and in putting shear energy into a lower viscosity masse.

Once this initial power peak has started to decrease, it is desirable to increase the power being put into the masse by the conche. There are several ways of doing this, with many current machines being servo-controlled to increase the speed of rotation of the mixing shafts in order to obtain a constant power usage (Figures 9.6 and 9.7). Some conche designs reverse the direction of movement in order to increase the energy input, when the chocolate has become thin enough for this to take place.

The vertically stirred conches normally have a very good temperature control. This is especially necessary when high power motors are used, as these develop much frictional heat within the conche, which may be undesirable for flavour reasons. Various methods are used to improve heat transfer. This is normally needed for heating at the beginning of conching, to melt the fat in the refiner flake, and then cooling once the shearing/heating becomes dominant. These include designing the conche chamber to maximize the area through which the heat can be transferred, ensuring that the surface is well scraped – chocolate is a very good insulator for heat – and ensuring a rapid change of water in the conche jacket. This is particularly important during the cooling stage at the end of many conching programmes. The liquid phase can take a significant length of time, although having a negligible effect on the chocolate flavour and a minimal one on the viscosity.

The demand for shorter processing times, coupled with the need to retain the same flavour and flow properties of the chocolate, has led to the use of high-speed mixers as conches. An example is manufactured by Lipp Mischtechnik of Germany (Figure 9.13). In order to achieve a high shear rate, the outer container and shearing arms are machined to a high tolerance, so that the gap between them is reduced.

In equation (9.1) it was noted that the shear rate is inversely proportional to this gap, so the rate of shearing is high. The ratio of surface area to masse of chocolate is also higher than for many traditional conches, thus improving heat transfer and temperature control. Forced ventilation is necessary for moisture removal and volatile extraction. By designing the mixing elements so as to cover a relatively high proportion of the surface, a higher proportion of the chocolate is being sheared at any one time, than in many traditional machines. The lecithin and fat additions are fed through very highly shearing devices set into the sides of the mixer/conche.

There are other single shaft conches available such as the Bühler Company's Frisse ELK conche (Figure 9.14). With this type of machine the attachments to the mixing arms can make a big difference to its performance, as these attachments/tools must carry out three operations namely: mixing, shearing and aeration/drying. Figure 9.15 shows the mixing arm of a Frisse ELK conche was developed to perform all three operations.

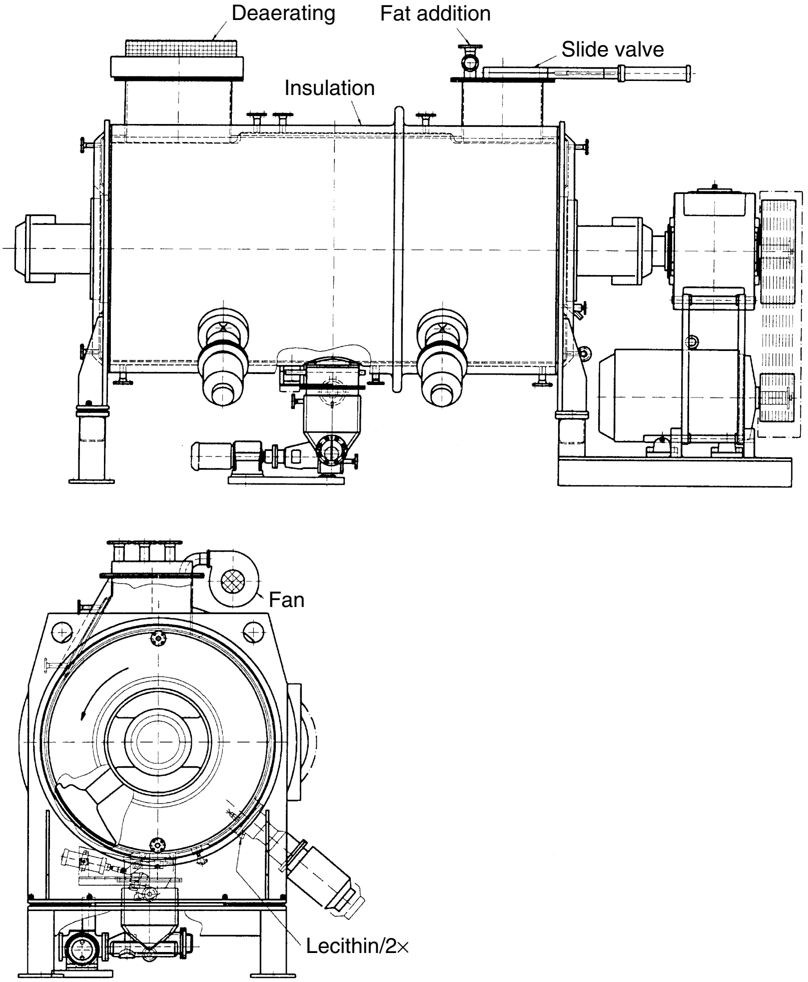

Figure 9.13 The Lipp shear mixing conche.

The point of the rotating shovel almost touches the cylindrical wall of the trough whereas the wider end of the shovel turns further away from the wall. The wide end of the shovel is bent in such a way that when the arm is turning with the wide end forwards, the chocolate masse is pulled into the gap between it and the cylindrical wall. This gap decreases rapidly towards the point. After filling with refiner flake, the machine runs in the direction of point forwards for one or two hours. This fluidizes the chocolate masse removing moisture from the flakes, as they are flung into the air.

The masse then changes into a paste. When this reaches a predetermined softness the software automatically changes the direction of motion, so that the shovels turn with the wide end forwards. High shearing occurs as the

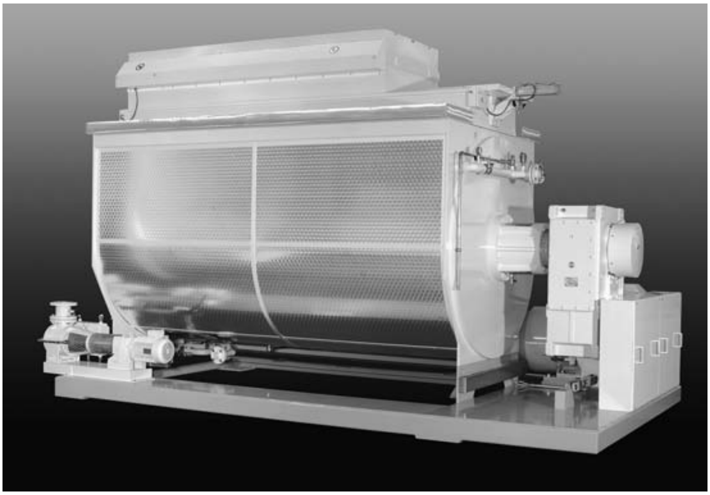

Figure 9.14 Frisse ELK conche. See Plate 5 for the colour image.

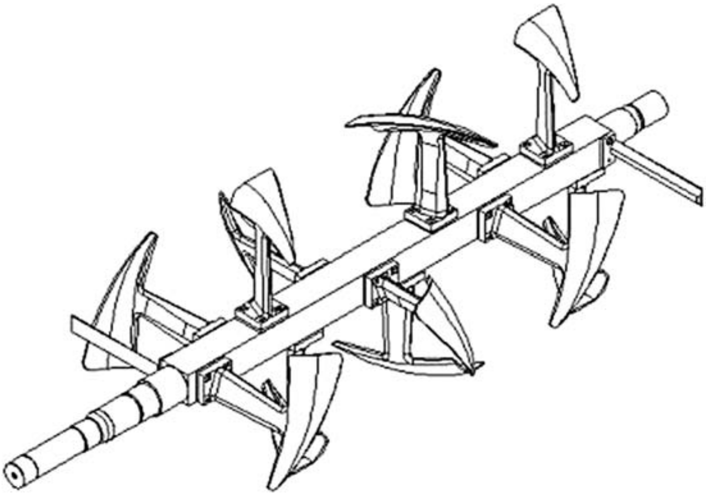

Figure 9.15 Illustration of mixing shaft of Frisse ELK conche.

product is squeezed between them and the wall. This aids the transfer of flavours between the different ingredients (as was described in Chapter 8) as well as producing a viscosity that is the same as for the three shaft conche when processing the same recipe.

9.4.3 Continuous conches

The grinding of the chocolate masse by both roll refining and dry milling is a continuous process, as are many of the usage operations. It therefore would appear desirable from an operational point of view to have a continuous conching procedure. Two distinct types of continuous conches have been developed. In one the chocolate is passed from one container to the next, each one capable of giving an increased rate of mixing/shearing. These machines are usually capable of a relatively long conching time and can be used on lower fat chocolates. Because they contain a relatively large amount of chocolate, however, they are best suited to factories where a limited number of chocolate recipes are manufactured.

In many of these conches only a small proportion of the chocolate is being mixed at any one time. An alternative approach is to take a smaller amount of chocolate and mix it intensely for a much shorter time. These short dwell time conches contain very little chocolate and so are suitable for situations where a large number of different recipe chocolates are manufactured.

9.4.3.1 Larger volume continuous conches

One of the earliest continuous conches was developed by co-operation between Cadbury UK and the Tourell Conche Manufacturing Company.

9.4.3.2 Tourell conche (Figure 9.16)

This consists of an arrangement of horizontal troughs with stirrer/mixing elements. These move the product through the trough until it reaches a barrier (weir) at the output end. The product falls over this barrier and is

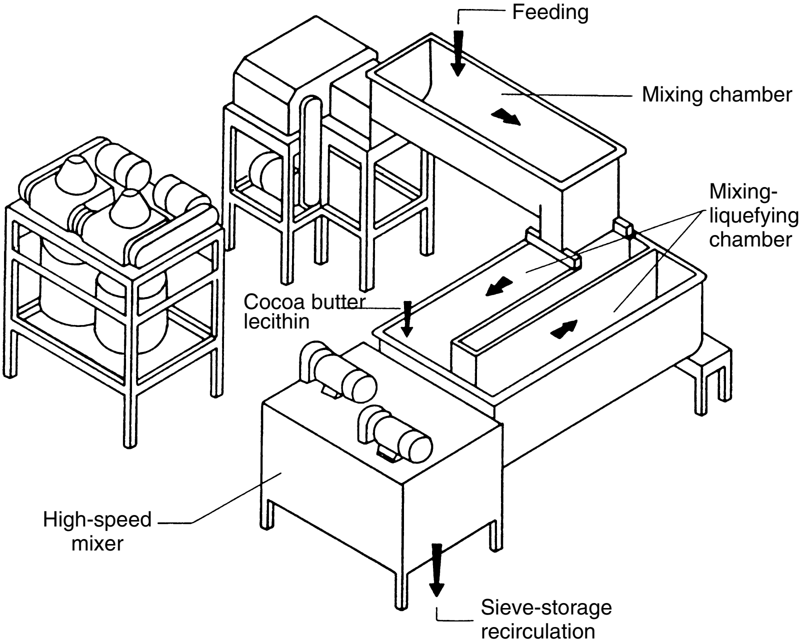

Figure 9.16 The Tourell conching system.

pumped into the next section. The height of the barrier gives some control over the residence time of that stage.

The stirring paddles of the first trough are arranged on two parallel shafts and work in opposite directions. This results in a high mixing and shearing action required to plasticise the dry crumbly masse from the feed hopper, before it is discharged into the second section. Here the paddles may provide a relatively low shearing and transport action. In the subsequent stages the shearing is increased at each stage, usually by counter-rotating shafts. The actual number of troughs used may be as high as 5 or 6, with the lecithin being added in the final, liquid conching stage. The transit time depends upon the feed rate, barrier height and number of troughs, but normally varies between 2 and 8h. The capacity of a Tourell line is normally above 3 tonnes per hour, making their use mainly restricted to the larger chocolate manufacturers.

Two other machinery manufacturers, Thouet and Frisse, have developed continuous systems based on their batch conches. Some manufacturers also use this type of conche in a batch/continuous mode, in which the masse is turned into a paste in the normal way. It is then passed through one of the continuous high shearing devices described in Section 9.4.5. Two or more conches feed a single liquefier to give a continuous supply of chocolate.

9.4.3.3 Thouet continuous process

This system is based upon the Thouet DRC conche (Figure 9.11) with the small central mixer removed. The positioning of both large rotor arms has also been moved so that they overlap each other. This reduces the back to front movement of the material in the conche. The machine is initially filled with flake from the refiner and the dry and pasty conching stages carried out as for the batch process. The feeding continues, however, and the conche is then continuously emptied from the front at a rate equal to the feed of new refiner flake into the back of the conche. Thus, a continuous dry conching process is started. The partially processed conche masse is fed into an extruder type of device, for the pasty and liquefying stages and where the remaining fat and lecithin are added. The mixture is then sheared to produce the final viscosity. The residence time is governed by the feed rate from the roll refiner and is normally about 3–6h.

9.4.3.4 Frisse continuous process

Here the conche is divided into several sections by dividing walls or weirs. As each becomes full with chocolate, it flows over the weir into the next section. The liquefying is carried out in two separate shearing devices, with one filling as the other is liquefying the chocolate.

9.4.3.5 Short dwell time continuous conches

This type of conche operates by intensively shearing a relatively small amount of chocolate for a few minutes. Extruders have been used in this process and are described in more detail in Chapter 17.

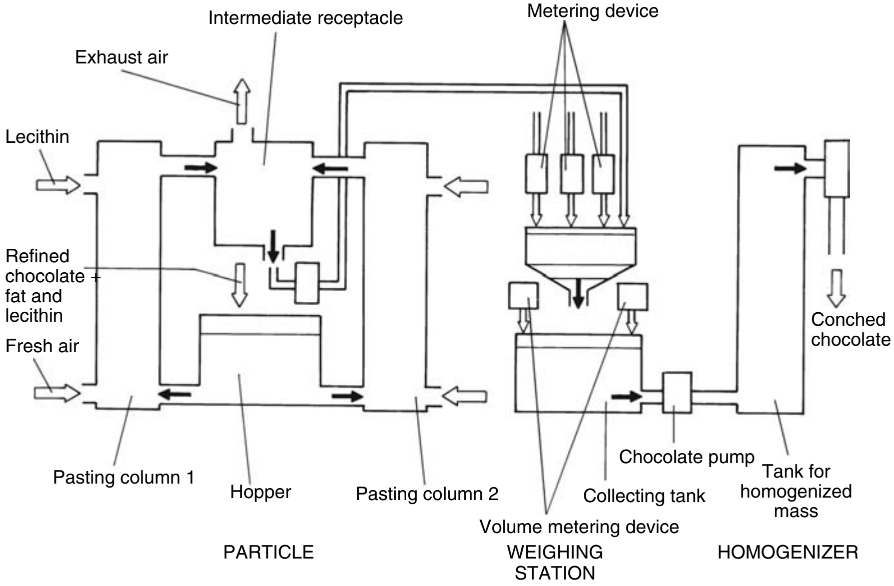

Figure 9.17 The Heidenauer HCC continuous conche.

9.4.3.6 Continuous HCC conche

One example is the Petzholdt Heidenauer HCC range (Bauermeister, 1996), which is capable of operating at throughputs of about 1 tonne and 5 tonnes/h. The method of operation is illustrated in Figure 9.17, although most commercial systems have two or more high-intensity shearing columns.

The roll refiner flake or milled masse enters a stirred hopper, from where it is taken by a variable speed feeding screw into a high shearing column, called a paster. Small amounts of lecithin or fat may be added at the screw stage, if necessary, with the screw itself providing the mixing/kneading action required to blend in these components.

Each column is fitted with adjustable baffles, fixed to the inside wall and shearing 'wings' attached to the central rotating shaft. These both subject the masse to an intensive shearing action and also help to transport it towards the top of the column. As central shaft rotates between 600 rpm and 1200 rpm, the temperature of the column is maintained at the required conching temperature by the surrounding liquid circulation jacket. During the shearing, conditioned air is passed up the paster column to remove moisture and other volatile components. The paster converts the crumbly masse into a viscous paste. This in turn is converted into a liquid by the addition of a small amount of lecithin at the top of the column, coupled with further mixing in stirred scraped tank.

This tank feeds a weighing station, where the remaining fat and/or emulsifier additions are made. The liquid conching phase is then performed in a liquefier, consisting of a column containing a rotating vertical shaft, with horizontal mixing bars.

The total conching time is usually of the order of 15–20 min, of which 4–5 min are required for the paster. This relatively short time is possible, because unlike many large batch conches, almost all the masse is being intensively sheared the whole time it is within the paster. The short time also means that relatively little chocolate is being processed at any one time, which is an advantage when changing recipes. This also means that the machine needs less floor space and has a lower floor loading than a conventional conche with an equivalent throughput.

9.4.4 Cocoa mass (liquor) treatment devices

The aim of all these devices is to perform the flavour changes required for the chocolate and so leave the remaining conching process to one of liquefying. In doing so, it may be possible to optimize both procedures and to greatly reduce the time required to conche the chocolate.

Most devices operate on the principle of producing a thin film of cocoa mass, thereby producing a large surface area from which the volatile components can be evaporated and removed. Care must be taken not to remove the desirable flavour components together with the highly acidic ones and also to control the temperatures (normally below 100°C (212°F)) to avoid a secondary roasting effect. Thermal damage, which has occurred during roasting, cannot be reversed in these machines. Frequently, water is added to the cocoa mass, so that when it is evaporated it steam distils many of the more acidic flavour components such as acetic acid. Most processes operate continuously and the required operating conditions can be determined using techniques such as gas chromatography.

The following treatments and processes are examples of those being operated by chocolate manufacturers: (i) Petzomat Treatment; (ii) Convap treatment; (iii) Carle–Montanari process.

9.4.4.1 Petzomat STC treatment (Figure 9.18)

A Petzomat system consists of one or more spray columns, depending upon the required throughput. The cocoa mass, in the form of a turbulent-spray thin film, falls down the column as hot air is blown upwards. This counterflow principle ensures that the mass loses its moisture (and added water) and other volatile components to the air. If sterilization or the removal of bacteriological contamination is required, the Super-Petzomat is used as a pressure reactor in an additional stage of treatment. Secondary roasting can also take place, in cases where the initial mass has been under-roasted.

Individual possible processing steps for the cocoa mass are:

(1) Dosing and injecting water or flavour-enhancing solutions for example sugars
(2) Pre-degassing and deacidifying

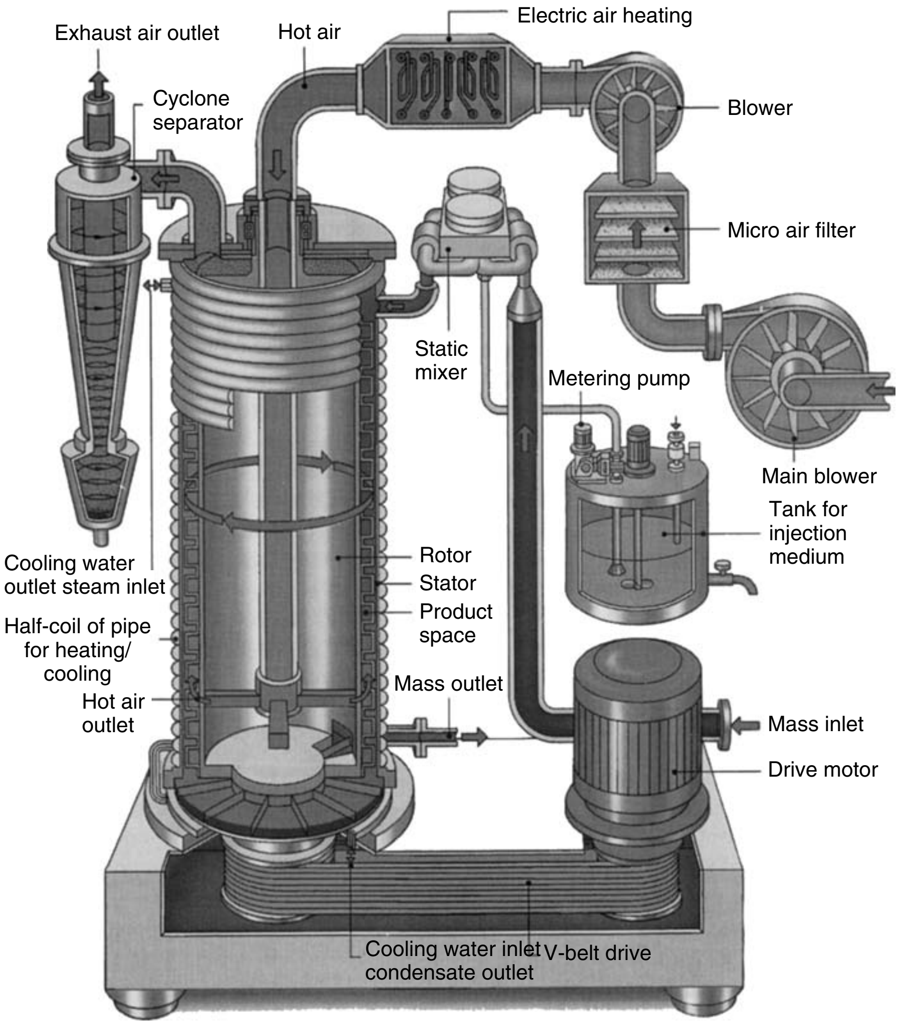

Figure 9.18 Petzomat mass roasting system (Petzholdt Heidenauer, Germany).

(3) Sterilization
(4) Roasting
(5) Cooling.

Typical throughputs are 1000–15 000 kg/h (1–1.5 tonnes/h). The Petzomat can also be used to produce cooked or caramelized flavours in milk chocolate by the chocolate liquor-milk powder-compounded (CMC) process. In this milk powder, cocoa butter and pre-treated cocoa mass are mixed with up to 5% of sugar before being processed in a modified Petzomat column.

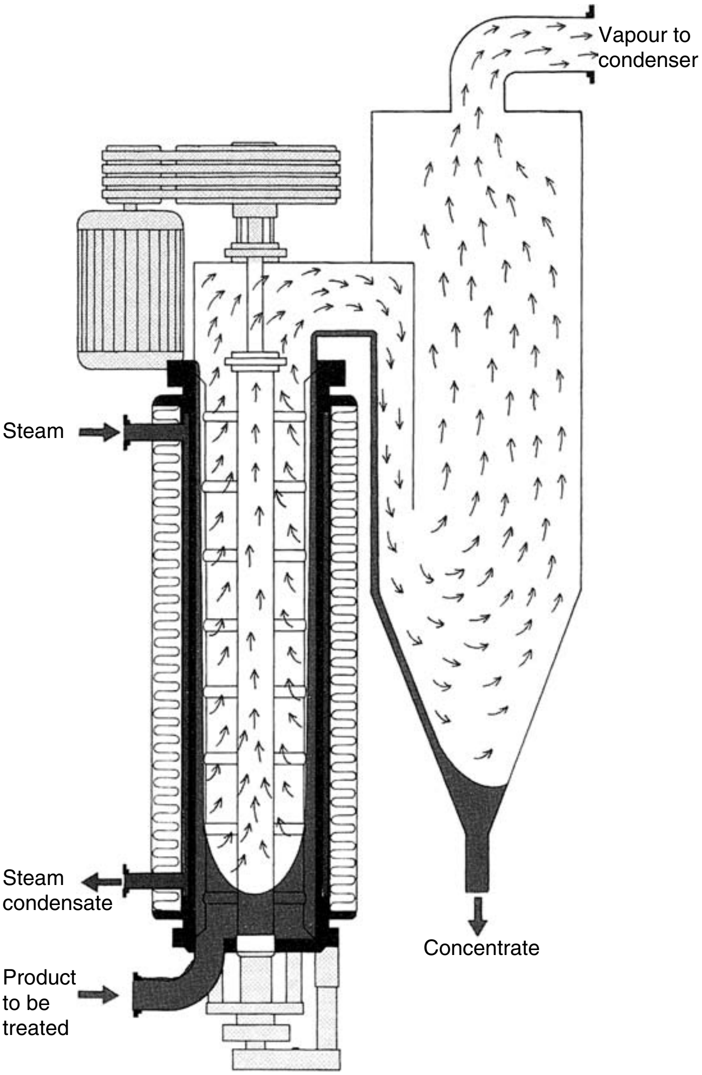

Figure 9.19 Schematic representation of the Convap thin film evaporator (The Contherm Division of Alfa-Laval Inc.).

9.4.4.2 The Convap treatment

The principal component of this process is a thin-film evaporator (Figure 9.19). Water, with or without flavour modifying compounds dissolved in it, is thoroughly homogenized with the cocoa mass before being fed into the evaporator. Owing to the centrifugal effect of the rotor, the cocoa mass is thrown on to the precisely machined inside wall of the machine, from where it is removed by sharp scraper knives. This produces a very thin film which rapidly comes to the wall surface temperature, before being removed and replaced by another film. The Convap can operate under pressure or vacuum. When using the latter, care must be taken to ensure that the good flavour components are not removed together with the undesirable ones. A number of manufacturers produce this type of machine, with typical throughputs being of the order of 750 kg/h (0.75 tonne/h) per cylinder/column.

The Carle–Montanari PDAT process (Meursing and Zijderveld, 1999).This differs from the thin-film evaporator approach in that it is a batch process. The temperature-controlled cylindrical reactor (autoclave) is equipped with centrally arranged pawl pumps and a stirrer. Volumetrically controlled inputs are provided for water, sugar and alkali solutions, inert gas and roasting air. Possible processes include: pasteurization, deacidification, alkalization, flavour development and roasting. Milk can be added to produce a 'crumb'-type flavour in chocolate. The batch operation enables processing conditions to be changed according to the quality of the mass being treated. The treatment cycle is usually about 1 h and capacities range from 500 kg to 2000 kg (0.5–2 tonnes).

9.4.5 Liquefiers

These machines have been designed to produce as low a chocolate viscosity as possible in the shortest possible time. Most are in-line high shearing devices, with little or no flavour change. One batch/continuous process, designed by Petzholdt (Figure 9.20), does however allow for some flavour modification, when untreated ingredients are used.

9.4.5.1 The Petzholdt PIV intensive treatment unit

When this unit is used with pre-treated mass it is possible to reduce the treatment time to 1 h for a 10 000 kg (1 tonne) vessel. Normally, a PIV system consists of two or more reaction vessels. This enables one vessel to be filling as others are liquefying or emptying – thus giving a batch/continuous mode.

As with the PIV-HLC conche (Figure 9.10) an 'anchor' stirrer forces the masse at right angles into interleaving worm screws. In the early stages of conching, fat additions are made automatically to match the viscosity to the power of the drive motor and so give the maximum work input for that system. Subsequently, as with many other conche designs, the rate of shearing of the stirring elements is automatically controlled to match the chocolate viscosity. In this case, however, the three-armed 'anchor' stirrer can be controlled independently of the twin screw elements. Hot air can be blown over the top of the vessel, if required to aid the removal of moisture and other volatiles.

9.4.5.2 In-line high-shear devices (Figure 9.21)

In this type of device the chocolate is pumped through a tube through the centre of which runs a shaft capable of high-speed rotation. At right angles

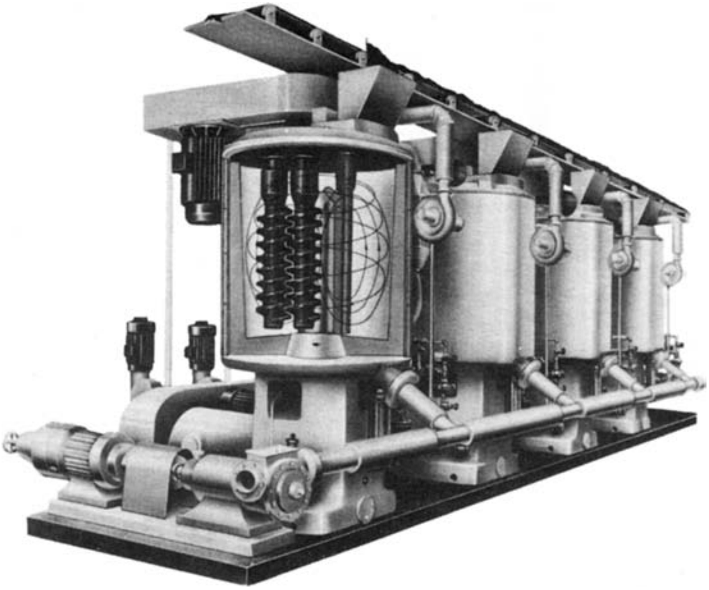

Figure 9.20 Petzholdt high-intensity short-dwell PIV 4000 conche (Petzholdt Heidenauer Maschinenfabrik AG).

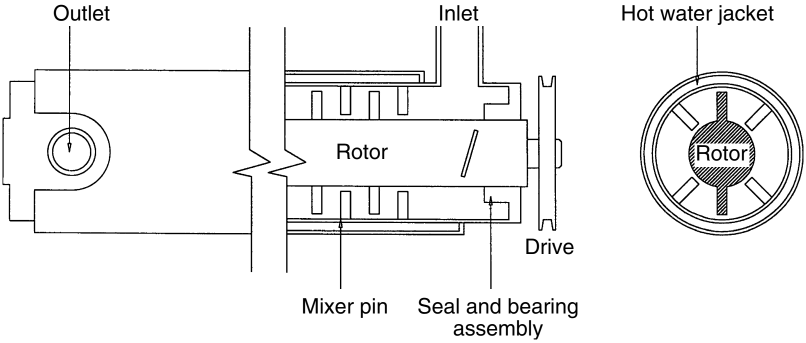

Figure 9.21 Illustrative diagram of in-line liquefier.

to the shaft are mixing bars or elements, and on some models static elements are attached to the outer walls to increase the mixing action. As there is no ventilation, there is little taste change, other than the possible introduction of cooked notes. Most designs, however, have efficient cooling jackets capable of stopping this happening.

Another design by Lipp Mischtechnik (Figure 9.22), has a rotor which forces the chocolate out through holes in the side of the mixer, thus helping the break up of agglomerates and adding a high degree of elongational mixing (see Section 9.2.3) to the high-intensity shearing.

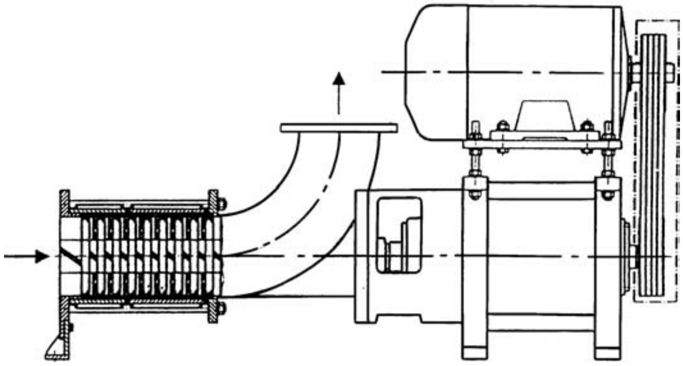

Figure 9.22 Schematic diagram of Lipp in-line liquefier.

These devices are able to rapidly reduce the viscosity, because almost all the particles inside them are being constantly sheared for several minutes. The liquefier can be placed either during, or after the conching process or may indeed replace it altogether.

In the Carle–Montanari Homega conche, during the pasty and subsequent liquid phase, it is possible to use an in-line liquefier, known as a conching accelerator. A proportion of the conching masse is continually pumped out of the conche vessel and through the intensively shearing pipe system before being returned to the main conche.

Lipp Mischtechnik, on the other hand, describe putting the liquefier between two storage tanks or indeed recirculating from the bottom of a single tank, through the device and then back into the top.

Lehmann have coupled in-line liquefiers with ball mills to produce a continuous chocolate production process. The ball mill breaks up the particles, but leaves some of the newly broken surfaces un-coated by fat. The in-line liquefier coats these surfaces and reduces the viscosity. The chocolate is then passed through a further series of mills and liquefiers until the final particle size and viscosity is attained. If flavour modification is required, the masse is spread out in a thin film and hot air is blown over it.

9.4.6 Combined grinding/conching machines

Many smaller chocolate manufacturers, in particular, require a compact chocolate making plant, which is less expensive than the traditional roll refiner/conche system. Many of these have been developed. Perhaps the most common are based on recirculating through a ball mill or on a drum with internal scraping/breaking elements, known as the Macintyre system.

9.4.6.1 Recirculating ball mill systems (Figure 9.23)

Unlike the continuous Lehmann process, described above, these machines have a single ball mill, and chocolate is continually recirculating between

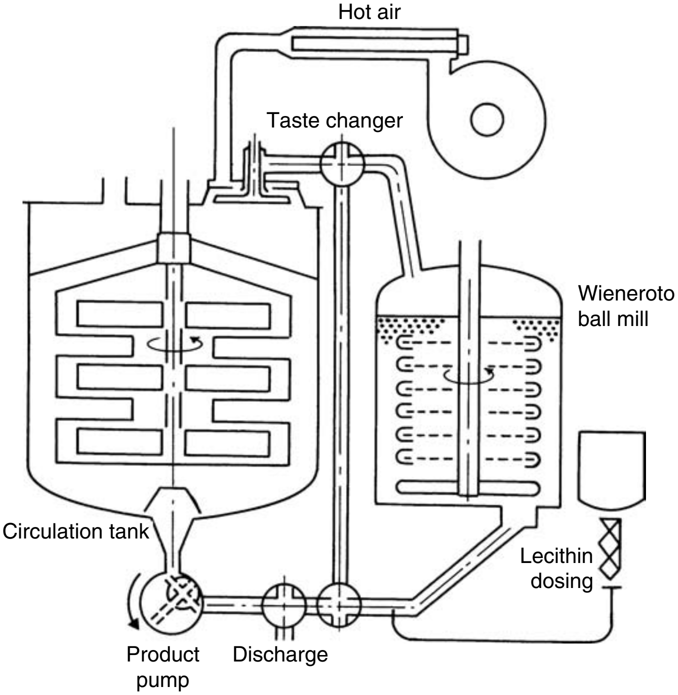

Figure 9.23 Diagram of Wiener chocolate making plant, using recirculation through a ball mill.

this and a stirred holding tank. The tank may be force-ventilated and usually has a capacity between 3 and 5 tonnes. Additional spray or centrifugal thin film devices, which have air blown over or through the masse, may also be used to aid moisture removal and produce flavour changes. This type of operation requires little supervision and once again has a throughput suitable for a smaller chocolate manufacturer. Another advantage of this system, over many others, is that the product is totally enclosed, which aids hygiene and the possibility of foreign body contamination. Its ability to modify chocolate flow properties is, however, somewhat limited.

9.4.6.2 Macintyre system (Figure 9.24)

This type of machine consists of a double-jacket drum with a serrated internal surface. Spring-loaded scrapers rotating inside the drum break the particles as they are forced between it and the outer wall. A water jacket allows for heating or cooling of the chocolate masse, whilst force-ventilated air removes moisture and other volatiles. Over a period of 12 or more hours it is possible to produce a chocolate of finished fineness. Batches of between 45 kg (91 lb) and 5 tonnes can be produced at a time. The major disadvantage of this type of machine is that it is difficult to optimize the flow properties and flavour of the final product, when the machine is used without any external attachments.

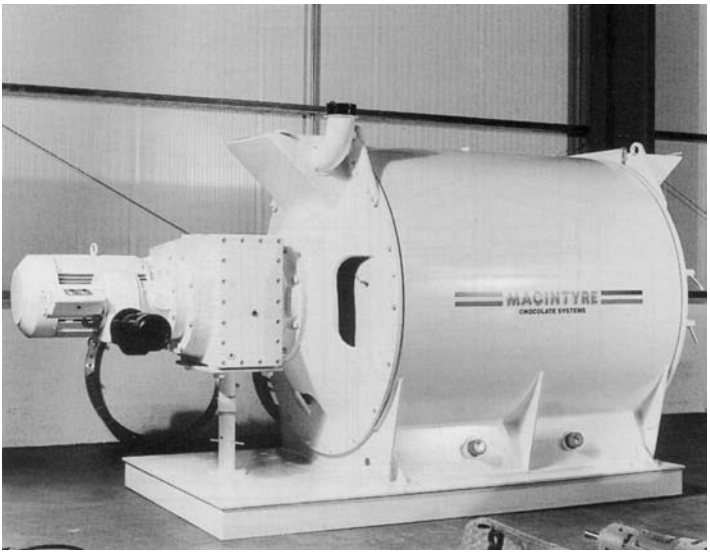

Figure 9.24 L&D Macintyre refiner/conche (Low & Duff (Developments) Ltd).

Initially this type of machine rapidly reduces the particle size. Once the masse has become liquid, however, the few remaining larger particles have a reduced probability of being trapped in the grinding gap. For this reason the final stages of processing can be very slow. Ball mills, on the other hand, operate more efficiently with a lower viscosity finer feed material. By combining the two types of machines it has been shown to be possible to greatly reduce the processing time and obtain a particle size distribution, which has been claimed to be better than that from a roll refiner system (Tadema, 1993).

Other combinations of machines are possible. Low & Duff have, for example, combined a Macintyre with a two-roll refiner. This has considerably reduced the viscosity of the chocolate produced, and is able to manufacture products with a much lower fat content than had previously been possible.

Summary

As has been illustrated in the previous sections, there is a very wide variety of conches available to the chocolate manufacturer. There is, of course, no perfect all-purpose conche, so what criteria should be used when choosing a new machine?

The most important parameter is the ability to produce the required chocolate flavour, as each design of conche tends to remove the volatile components in a different way. Strangely, the same type of conche in different factories have been known to produce different flavours using the same recipe. This flavour matching may not be important if a new product is being launched, but is critical for an established brand. Very often trials are carried out on small or pilot-scale equipment. This can give very different results and unfortunately there are no rules for scaling to full-size production machines. The only certain way is to evaluate a full-size test machine on site. Where it is necessary to match a current process, a useful guideline is to try to maintain a similar temperature profile (time vs. temperature curve).

Another important factor is the viscosity of the product. This will be related to the degree of shearing through the mixing elements. Powerful motors are required to produce a high shear rate. Although these use more energy per unit time, they frequently reduce conching time, which may result in an equivalent energy use per tonne of chocolate. High shearing systems also rapidly heat the product, so an efficient temperature control system is needed on the conche.

The space available for a conche may be the limiting factor. In this instance, a continuous system may be preferable to a batch one.

The type of chocolates to be manufactured, is another consideration. Some manufacturers make very large amounts of a single recipe, whereas others may only need a few tonnes, before changing it. The former is likely to use relatively large conches and the latter prefer the Macintyre or ball mill combined grinding/conching systems.

The size of conche to purchase is another factor. Small conches may be better for frequent recipe changes, but are relatively expensive in terms of capital cost. Large volume conches, although cheaper to purchase, have the disadvantage that they frequently have long filling and emptying times, during which no processing is taking place. In addition, in general only a small proportion of the chocolate within the conche is being mixed at any one time.

In conclusion, just as there are many different chocolates, so there are many different conching requirements and a wide variety of machine designs to try to meet these needs.

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Chapter 10

CHOCOLATE FLOW PROPERTIES

S.T. Beckett

10.1 Introduction

The flow properties of chocolate are important for two reasons. Firstly, if the chocolate's viscosity is incorrect then a poor quality product will be made, which may have to be sold cheaply as a miss-shape or perhaps have to be reworked (Chapter 18). For example if the viscosity is too low the weight of chocolate on an enrober-coated sweet will be too low. When it is too high, 'feet' may form (Figure 10.1) or bubbles not come out of a moulded tablet.

The second reason is not so obvious, but the flavour of a chocolate in the mouth is also affected by the viscosity, so incorrect flow properties can be perceived by the consumer. The reason for this is that the mouth contains a lot of different flavour receptors each capable of detecting a single type of flavour for example sweet on the tip end of the tongue and sour at the throat end. As the chocolate melts it comes into contact with these receptors. The perceived taste depends upon the order and rate of contact, which is related to the viscosity and the rate of melt. This can be demonstrated by placing part of a chocolate in the refrigerator and the remainder in a warm room. If the two are eaten consecutively, then they appear to have very different flavours.

The flow property of chocolate is very complicated because the viscosity is not a single value and is what is known technically as non-Newtonian. This means that if we measure its viscosity it will vary depending how fast the chocolate is flowing. In some ways it resembles non-drip paint, which is very thick when stationary in the tin, but becomes very thin when it is brushed on a surface. This will be discussed further in Section 10.2.

What is important is that we measure a viscosity at a similar rate of movement to that at which it is used. When the product is being deposited into a mould, this is very fast, but when chocolate is running down the side of a coated sweet it is doing so very slowly. It is therefore important to measure the viscosity at more than one flow rate. The results can be presented as several single point measurements or by combining these using mathematical models to produce flow parameters, such as the yield value and plastic viscosity. The Casson model is most frequently used within the confectionery

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Figure 10.1 Chocolate with 'foot' due to incorrect viscosity (reproduced from Beckett, 2000). See Plate 6 for the colour image.

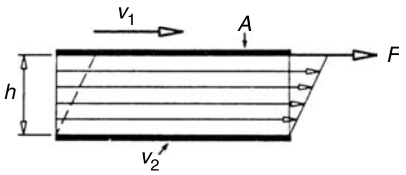

Figure 10.2 Diagram illustrating shear. v_1 = velocity upper plane, v_2 = velocity in lower plane, A = surface area of plane, F = force and h = distance between planes.

industry and this will be explained, together with some of its limitations, in Section 10.3.

Single point measurement systems do exist and these will be described, together with their limitations, in Section 10.4.

Rotational viscometers have become the industry standard and these are described in Section 10.5. The chocolate viscosity is however altered by how it is treated and also by how the measurement is carried out (Section 10.6).

The chocolate viscosity can be incorrect for a variety of reasons and it is important to determine the actual cause of a quality failure, so that it can be corrected. Section 10.7 reviews the factors that affect the flow properties of chocolate.

10.2 Non-Newtonian flow

Chocolate is a suspension of solid particles within a continuous fat system. Without the particles being present the liquid cocoa butter would have a single viscosity at whatever flow rate it was measured, i.e. it is Newtonian. Figure 10.2 shows two surfaces of area A cm^2 within a liquid, h cm apart and moving with velocities v_1 and v_2 respectively. The velocity gradient across this will be $(v_1 - v_2)/h$ and represents the rate at which the liquid is being sheared. This has the units (cm per second)/cm, or s^{-1} (reciprocal seconds) and is normally referred to as shear rate represented by the letter D.

The shear stress, which makes it move, is usually represented by the letter τ (tau). Viscosity (η) relates this force to the rate that it actually moves:

$$\eta = \tau/D \tag{10.1}$$

At any particular shear rate the value of η is known as the apparent viscosity and is normally measured in Pascal seconds (Pa s) or Poise. For cocoa butter the force that is applied relates directly to the rate at which it moves, so the apparent viscosity is the same at all shear rates (Figure 10.3), i.e. Newtonian flow.

In chocolate this is more complex due to the solid particles within it. This is illustrated schematically for two flow rates in Figure 10.4. At low flow rates the particles bump up against each other and resist the force, initially preventing movement and then making the apparent viscosity relatively high. Once the chocolate is flowing faster the particles can all move together along with the flow rather than resist it, so the chocolate has a lower apparent viscosity and behaves like a thinner liquid. The plots of shear stress and apparent viscosity against shear rate are then quite different (Figure 10.5).

The shear stress at which the flow starts τ_0 is often referred to as the yield value and is particularly important for enrobing or dipping chocolates, where

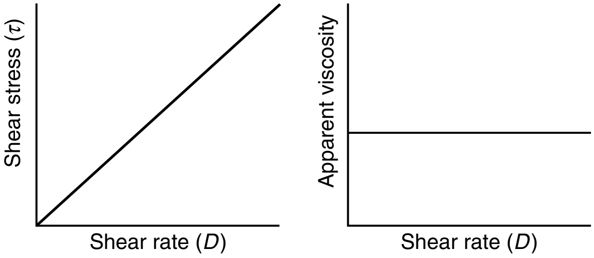

Figure 10.3 Plots of shear stress and apparent viscosity against shear rate for a Newtonian fluid.

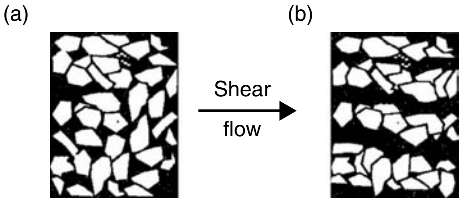

Figure 10.4 Schematic diagram of particles within a suspension, (a) at rest, (b) during flow.

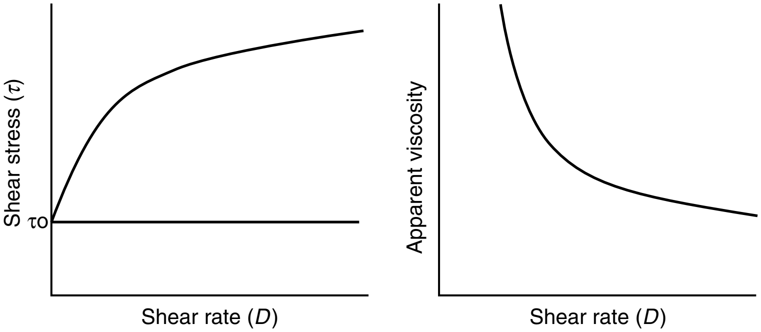

Figure 10.5 Plots of shear stress and apparent viscosity against shear rate for a non-Newtonian fluid.

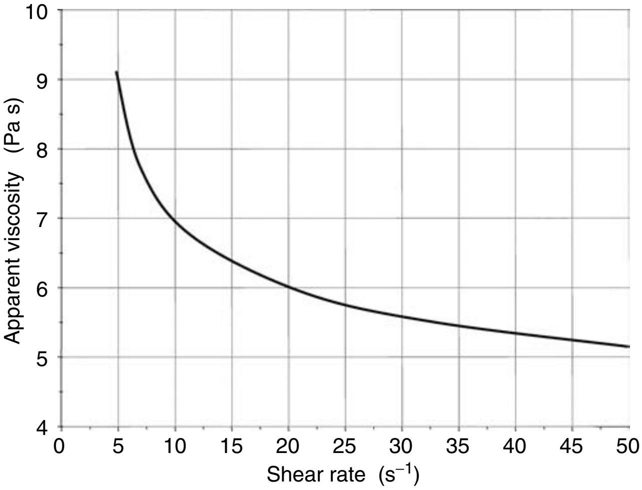

Figure 10.6 Plot of apparent viscosity versus shear rate for a typical milk chocolate.

the movement is slow and hence there is a low shear rate. This is measured in Pascal (or dynes/cm^2).

Figure 10.6 illustrates the apparent viscosity of a typical milk chocolate when it is stirred at shear rates ranging from 5 to 50 s^{-1}at a temperature of 40°C. This shows a fall from 9 Pa s to about 5 Pa s, which is very large taking into account that the addition of 1% of cocoa butter would change it by about 1 or 2 Pa s. The important fact is however, that the viscosity of chocolate is not a single measurement, but changes according to the speed that it moves. It should be measured therefore at the shear rate at which it is being processed. Usually this is more than one, for example very high during depositing, but slow for the removal of bubbles from a mould. This means that when the viscosity of a chocolate is specified, more than one figure is normally needed.

10.3 Presentation of viscosity measurements

Presenting the viscosity of a chocolate as a curve, such as is shown in Figure 10.6, is not very helpful when trying to specify a chocolate from a supplier or to determine whether it has been giving production problems. Provided that the measuring technique is carefully controlled and the same shear rates are used, the apparent viscosity can be used. The International Office of Cocoa, Chocolate and Sugar Confectionery recommend that the apparent viscosity should be reported in least 5 points so as to cover the low, medium and high shear rate ranges (OICCC, 2000). In practice most chocolates can be characterized by two measurements, one at about $5\,\mathrm{s}^{-1}$ for low flow situations and to approximate to the yield value and a second one between $10\,\mathrm{s}^{-1}$ and $20\,\mathrm{s}^{-1}$ for higher flow rates.

An alternative method of expressing the viscosity is to fit a mathematical equation to the flow curve for the liquid chocolate. There are a large number of these of varying complexity (Windhab, 1995), but the Casson model is the most widely used within the chocolate industry. Several variations of the model exist, some taking into account the configuration of the viscometer measuring system being used. The basic equation is:

$$\sqrt{\tau} = K_0 + K_1\sqrt{D} \qquad (10.2)$$

where K_0 and K_1 are constants, which depend upon the viscosity of the chocolate being measured. This equation can be expressed in graphical form as is shown in Figure 10.7 and shows that when there is a shear stress (τ) less than or equal to $K_0{}^2$ being applied no movement is taking place. This value is known as the Casson yield value (τ_{ca}). The gradient of the line, K_1, is equal to $\sqrt{\tau}/\sqrt{D}$, which using equation (10.1) shows it to be the square root of the

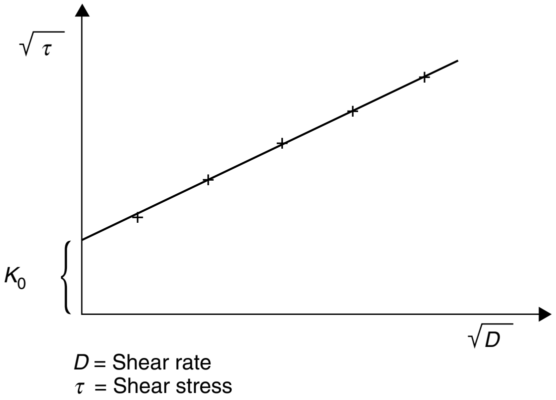

Figure 10.7 Viscosity plot for a Casson liquid.

viscosity. The value of the slope of the line squared = K_1^2, is known as the Casson plastic viscosity (η_{ca}) which characterizes the faster flow properties of the chocolate.

The Casson equation therefore provides two figures that can be used in production to describe a chocolate and it does indeed provide useful information and the measurements are made on a single viscometer. Where several laboratories are involved in measuring the same chocolate, for example when it is transported between two factories, then the apparent viscosity should be used, as measured at agreed shear rates (Beckett, 2001). The reasons why the Casson model is unreliable for this purpose was illustrated when the same chocolates were measured in thirty-two laboratories in eight countries (Aeschlimann and Beckett, 2000). These showed that for shear rates greater than $5\,s^{-1}$, the apparent viscosity could be measured between laboratories with a reproducibility with a coefficient of variation of less than 8%. (The repeatability within a single laboratory was better than 2%.) Using the same data in the Casson equation, the Casson yield value was found to vary between 3 Pa and 23 Pa and the Casson plastic viscosity from 2 Pa s to 4 Pa s. This covers the range for most useable chocolates, whereas measurements need to be useful to the manufacturer and ought to be accurate to better than 20%. There were several reasons for this. One related to the fact that there are several different Casson models being used in the industry, also it makes a difference whether the data is fitted to the model in the linear or square root form. Many viscometers automatically calculate the Casson parameters without saying how this is done.

Another problem is that very few chocolates have a flow curve that fits the square root (power 0.5) relationship of the Casson model, indeed many flow according to a 0.6 power (Chevalley, 1991). The Casson yield value is obtained by predicting outside the range of measurement and the very large errors will arise, so the actual values obtained may be incorrect.

10.4 Single point flow measurement

A single point measurement can give you information about part of the flow curve and if this is the critical one for the process, this may be all that is needed. If the measurement is outside of specification then corrective action is necessary. If it is correct however, this does not mean to say that the chocolate will process correctly. Figure 10.8 shows the measurements obtained for two chocolates by a higher shear rate measuring instrument (flow cup) plotted against a low shear rate measuring one (ball fall) over a period of several days. As can be seen for chocolate 1 the ball fall had a big range indicating large fluctuation in yield value, whereas the flow cup was relatively stable. If only the ball fall had been used the chocolate would probably have been modified, but this would not have been the case for the flow cup. The reverse situation occurred for chocolate 2.

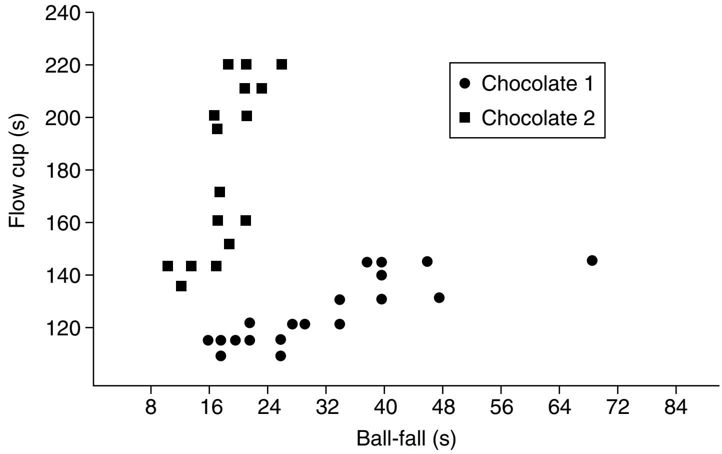

Figure 10.8 Flow-cup and ball-fall measurements for two chocolates.

The instruments used are relatively inexpensive and are still found widely throughout the industry. Some of the more common ones are described below. Sometimes it is possible to obtain more information about the flow curve by taking several readings using these instruments under different conditions.

10.4.1 Flow-cup viscometer (Riedel, 1980)

In this method, the time taken for a known amount of chocolate to drain out through a hole in a cup (or other container) is measured using a stopwatch. Sometimes this is done by draining the chocolate directly into a container on a set of scales. As the chocolate is flowing relatively quickly (the thinner the chocolate the faster it flows), this gives a single value tends to relate to a viscosity at a medium shear rate rather than the yield value. The Redwood viscometer belongs to this family and its application and use were described by Harris (1968).

10.4.2 Falling-ball viscometer (Figure 10.9)

The principle of the falling-ball viscometer is Stokes' law, which relates the viscosity of a Newtonian fluid to the velocity of a falling sphere. If a sphere of radius R and density d_1 falls through a fluid of density d_2 and viscosity η at a constant velocity v, the balance of forces gives the following relationship:

$$\eta \text{ is proportional to } (d_1 - d_2)R/v \tag{10.3}$$

i.e. the faster that it falls, the lower is the chocolate viscosity.

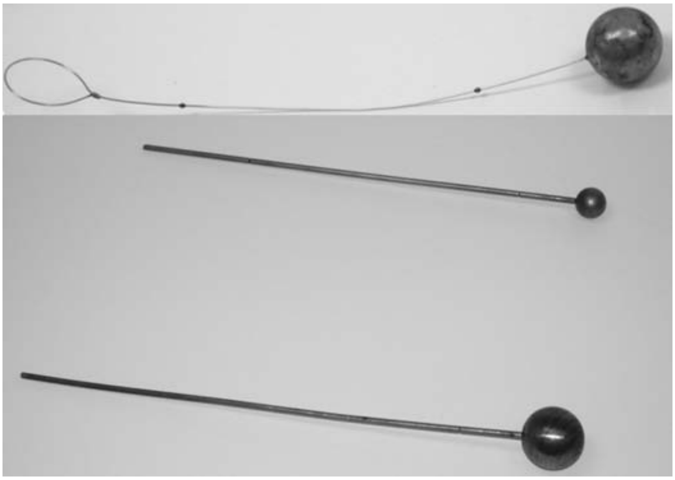

Figure 10.9 Ball-fall viscometers.

In the case of the Koch falling-ball viscometer (Koch, 1959), a steel ball is suspended on a wire on which are attached two markers. This assembly is lowered into the chocolate and the interval between the submersion of these markers is timed as the plunger sinks. By using balls of different size and density, it is possible to achieve different shear rates and shear stresses which can be used to construct a multipoint rheogram. For most chocolates however the ball falls relatively slowly and the value obtained relates more closely to the yield value. Frequently the measurement is made several times with the same ball, with the first reading being neglected as being different from the subsequent ones.

10.4.3 Gardner mobilometer

This instrument has been described in detail in two papers (Martin and Smullen, 1981; Stumpf, 1986). It consists of a metal cylinder, which is filled with melted chocolate, and a disc with four holes, which is threaded on to a plunger rod to form a piston. The time in seconds taken by the disc/rod (piston) assembly to fall 10 cm (4 in.) through the chocolate (mobilometer descent time) is measured. The weight of the disc/rod assembly may be modified by adding weights on a tray at the top of the rod. By plotting the reciprocal of descent time (proportional to shear rate) versus weight (proportional to shear stress), a rheogram can be obtained.

(1) Between mobilometer descent times (at constant weight) and plastic viscosities (Martin and Smullen, 1981).
(2) Between the intercepts on the weight axis (for the plot of the reciprocal of descent time versus weight) and yield values.

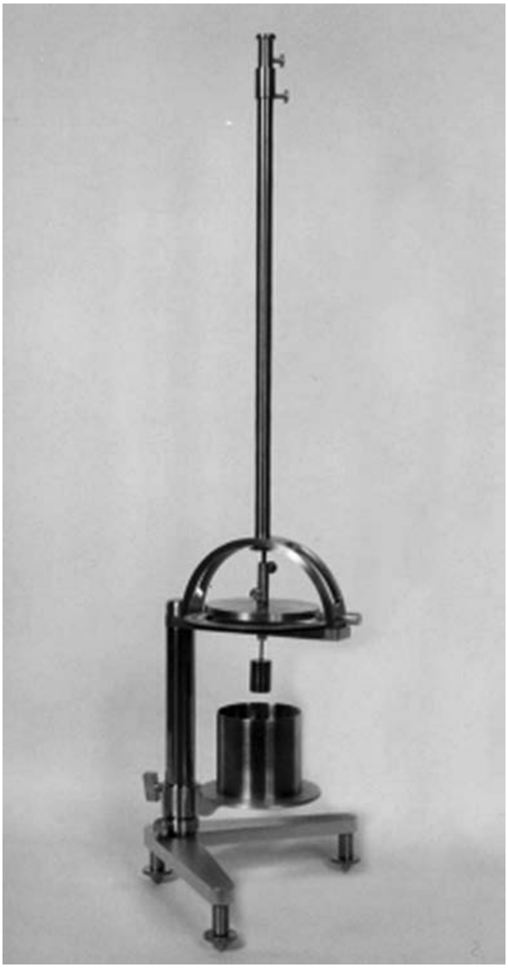

Figure 10.10 Gallenkamp viscometer.

10.4.4 Torsion viscometer (Gallenkamp or Fison) (Figure 10.10)

This viscometer consists of a torsion wire, suspended at the top and with a bob at the bottom. Approximately half way up the wire is a pointer set at right angles to the wire. The bob is placed in the chocolate and the pointer turned so as to twist the wire through 360°. Upon release the pointer swings back beyond its original zero position. The amount of the over-swing relates to the viscosity of the chocolate, being small for thick chocolates and very much larger for thinner ones. Care must be taken to ensure that the instrument is operated in a vertical position.

10.4.5 MacMichael viscometer

This device is somewhat similar to the Gallenkamp. In 1949 it was adopted by the USA chocolate industry as the standard instrument for measuring viscosity of chocolate for bulk commercial use. The specifications for its use for chocolate requires a 26 gauge wire, the bob has a 2 cm (0.8 in.) diameter cylinder that is immersed into the sample to a depth of 3 cm (1.2 in.) in a 7 cm (2.8 in.) diameter cup. The cup with chocolate is turned at a rate of 15 rpm. The viscosity of the chocolate causes the wire to twist. The product temperature must be adjusted separately – usually to 38°C (100.5°F). The spindle that holds the wire is equipped with a circular scale that measures the amount of twist of the wire.

The scale is 0–300 (not 360) and the amount of twist is referred to as °M (degrees MacMichael). It can be converted into an apparent viscosity of centipoise, but it rarely is. The design of the MacMichael makes the 26 gauge wire highly vulnerable to bending, which voids the reliability of the wire. Furthermore, the torsion constants of the 26 gauge wires vary over a range of 20%. The geometry of the bob and cup and the low r.p.m. means that the shear rate of the MacMichael is low and is thus highly influenced by yield value.

The MacMichael viscosity is a single value that does not sufficiently define the flow properties of the chocolate and each reading is equivalent to a range of Casson yield values and Casson plastic viscosities (Seguine, 1988). During the 1980s, the USA industry replaced the instrument with the rotational Brookfield viscometer. It can duplicate the MacMichael measurement, avoiding many of its short-comings and in addition can measure Casson yield value and plastic viscosity.

10.5 Rotational viscometers

In order to measure a flow curve it is necessary to measure the rate a chocolate moves at under a certain stress, or to move it at a given rate and measure the force required to do so. Although both types of instrument exist, the latter is much more common within the confectionery industry. Figure 10.2 illustrated the flow between two parallel planes and indeed it is possible to carry out measurements in this way or between a plane and a cone. The results however tend to be less reproducible than those obtained with the concentric cylinder (bob and cup) systems (Aeshlimann, 2000). Here the chocolate is poured into a temperature-controlled cup and a bob immersed in it.

There are two types of bob in common use as illustrated in Figure 10.11. As the bob turns there is a situation like Figure 10.2, with a constant distance between two parallel surfaces that are moving at different rates. The apparent viscosity is then directly related to the force trying to stop the bob moving at a given speed. At the base of the bob the flow of the chocolate is different

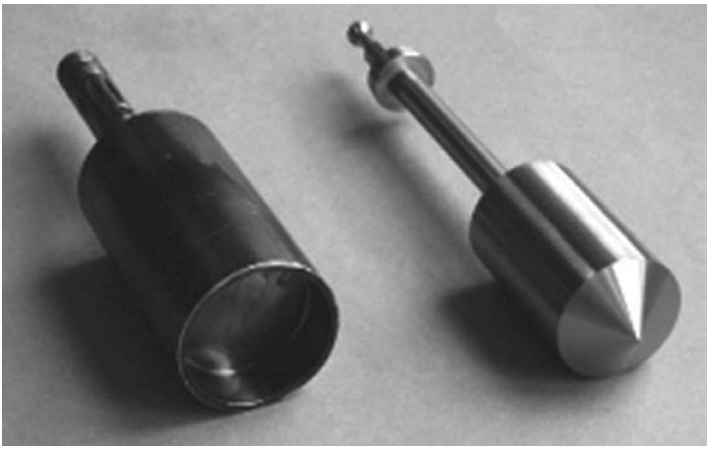

Figure 10.11 Bob types for concentric cylinder viscometer.

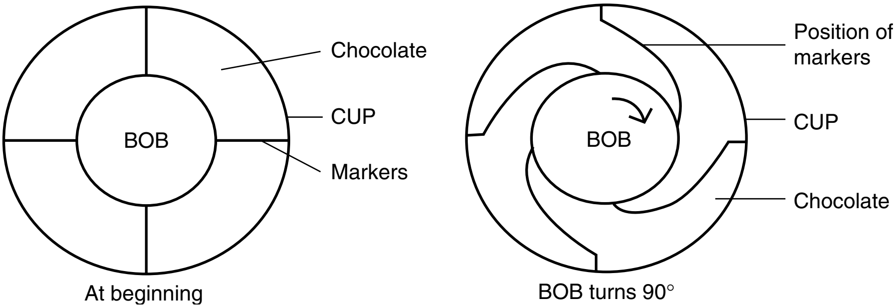

Figure 10.12 The flow between the cup and the bob of a concentric cylinder viscometer.

and difficult to calculate. The bobs shown have therefore been designed to minimize this end effect.

It is also important that the chocolate moves uniformly in the gap between the bob and cup. If the gap between the two is too wide this will not be the case as only the chocolate near the moving bob will be affected, see Figure 10.12. The distance into the chocolate being moved will also depend upon how fast it is turning and upon the viscosity of the chocolate itself. The faster it turns the more of the chocolate within the gap is moved. This means that the lower shear rate (speed) readings are too low. Similarly a thinner chocolate may be measured across the full gap, but a very thick one for only half of it, which makes the thick one appear to be thinner than it actually is. For this reason it is recommended (OICCC, 1973) that the ratio of the bob diameter to the cup should be greater than 0.65. There are viscometers available which do not have the outer cup and often have a spindle with a narrow cylinder (sometimes conical shaped). For the above reason they cannot be used to give precise viscosity measurements especially at low shear rates or over a wide range of viscosities. Their use should be limited to determining whether samples lie within a particular range, which has previously been determined using the viscometer concerned.

In the most widely used instruments the internal coaxial bob rotates, with the shear rate being fixed by a geared drive motor and the shear stress measured by means of a torsion spring connected to the rotating bob. Examples of this type of viscometer include Brookfield (Seguine, 1986), Contraves and Haake instruments (Hogenbirk, 1986).

Shear stress (τ) is proportional to the torque (M), which is itself proportional to the viscometer reading (n):

$$\tau = M/2\pi r^2 h = A\,n \qquad (10.4)$$

where h = length and r = radius of the internal cylinder.

$$A = \text{constant} = k/2\pi r^2 h \qquad (10.5)$$

$$\text{and } k = \text{torque constant} = M/n \qquad (10.6)$$

The shear rate at the inner cylinder D_N is given by

$$D_N = BN \qquad (10.7)$$

where B is a constant related to the ratio of the cup and bob radii and N is the number of revolutions per minute of the bob.

The constants of proportionality A and B are strongly dependent on the geometry of the viscometer. Generally, viscometer manufacturers specify the values of A and B for their instruments, as well as any other properties which are relevant. By taking different measuring systems, the range of measurements may be extended.

10.6 Sample preparation and measurement procedures

10.6.1 Sample preparation

The sample being tested must be representative of the chocolate being sampled. Liquid chocolate should be stirred thoroughly before the sample is taken and where possible they should not be taken from the top of storage tanks, as some separation of fat may have taken place.

The viscosity measurement on chocolate should be made at exactly 40°C (104°F). The viscosity changes between 1% and 4% per °C, depending upon the recipe and the shear rate. The bigger effect being at the higher shear rates. The reason for choosing this temperature is that at temperatures below about 35°C (94°F) crystallization begins to occur, which makes the viscosity unstable. Above about 45°C (125°F) protein reactions within the milk can cause thickening to occur especially at low shear rates. Dark chocolate is also affected especially if there is no lecithin present (Chevalley, 1999).

If a sample is taken directly from a conche, then provided the temperature has not fallen below 35°C (94°F) the measurement may be taken as soon as the sample temperature has reached 40°C (104°F). All other samples, whether they are liquid or solid chocolate, must be heated to remove all the fat crystals. Any moisture will thicken the chocolate so this should be done in dry conditions and never over a water bath. If the chocolate is solid it should be divided into lumps rather than grated and melted in a sealed container in an incubator or oven. The liquid chocolate should be brought to 50°C (122°F) and then cooled again to 40°C (104°F). A 100 g (3.5 oz) sample of chocolate was found to take 75 min in an oven at 52°C (126°F) to reach this temperature (Aeschlimann and Beckett, 2000). Prolonged storage of milk chocolates should be avoided as thickening occurs with time. This is even more likely to occur for white chocolates, which should be stored at a lower temperature. Ideally, milk chocolate should not be kept in the liquid state for more than 2 or 3 h before the measurement is taken. Where the measurement is not going to take place for an extended time, then it is preferable to store a sample in solid form and reliquefy it, rather than keep it in the liquid state.

10.6.2 Checking the viscometer

If the bob has become scratched or bent it should be replaced. The calibration should also be checked at regular intervals with a calibration oil, whose apparent viscosity in the mid-shear rate range is similar to that of the chocolates being tested.

Wash and thoroughly dry the viscometer cup and bob between samples, as any residual moisture will affect the results.

As was noted earlier, temperature has a big effect on the viscosity. The temperature of the fluid being used to heat the cup is often measured elsewhere in the circuit. The actual temperature should be determined by placing chocolate in the cup and measuring its temperature with a calibrated thermometer.

10.6.3 Preconditioning

When the sample is placed in the cup it is unlikely to be at the correct temperature throughout. Chocolate is a poor conductor of heat, so some mixing by stirring with the bob is required. If this is done too vigorously the chocolate will become thinner (chocolate is what is called thixotropic and is stirred probably due to the breakdown of the structure formed between the solid particles when they are at rest). The chocolate should therefore be stirred between 18 and 60 s^{-1} until the shear stress reading becomes stable.

The viscometer should then be stationary for about 30 s before the actual measurement is taken. Using very low or very high pre-shearing rates can give rise to anomalous results (Aeschlimann and Beckett, 2000).

10.6.4 Shear rate range

Although in theory the lower the shear rate the better the determination of the yield value, the low shear rates are very difficult to measure and the results become highly irreproducible. Inter-laboratory trials have shown that $5\,s^{-1}$, is able to produce repeatable measurements on most viscometers. The highest shear rate will depend upon the thickness of the chocolate and the scale range. It is not advisable to exceed 80% of full-scale reading. Viscometers should be able to provide readings up to about $50\,s^{-1}$ on a standard enrobing or moulding chocolate.

10.6.5 Holding time at the maximum shear rate

Measurements of shear stress can then be taken over a range of shear rates. The increase in rate can be continuous or carried out as a series of steps. After a period at the maximum shear, the measurements are repeated as the shear rate is reduced again. At the maximum shear rate, the shear stress will slowly decrease due to the thixotropic nature of chocolate. It is impractical to wait for a long time in the middle of the measurement until this decrease has stopped. The final measurement therefore depends upon the time the viscometer remains at this shear rate. It is therefore necessary to standardize this when carrying out comparative measurements. Normally this should be of the order of 1 min.

10.6.6 Hysteresis

If the shear stress is plotted against the shear rate for both ascending and descending curves, it is often found that the descending values are lower at a particular shear rate for most of the curve. The difference between the two is known as hysteresis and is a measure of how well the chocolate has been processed. A poorly mixed or conched chocolate will have a big difference between the two curves. In this case the chocolate is being further processed by the shear within the viscometer itself.

10.6.7 Overall measurement time

The overall measurement time will also affect the final result (Aeschlimann and Beckett, 2000) and so needs to be standardized. The OICCC standard method (2000) recommends an overall time of 7 min, comprising of 3 min of ascending shear rate, 1 min at maximum shear rate followed by 3 min of descending readings.

10.7 Factors affecting the flow properties of chocolate

A major reason for being able to measure the viscosity of chocolate is to be able to correct it, when production difficulties occur. Some may relate to the yield value rather than the plastic viscosity and vice versa. It is therefore important to know which factors affect the flow property concerned, in order to correct it. Some of these factors are therefore described in the following sections.

10.7.1 Fat content

It is useful to consider the micro-structure of chocolate in order to understand how it flows. This is illustrated schematically in Figure 10.13. It is the liquid fat (both cocoa butter and milk fat) that enables the chocolate to flow. In weight terms it constitutes about one third of the chocolate, but in volume terms (because fat has a lower density) it is almost half. As the fat content increases the distance between the solid particles increases so the viscosity drops. Some of the fat is bound by and within the particles (see Chapters 4 and 5), so does not aid the flow. If a chocolate is too thick, the further grinding of the cocoa liquor or the use of an alternative milk powder source should be considered.

It is the free fat that enables the chocolate to flow and if the total fat content is low (e.g. about 25%), then the proportional increase in free fat content of an extra 1% of cocoa butter is going to be a lot greater

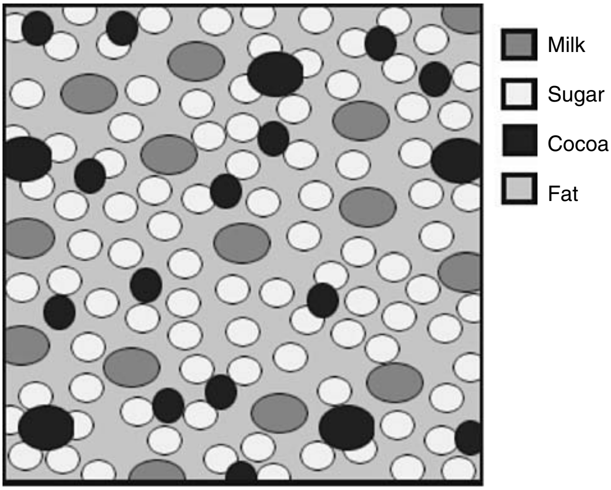

Figure 10.13 Schematic representation of the solid particles and fat within a milk chocolate.

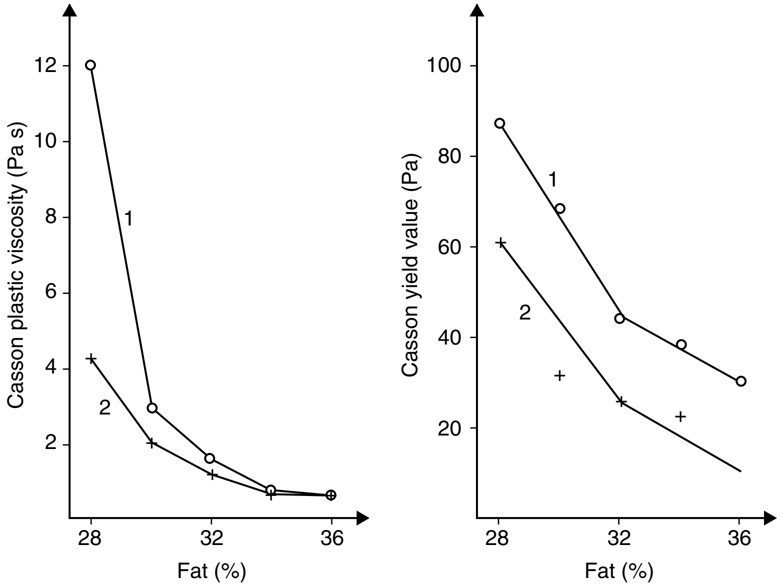

Figure 10.14 The influence of fat content on the Casson viscosity parameters in two milk chocolates with 0.25% lecithin: (1) fine chocolate with 5.7% particles >20 μm; (2) moderately coarse chocolate with 16% particles >20 μm.

than for one with 35% fat content. This means that the effect on viscosity of additional cocoa butter is much greater at lower fat contents and becomes very small indeed above 35% (see Figure 10.14; (Chevalley, 1999). The yield value arises mainly from the inter-particle reactions, which means that it is less affected than the yield value by the addition of fat. Where the yield value is incorrect other factors should be investigated.

All the factors tend to be interrelated. In Figure 10.14 it can be seen that the magnitude of the effect of adding extra fat depends upon the particle size.

10.7.2 Particle size distribution

It is necessary to grind all the sugar and other solid particles below about 30μm to avoid the chocolate tasting gritty. Granulated sugar has a diameter of about 1mm (0.04in.) so must be broken many times during the chocolate production. Each time it is broken new surfaces are created, which have to be coated with fat (Figure 10.13), so in general the finer the chocolate the higher the viscosity. Particle size, like viscosity, is not a single parameter however, but a distribution, which can be measured using laser light scattering

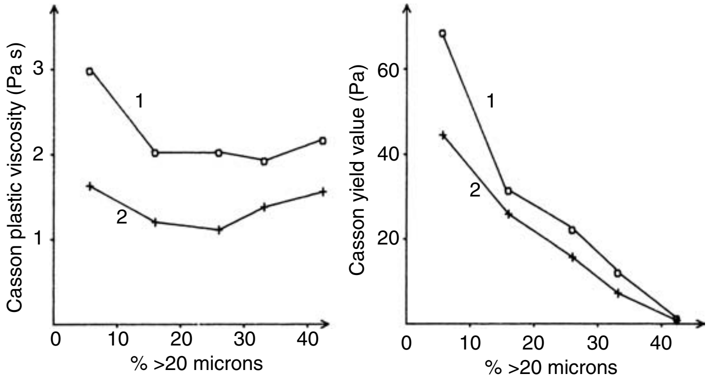

Figure 10.15 The influence of particle fineness on the Casson viscosity parameters in two milk chocolates with 0.25% lecithin: (1) 30% fat; (2) 32% fat.

devices such as the Malvern (Chapter 22). This type of instrument is able to show the distribution from sub-micron to above a millimetre. The percentage of larger particles is required to determine the textural roughness of the chocolate. Another parameter that the instrument calculates is the specific surface area, which relates to the surface area of solid particles which must be coated with fat.

As the chocolate is ground finer, there are more particles to interact so the yield value is increased. In practice, the effect upon the yield value is much greater than for the plastic viscosity (Figure 10.15, Chevalley, 1999). The yield value normally correlates with the measured specific surface area. This is not the case for the Casson plastic viscosity, however, where at very large particle sizes the plastic viscosity can indeed increase again. This may be due to increasing amounts of bound fat or to how the solid particles pack themselves together. If spherical particles all of a similar size are packed together a lot of space remains between them, which must be filled with fat or smaller particles (Figure 10.16 and Chapter 7, Section 7.6). In the extreme of having a lot of larger particles or chocolates with very few very fine ones, further grinding will reduce the viscosity. This is however very unusual.

Where an industrial chocolate is found to have a very high yield value, but the plastic viscosity is correct or only slightly high, then the particle size should be investigated as it is possible that the grinding procedure is producing an excessive proportion of fine particles. A high yield value can be counteracted by the use of a surface-active agent.

10.7.3 Surface-active agents (emulsifiers)

Although it is necessary to coat sugar particles with fat, this is not always easy as the sugar surface is lipophobic, i.e. it tries to repel the fat. The flow

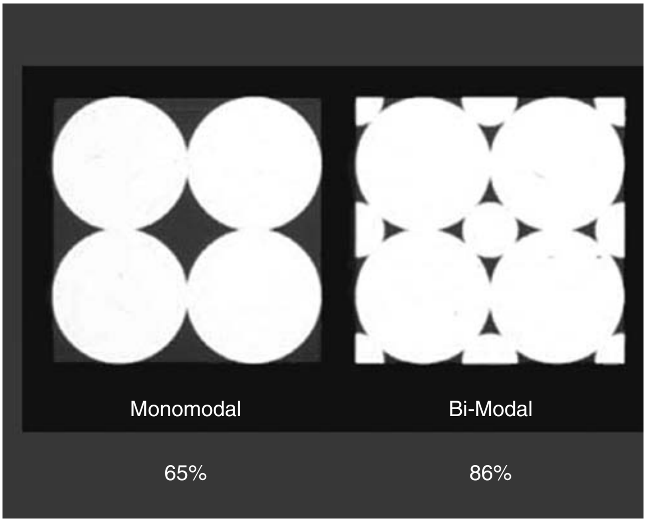

Figure 10.16 Illustration of the packing of spheres that are: (1) all the same size; (2) two different sizes.

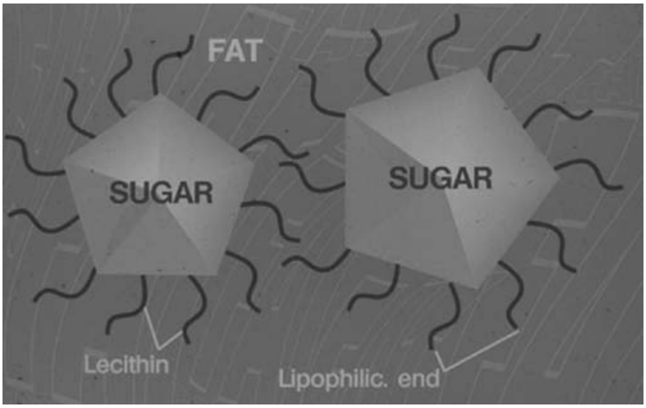

Figure 10.17 Schematic diagram of lecithin molecules around a sugar particle.

can be aided however by placing a surface-active agent, normally known as an emulsifier between the two (see Figure 10.17). The most common emulsifier is lecithin, which has been used in chocolate since 1930. It is naturally occurring, often produced from soya and is said to have positive health benefits. One end of the molecule is lipophilic so remains in the fat, whereas the other end lipophobic end attaches itself to the sugar surface (it will affect the other solid particles, but the predominant effect is with the sugar). This aids the flow properties to such an extent that for additions of up to about

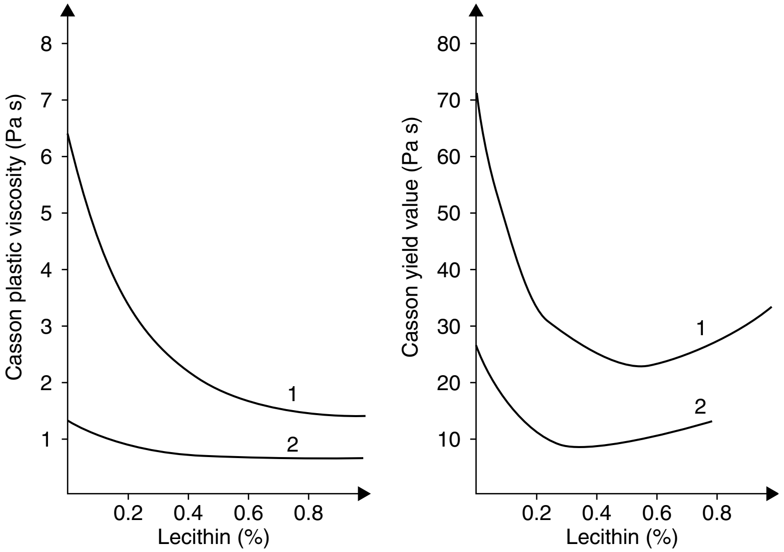

Figure 10.18 The influence of soya lecithin addition on the Casson viscosity parameters in two dark chocolates: (1) 33.5% fat, 1.1% moisture; (2) 39.5% fat, 0.8% moisture (Finke, 1965).

0.3% it has an effect equivalent to ten times this weight of cocoa butter. As with cocoa butter editions, the higher the viscosity, the more effective is the addition of the emulsifier, see Figure 10.18. Unlike cocoa butter however, further additions of lecithin can cause the yield value to increase. This may be due to lecithin particles attaching themselves to each other forming new particles called micelles, or due to the lipophilic ends attaching themselves to the lipophilic ends of a second layer of lecithin and reducing its effectiveness. The point at which this occurs depends upon the surface area of the solid particles being coated. A fine chocolate with a high sugar content can therefore tolerate a higher lecithin level than a coarse one or one with a lower sugar content. In addition it will depend upon the type of lecithin used.

Lecithin can vary and some manufacturers have tried to optimize those components which are beneficial to chocolate flow (Preston, 1989) and fractionated lecithins are available. The phosphatidylcholine part of lecithin has been shown to be particularly effective in reducing the plastic viscosity of some dark chocolates (van Nieuwenhuyzen, 1995), whereas other fractions are less effective than standard lecithin in reducing the yield value. Because the ratio of the different phospholipids vary within standard lecithins, its effectiveness in reducing chocolate viscosity can change from batch to batch. For this reason, some suppliers provide a standardized product (Schmitt, 1995).

Table 10.1 Flow characteristics of plain chocolate with added emulsifiers at 50°C (Harris, 1968).

Addition	Casson plastic viscosity (Pa s)	Casson yield value (Pa)
0.3% soya lecithin	0.6	9.2
0.3% YN	1.03	3.0
0.3% sucrose dipalmitate	0.9	16.6
0.3% PGPR	3.25	2.5
0.8% PGPR	2.0	0

In addition to lecithin, other new surface-active agents have been developed for chocolate. One of the most widely used is the synthetic lecithin, YN (obtained from partially hardened rapeseed oil after glycerolysis, phosphorylation and neutralization). YN is more constant in composition than soya lecithin: its flavour is bland and neutral; its efficiency is said to be greater than that of soya lecithin, and at levels above 0.3%, no thickening occurs. When compared with soya lecithin, YN can sometimes have a stronger effect on τ_{CA} than on η_{CA} (see Table 10.1). Concern about genetically modified soya has led to increased interest in YN and lecithin produced from other crops such as sunflower.

Another widely used emulsifier is polyglyceryl polyricinoleate (PGPR), sometimes known as Admul-WOL. PGPR has the ability to strongly reduce or even cancel the yield value of chocolate (Table 10.1). This useful property is exploited by the confectioner in such applications as the moulding of Easter egg shells and also for correcting the viscosity of a chocolate that has too many fine particles, or indeed if too much lecithin has been added. A combination of lecithin and PGPR can in fact produce good flow properties, especially in low fat chocolates. It is possible to purchase this combination as a mixture.

Other emulsifiers include citrem, soritan tristearate, sucrose esters and calcium-stearoyl lactoyl lactate. Citrem (citric acid ester) has the properties of the lecithin/PGPR combination, whereas sorbitan tristearate is an emulsifier which is used to reduce bloom formation rather than control viscosity.

Emulsifiers sometimes affect the tempering of chocolate, which in turn affect the flow properties of the tempered chocolate. The effect of the emulsifier on chocolate flow is normally evaluated on untempered chocolate as in Figure 10.18. It is however useful to check the results on tempered chocolate (Weyland, 1994). It should also be noted that over tempering thickens chocolate and can cause a low viscosity chocolate to become unuseable.

The stage in the process at which the emulsifier is added is a very important factor for example lecithin added towards the end of conching reduces viscosity by a greater amount than when exactly the same amount is added at the start. The reason for this is that, as the action of lecithin is a surface effect, if it is added to the masse too early, some of it may (by prolonged mixing and grinding) be absorbed into the cocoa particle, thus reducing its efficiency (Minifie, 1980). It is also known that exposure to relatively high temperatures for long time reduces lecithin performance. In addition it can reduce the work input provided by the conche.

10.7.4 Conching

Besides the time of addition of the fat and emulsifier, the time and intensity of the conching have a big effect upon the final chocolate viscosity. The longer a chocolate is conched normally the thinner a chocolate becomes. However with increased time, the lowering of viscosity becomes less significant or economic. The intensity governs the rate at which the solid particles are coated with fat. This is normally governed by the conche design, but can be helped by changing the amount of material in a conche and the time and order in which the fats and emulsifiers are added. A low intensity conche will never produce as thin a chocolate as a high intensity one however long it is operated. As was noted earlier (Section 10.6), poor conching results in big differences between the up and down measurements in a viscosity. Further details concerning the effect of conching parameters on chocolate viscosity are given in Chapter 9.

In addition to coating particles, conching also removes moisture from the chocolate masse, which also has a big effect upon viscosity.

10.7.5 Moisture

If some per cent of moisture is added to chocolate it will become very thick. Indeed if as little as 0.3% extra moisture is left within the chocolate it will be necessary to add another 1% of cocoa butter to restore the viscosity to what it should have been. This is probably in part due to water on the surface of the sugar particles sticking them together and impeding the flow. Where lecithin is also present this is less likely to happen and indeed chocolates containing this emulsifier can have more water present and yet retain their correct flow properties. Lecithin can have a negative effect during conching however when its hydrophilic properties will reduce the amount of water evaporating from the masse.

Below the 1% level, however, most of the moisture is bound into the ingredients for example as water of crystallization in lactose, and so has little effect upon the flow properties.

10.7.6 Vibration

This is important for removal of air bubbles or the weight control of enrobed sweets (Chapter 14). Bartusch (1961) showed that apparent viscosity (at a slow shear rate of $1\,s^{-1}$) decreased with increasing amplitude of vibration and he postulated that the yield value had disappeared. This was confirmed by Barigou *et al.* (1998) on both milk and dark chocolate. Here the effect of frequency was found to be more important than amplitude. It was possible to obtain chocolate with a Newtonian flow by vibrating it at 50 Hz and an amplitude of 0.1 mm (0.004 in.). The effect was reversible however and the chocolate regained its previous viscosity as soon as the vibration stopped.

Conclusions

The flow properties of chocolate are very complex. However, an understanding of both flow property measurement and factors affecting the flow can greatly help trouble-shooting and plant optimization.

It is always important to measure the flow properties of chocolate under conditions that are as close as possible to those under which it is being processed. Where faults occur, it is necessary that corrective action should be taken according to the flow parameter that is incorrect for example add PGPR for a high apparent viscosity at a low shear rate (Casson yield value), or cocoa butter for a high reading at a high shear rate (Casson plastic viscosity).

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Chapter 11

BULK CHOCOLATE HANDLING

J.H. Walker

11.1 Introduction

The output from chocolate manufacturing plants has continued to increase and this, coupled with a demand for higher rates of productivity, has resulted in the transport of the ingredients and the finished masse becoming more important. Wheeled tanks and the transport of solid blocks of material have often been replaced by the use of pumps and heated pipe work. Within large confectionery factories, the flow rate of chocolate in the pipelines can be as high as 10 tonnes/h and the distance to which it is transported is often as far as 200 m (600 ft) or even more. It is important, therefore, that the pump and pipe system is designed to meet the expected duty. Liquid chocolate is a non-Newtonian fluid and this means that both the yield value and the plastic viscosity and operating temperature (see Chapter 10) must be considered when specifying the chocolate delivery system.

There are many different types of pump that can be used to transport chocolate, each with its own advantages and disadvantages. In addition, there are numerous applications for pumps, ranging from the metering cocoa liquor to pumping tempered chocolate, which means that many different types of pumps are employed in a single manufacturing plant. The purchase cost of the pump may also influence the choice, however it should be remembered that the incorrect choice could lead to considerable problems.

11.2 Viscosity and viscometry

11.2.1 What is viscosity?

It is easy to tell the difference between a thin and thick chocolate, but difficult to quantify viscosity in a meaningful way except by using specialized instruments. It is important to understand the influence of the chocolate viscosity since a high viscosity chocolate requires more power to pump than a low viscosity one. Knowing its rheological behaviour therefore, is essential when designing pumping and piping systems. When specifying pump

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requirements to a supplier, it is always necessary to quote the expected viscosity and temperature variations, together with the flow rate and pressure limitations for sensitive ingredients or vulnerable equipment such as tempering machines.

Viscosity is the measure of the internal friction of a chocolate. This friction becomes apparent when a layer of chocolate is made to move in relation to another layer. The greater the friction, the greater the amount of force required causing this movement, which is called 'shear'. Shearing occurs whenever the chocolate is physically moved or distributed, as in mixing, pumping, stirring, depositing, etc. Highly viscous chocolate therefore requires more force to move than less viscous chocolate.

Isaac Newton defined viscosity by considering the model shown in Figure 11.1. Two parallel planes of fluid of equal area 'A' are separated by a distance 'dx' and are moving in the same direction at different velocities '$V1$' and '$V2$'. Newton assumed that the force (F) required to maintain this difference in speed was proportional to the difference in speed through the liquid, or the velocity gradient at the part of liquid under consideration.

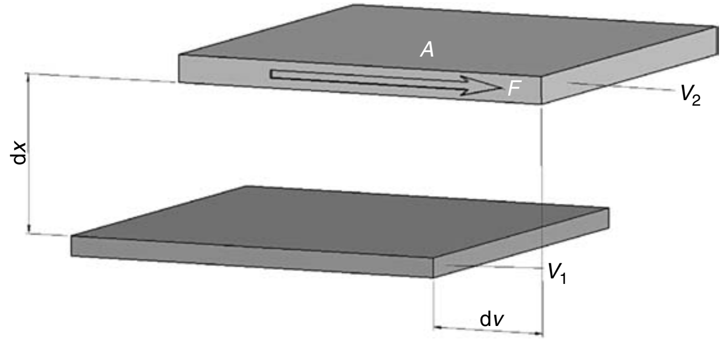

Figure 11.1 Diagram illustrating shear.

The velocity gradient $(V2 - V1)/dx$, is a measure of the change in speed at which the intermediate layers move with respect to each other. It describes the shearing the liquid experiences and is thus called the 'shear rate' and is often symbolized as 'D'.

Its unit of measure is the reciprocal second (cm per second/cm or s^{-1}).

The term F/A indicates the force per unit area required to produce the shearing action and is known as the shear stress (τ).

Newton stated that the coefficient of viscosity remained the same at varying flow rates, but this only applies to Newtonian fluids at a fixed temperature. Using these simplified terms, viscosity (η) may then be defined mathematically by this formulae:

$$\text{Viscosity} = \eta = \tau / D = \text{shear stress/ shear rate}$$

For confectionery products, the units of viscosity are usually centipoise, poise or Pascal seconds.

If the viscosity η is a constant and does not vary with changing values of D, then the fluid is Newtonian. A Newtonian liquid is therefore one for which the graph of shear stress plotted against the rate of shear is a straight line for example glucose syrup (see Figure 10.3). For such materials, the pump supplier only needs one viscosity figure at the temperature of use. N.B. Viscosity can vary a lot with temperature, so it may be necessary to carry out several measurements.

A non-Newtonian fluid is defined as one in which the relationship of shear stress/rate of shear is not a constant, as is shown in Figure 11.2. In other words when the shear rate is varied, the shear stress does not vary in the same proportion. The viscosity of such fluids will therefore change as the shear (flow) rate is varied. The measured viscosity at any particular shear rate is known as the 'apparent viscosity' at that shear rate. The value of the shear rate should always be quoted. When providing the viscosity specification to a plant designer, measurements should be obtained at both a high and a low shear rate. The type of viscometer that is used can also affect the measurement obtained (see Chapter 10).

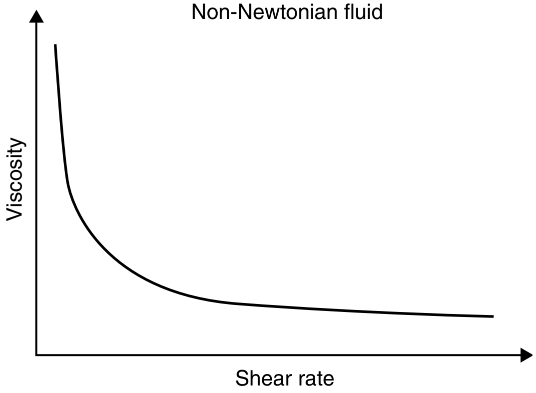

Figure 11.2 Diagram illustrating non-Newtonian flow.

11.2.2 Laminar and turbulent flow

The flow of a fluid down a pipe may be either laminar or turbulent. In laminar (streamline) flow, the molecules within the fluid follow well-defined paths, which may converge or diverge, but their motion is in the general direction of the bulk flow. The viscosity is dependent upon temperature but largely independent of pressure and surface roughness.

If the shear rate becomes very high however, the movement of the molecules within the fluid becomes more random and some molecules can even move in the opposite direction to that in which they are being pumped and the flow becomes turbulent. This should never be allowed to happen within a chocolate pipeline as it can cause damage to the system. The shear stress down a pipe is proportional to its diameter, so larger pipes should be installed if any turbulence occurs. In addition, since many of the chocolate pumps and pipeline fittings available are only suitable for working pressures of 10 bar maximum, it is advisable to size the pipeline to be big enough to operate below this limit.

11.3 Pump sizes

11.3.1 Power

The power requirement for the pump has to take into account all frictional inefficiencies, such as those arising from gearboxes, belt drives and the internal friction of the pump bearings and seals. These vary greatly between the different types of pumps that are used.

Never size a pump using the viscosity of chocolate measured for standard operating conditions. Allowances must be made for start-up conditions, particularly after shutdown periods such as weekends and holidays. If the chocolate is not constantly moved in the pipeline or storage tank, sedimentation of the solid particles within the chocolate may occur. This can result in an increase in the system pressure or even blocking of the pump.

11.3.2 Speed

The speed at which the pump operates should be as low as possible without causing the pump to slip excessively. Some chocolates are shear sensitive and can have their viscosity changed by over shearing by the pump. Excessive speeds can also produce heat which may result in caramelization of the chocolate, which in turn may eventually lead to the pump seizing. The life of the pump and the seal can also be extended by operating the pump at low speed.

Many chocolate pumps are built to a special configuration using large internal clearances between the fixed and rotating parts within the pump and are designed to minimize the damage caused by frictional heat to the chocolate whilst at the same time maintaining operational efficiency.

11.4 General criteria for choosing a pump

All pumps must have a means of keeping the chocolate warm when they are not in operation. This is usually achieved by the means of a hot water jacket or saddle built in to the pump.

When choosing a pump for the transport of chocolate or chocolate ingredients the following criteria should be considered:

- The quantity of chocolate the pump is required to deliver.
- The pressure the pump will need to overcome (pressure drop in pipeline).
- The accuracy to which the pump will need to operate, for example metering cocoa mass.
- The type of seal arrangement for example gland packing, lip seal.
- The operating control and shear action of the pump. Heating caused by excessive shear may cause caramelization or de-tempering of the chocolate.
- The length of time the pump will be required to operate without stopping, for example a ring main where the pump operates 24h per 7 days per week. Or intermittent batch operation such as discharging a conche.
- If inclusions are to be included in the chocolate, the pump will be required to accommodate this.
- The material in contact with the chocolate. Cast iron and steel pumps are normally satisfactory, but stainless steel may also be used.

11.5 Types of pumps

There any many different types of pumps used in the manufacture of chocolate, but most fall into the following categories:

- Gear pumps
- Sliding vane pumps
- Lobe and rotary piston pumps
- Screw pumps
- Progressive cavity (mono) pumps
- Pawl pumps
- Positive displacement piston and diaphragm pumps.

11.5.1 Gear pumps

Internal gear pumps are suitable for use with high viscosity chocolates. In addition they provide a non-pulsating flow and are self-priming. Because they have only two moving parts they are reliable, simple to operate and easy to maintain (Figure 11.3). By reversing the drive motor, the pump can operate in either direction. This facility is particularly useful to drain a tempering machine prior to a change of chocolate.

There are several types of gear pumps, but the most common types found in the confectionery industry are the simple spur gear pump and the internal gear pump. The spur gear pump has two meshing gears that revolve in opposite directions and has a very small clearance between the gear and the body of the pump. The chocolate that fills the cavity between

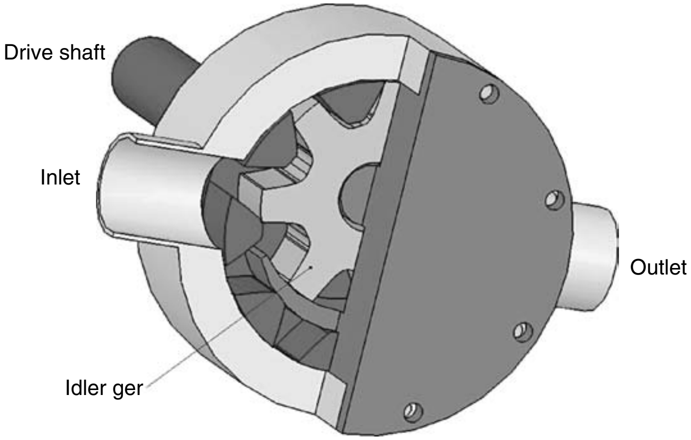

Figure 11.3 Internal gear pump.

two successive gear teeth must follow the rotation of the gear. When the gear teeth mesh together, the space between the teeth is closed and the entrapped chocolate is pushed out. As the gears revolve and the teeth disengage, the space on the low-pressure side of the pump is created, trapping new quantities of chocolate.

11.5.2 Sliding vane pumps

In a sliding vane pump the eccentric (off-centre) rotor incorporates sets of sliding vanes, which mechanically displace the fluid (Figure 11.4). Internal clearances although small, are required in this type of pump and therefore they cannot be truly classified as positive displacement pumps. By design this system of displacement creates a pulsation in the discharge flow from the pump. However these pumps can handle solids entrained in the chocolate.

These pumps are less suitable for applications that involve very high throughputs, high viscosity, or large pressure drops for example pumping over long distances.

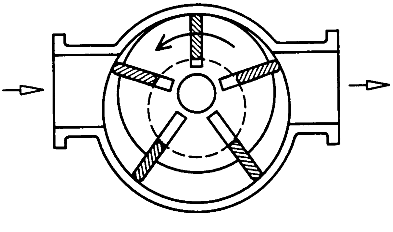

Figure 11.4 Mode of operation of a vane pump.

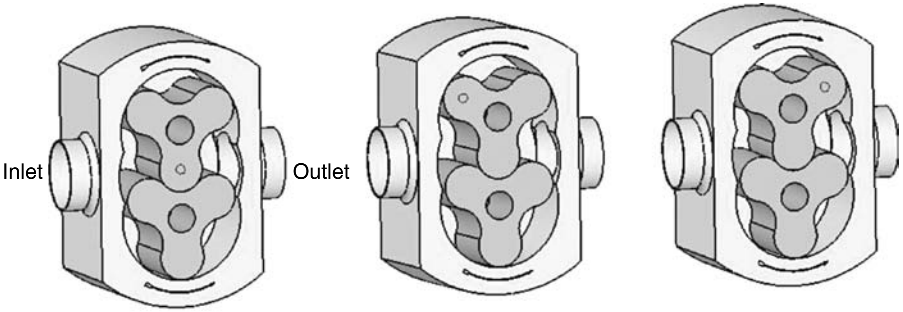

Figure 11.5 Mode of operation of a lobe pump.

11.5.3 Lobe and rotary piston pumps

Lobe pumps are similar to external gear pumps in operation in that fluid flows around the interior of the pump body (Figure 11.5). However in this case the lobes are prevented from making contact with each other by timing gears located in the external gearbox.

Rotary lobe pumps can handle large inclusions with minimal damage and a gentle pumping action minimizes product degradation. They are usually made from stainless steel and therefore can be cleaned with water. When the rotors have a covering of chocolate then the air gaps around them become ‘sealed’. This improves the efficiency of the pump to self-prime.

A lobe pump should not normally be used to move white chocolate, since severe caramelization of the chocolate can occur in the area of the lobe lock nut housing. (The front plate of the pump is recessed to fit around the locknut, and it is in this recess where chocolate can become heat damaged.)

11.5.4 Screw pumps

Screw pumps have been used for many years in the conveyance of bulk chocolate. They normally have two or three rotors. A twin-screw system is illustrated in Figure 11.6. As the twin screw systems is driven by a set of gears, situated in the gearbox, there is no contact between the two pumping screws. These pumps can operate equally well when driven in reverse and at low speed offer a gentle pumping action, together with a uniform flow with little pulsation or turbulence. They are available either manufactured from cast iron or stainless steel. Some designs can cope with inclusions in the product of up to 5 mm (0.2 in.).

The three rotor design comprises of a central rotor, which is connected to the drive motor and two idling satellite rotors which are driven by this central rotor. The rotors are encased in a closely fitting steel housing. The rotors are free to mesh together (there are no external timing gears). This therefore

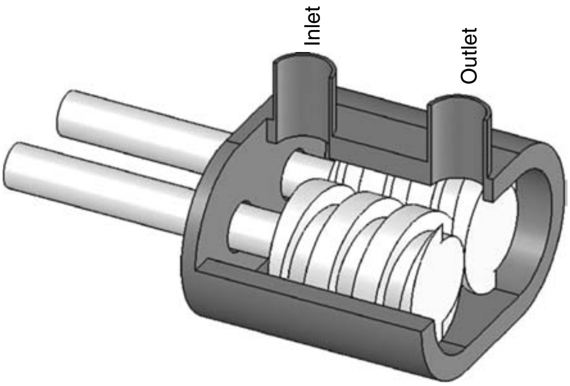

Figure 11.6 Illustration of twin screw pump.

consists of a sealed chamber through which the chocolate is conveyed. When the centre rotor is turned by the drive shaft these sealed chambers receive the chocolate to be pumped at the suction side of the pump and convey the medium in a uniform (non-pulsating) flow to the discharge port.

11.5.5 Pawl pumps

This type of pump is frequently used as a circulation pump in chocolate enrobers or to pump tempered chocolate. A gentle action is achieved by having a high conveying volume within the pump but operating at a very low speed. The central rotor is shaped so that two swept volumes of material are present within the pump. As the rotor turns, the material is pushed round the pump until it comes up against a scraper blade (Figure 11.7). This is forced against the rotor by a spring, which diverts the flow to the outlet and prevents the chocolate from re-circulating back into the suction area.

These pumps are suitable for medium pressure applications with or without inclusions such as nuts and raisins.

11.5.6 Progressive cavity mono pumps

The progressive cavity pump has a single helical rotor rolling eccentrically in a double thread helix of twice the pitch length. When the rotor turns it forms a series of sealed cavities, 180° apart, these progress from suction to discharge as the single helix rotates. As one cavity diminishes, the opposing cavity is increasing at exactly the same rate: so the sum of the two is constant. This results in a pulsation free flow which may contain particulate matter. The rotor is usually manufactured from hardened stainless steel and the stator from natural or synthetic rubber.

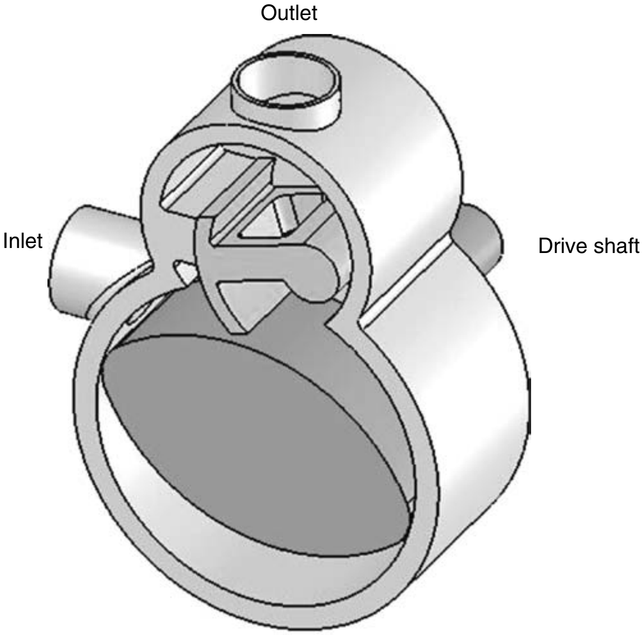

Figure 11.7 Operating principle of a pawl pump.

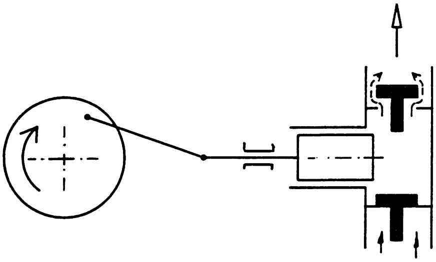

Figure 11.8 Positive displacement reciprocating plunger pump.

During continuous operation in a large-scale chocolate plant, wear of the stator may become a problem. This type of pump is versatile in small scale or pilot plants and it has been successfully used for metering applications. By increasing the length of the rotor–stator assembly it is possible to produce pumps for system pressures in excess of 30 bar.

11.5.7 Positive displacement piston and diaphragm pumps

The construction of this type of pump is illustrated in Figure 11.8. As the piston draws back, the lower valve lifts and liquid is pulled into the space created. On the return stroke, the lower valve is closed and the upper valve is opened, releasing the product into the pipeline. By adjusting the rotational speed of the drive or the eccentricity of the drive wheel, an accurate quantity of liquid can be displaced. This accuracy enables this type of pump to be used as a metering pump for cocoa mass and butter. In these cases the quantity of material to be moved is relatively small and the viscosity is low. However, care should be taken when choosing this type of pump to liquids that contain solid particulates such as nuts, which can get caught in the valves.

Diaphragm pumps use positive displacement to move liquids. They are similar in construction to the piston pump, but are designed with a diaphragm that seals the pumping chamber from the piston. This eliminates the problem of sealing the reciprocating piston, minimizing the possibility of leakage. The diaphragm is moved by means of a mechanical linkage, compressed air or a food grade liquid.

11.6 Pipeline pigging

Pipeline pigging was developed in the USA to clear the debris in crude oil pipelines. They are now widely used to clear pipelines carrying chocolate. The term ‘pig’ comes from when the device was first used to clear a pipe carrying a product with poor lubrication properties. The lack of a lubricant caused the projectile to squeal like a pig.

A pig acts like a free moving piston inside the pipeline, sealing against the inside wall with a number of elements and is propelled along the pipe by either compressed air or by other products. The compressed air used should be filtered to meet all hygiene requirements. The pig pushes any residual product from the pipe and via an open valve into a receiving tank. This technique allows a single pipe to be used to sequentially carry many batches of products with fast changeover times and without the lengthy process of disassembling the pipeline for cleaning. A diagram illustrating a pigging system is shown in Figure 11.9.

The pig should be manufactured from the correct grade of food compatible plastic such as polyurethane or neoprene, any swelling or change in colour of the pig could be caused by the absorption of fat or the leaching out of plasticizers into the chocolate.

Pigs generally need specially designed launching and receiving vessels and valves to introduce them into the pipe work. The pipeline should be designed in such a way as to not have any obstructions that may impede the movement of the pig along the pipeline. All ‘T’ junctions and ‘Y’ type fittings may have to have rails or bars welded across the openings to guide the pig past them. All in-line valves must be of the full port design with a 100% pipe size opening.

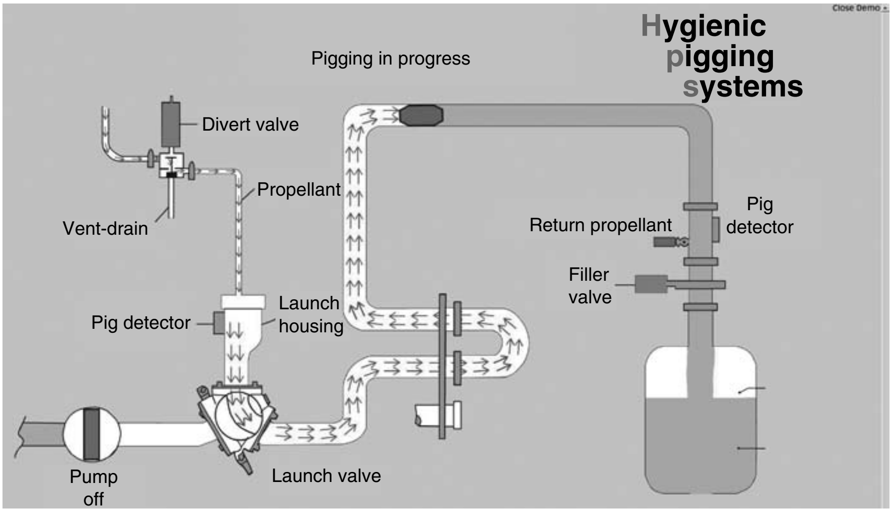

Figure 11.9 Diagram of pigging system.

11.7 Storage of liquid chocolate

Liquid milk chocolate should be stored between 40 and 45°C (103–110°F) and white chocolate from 38 to 40°C (100–103°F). In all cases however, care should be taken to ensure that the temperature of the chocolate is uniform throughout. Hot or cold areas can give rise to several problems and it is for this reason that the storage tank is constructed with a water-heated jacket. As in pipelines temperature control is important. At low temperatures the chocolate becomes viscous, making it difficult to stir and pump. There is also the possibility that if the chocolate becomes too viscous the stirring mechanism may be damaged.

The liquid chocolate in any tank or vessel requires agitation. Failure to do so results in fat separation from the solid chocolate particles. In extreme cases the sediment can cause damage to the pump and will prevent the flow of chocolate out of the tank. The rotational speed of the tank stirrer depends upon the diameter of the tank and the quantity of chocolate being stored. Recipes and manufacturing process also play an important part: some chocolates become thinner while others thicken. If the stirrer speed is insufficient, a puddle of fat will appear on top of the chocolate.

The above recommendations also apply to the bulk transportation of chocolate in road tankers. These are sometimes heated or have localized heaters, resulting in hot spots.

Chocolate that is shaken in unstirred tanks during transportation is also more likely to separate and have a fat layer on top. Some further mixing may therefore be required at the receiving factory.

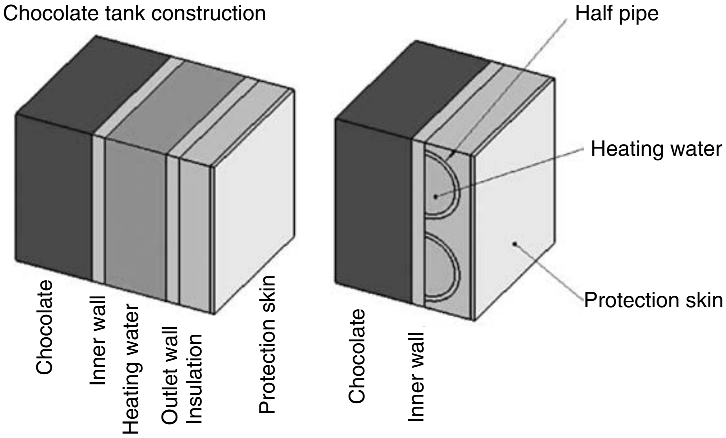

Figure 11.10 Illustration of sections through the walls of chocolate storage tanks.

The equilibrium relative humidity of most chocolate at 40°C (103°F) is about 30%. This means that if the relative humidity in the area where the chocolate is being stored is above 30% the chocolate will pick up moisture and this will increase the viscosity of the chocolate. Many tanks, especially those with built-in sieves are open to the atmosphere, therefore it is important to control the humidity of the room where the storage tank is sited, to avoid moisture pick-up. It is recommended that chocolate should have the minimum storage time possible.

Tanks manufactured from mild or stainless steel are used for the storage of chocolate and these can be constructed with a double skin jacket, a dimple jacket or a half-pipe jacket (see Figure 11.10). The tank should be insulated to conserve energy and to eliminate any cold spots. The water jacket of the tank, together with any associated jacketed pipe work, should be periodically examined for corrosion. The pressure of the water in the jacket should never exceed the working pressure of the vessel.

11.8 Jacketed pipe work

Jacketed pipe (Figure 11.11) can be manufactured from either mild steel or stainless steel. If mild steel is used the pipe will be joined with flanges and gaskets. For stainless-steel pipes, flanges or hygienic unions can be used, these are available to the maximum size of 100 mm (4 in.) and for most types the generally accepted maximum pressure rating is 10 bar. Wherever possible an over pressure protection device should be fitted into the pipe work, preferably just after the pump. This can be either a conventional spring operated valve or a pressure transducer interlocked with the stop circuit of the pump.

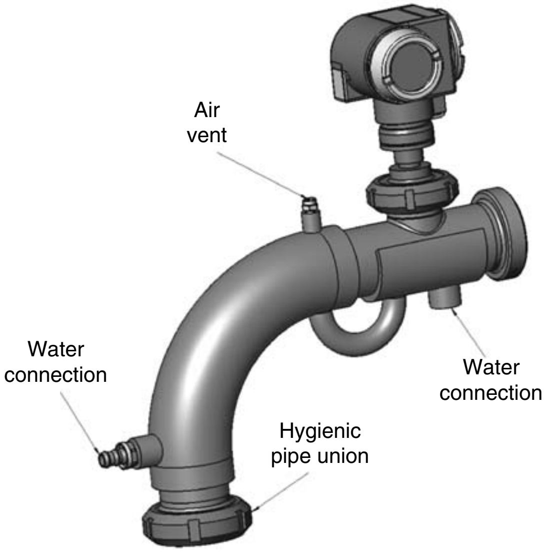

Figure 11.11 Illustration of section of lagged pipeline with pressure transmitter.

For stainless-steel jacketed pipe it is recommended that type 316 stainless steel is used throughout and good manufacturing practices should be used at all times during the welding process. On completion both the jacket and the internal pipe should be pressure tested.

11.9 Contamination removal

11.9.1 Magnets

The equipment used to manufacture chocolate is, more often than not, made from carbon steel of various grades. Wear of these machines can contaminate the chocolate with small amounts of ferrous material. Magnet traps, fitted into the pipeline, have been used to successfully remove ferrous contamination. The magnets are encapsulated in stainless steel and form a matrix of fingers that the chocolate flows around. The magnets are fixed into a water-jacketed housing and periodically they need to be removed for cleaning. Usually, the magnetic trap can only be installed in pipelines that operate below 5 bars and so are often installed in the feed to a tempering machine.

11.9.2 Sieving

It must be remembered that magnets cannot remove stainless steel and aluminium contamination. These and other hard particles can be removed by sieving. The position of the sieve may need careful consideration. It is normally recommended that a sieve is installed prior to the feed tank to chocolate tempering machines.

Conclusions

Pumps and pipelines are one of the least glamorous parts of chocolate manufacture. They are however extremely important and need to be chosen and designed correctly. If done well they can run without trouble for many years. An incorrect decision can result in large losses of production and even product recalls.

Chapter 12

CHOCOLATE TEMPER

G. Talbot

12.1 Introduction

Cocoa butter, because of its relatively simple composition, is highly polymorphic (i.e. crystallizes in many different crystal forms, see Section 12.2). Chocolate processing is strongly linked to the crystallization and polymorphic behaviour of the fat phase. Before chocolate can be satisfactorily processed from liquid to solid, it must be tempered. This is a technique of controlled crystallization, which is necessary to induce the most stable solid form of cocoa butter in the finished product.

12.2 Polymorphism of cocoa butter

Polymorphism is the ability of a molecule to crystallize in a number of different crystal packing configurations. While polymorphism is present in most fats, those rich in symmetrical monounsaturated triglycerides such as SOS (i.e. whose structure is saturated fatty acid–oleic acid–saturated fatty acid) are highly polymorphic. This high degree of polymorphism is not only found in cocoa butter, but also in those SOS-rich fat used in cocoa butter equivalents (Chapter 19). Historically, six different polymorphic forms have been identified for cocoa butter, although more recent research has suggested that this may not be the case. Traditionally, the confectionery industry has considered the polymorphism of cocoa butter to be that as defined by Wille and Lutton (1966) in which six forms are given the names Form I to Form VI. In the oils and fats industry, the convention is to use the Greek letters α, β and γ to define polymorphic forms. The β form is sub-divided into β and β' forms. While Wille and Lutton were using Form I to Form VI to define the polymorphism of cocoa butter, Larsson (1966) was using this Greek letter nomenclature. In general as we move from γ to α to β' to β the stability and the melting point of the polymorphic form increases. In tempering chocolate it is necessary to crystallize the cocoa butter in as stable a polymorphic form as possible.

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Table 12.1 Polymorphic forms of cocoa butter.

Wille and Lutton (1966)	Larsson (1966)	Van Malssen *et al.* (1999)	Chain packing
Form I	β'_2	γ or sub-α	Double
Form II	α	α	Double
Form III	Mixed	β' range	Double
Form IV	β'_1		Double
Form V	β'_2	β_V	Triple
Form VI	β'_1	β_{VI}	Triple

Table 12.2 Melting points (°C) (°F in parentheses) of polymorphic forms of cocoa butter.

Polymorphic form	Wille and Lutton (1966)	Van Malssen *et al.* (1999)
Sub-α/Form I	17.3 (63)	−5 to +5 (23–41)
α/Form II	23.3 (74)	17–22 (63–72)
β'/Form III	25.5 (78)	20–27 (68–81)
β'/Form IV	27.5 (82)	
β/Form V	33.8 (93)	29–34 (84–93)
β/Form VI	36.3 (97)	

More recent work by van Malssen *et al.* (1999) has, however, suggested that not only were both Wille and Lutton and Larsson wrong in their assignments of polymorphic form, they were also wrong in the melting points that they defined for each individual polymorphic form. Van Malssen *et al.* (1999) found only five polymorphic forms in cocoa butter. The assignments of each form by these three groups of researchers is shown in Table 12.1. The difference between the 'traditional' polymorphic assignments and those of van Malssen *et al.* is that the latter group found not two β' forms but a range of these indicating the presence of either five forms (if the range is treated as a single form) or many forms (if the polymorphic forms in the range are treated individually).

Van Malssen *et al.* (1999) also found that the melting points of each of the polymorphic forms had been wrongly assigned by Wille and Lutton and that the melting point of the lowest stability form (Form I or γ/sub-α) was significantly lower than that measured by Wille and Lutton, mainly because this form very quickly transforms into the α form making determination of its melting point quite difficult. For comparison, the melting points assigned to each of these polymorphs by both groups (Wille and Lutton and van Malssen *et al.*) are shown in Table 12.2.

Because of the familiarity in the confectionery industry with the Wille and Lutton convention this will be used in the rest of this chapter interchangeably with the new convention defined by van Malssen *et al*. To allow

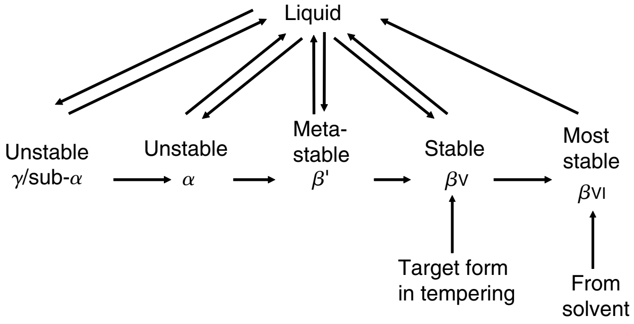


Figure 12.1 Polymorphic changes in cocoa butter. Reprinted with permission of Loders Croklaan.

for the presence of a range of β' forms as defined by van Malssen *et al.*, Forms III and IV will be treated as a single form when using the Wille and Lutton convention.

Form I (sub-α) is produced by rapid cooling at low temperatures. It is very unstable and rapidly transforms into Form II (α). This form will change more slowly into Forms III and IV (β').

β' is the polymorphic form which would generally be produced if untempered or extremely poorly tempered chocolate were then cooled in a cooling tunnel, as though it were properly tempered. This form will also fairly rapidly (sometimes even before leaving the cooling tunnel) transform into Form V (β).

Forms V and VI or the β forms are the most stable forms of cocoa butter. Form V is the state which is produced in a well-tempered chocolate. On lengthy storage this can very slowly transform into Form Vl, a change which is often accompanied by the formation of fat bloom. It is difficult to generate Form Vl cocoa butter quickly and directly, although this has been observed when cocoa butter is allowed to crystallize from a solvent (Figure 12.1).

These different polymorphic forms or packing configurations are characterized by differences in the distances between the glyceride chains and in the 'angle of tilt' relative to the plane of the end methyl group of the chain (see Figure 12.2).

The three main polymorphic forms found in fats (not only in cocoa butter); α, β' and β have crystal packing configurations as shown in Figure 12.2. The α configuration has alkyl (fatty acid) chains which are both straight and parallel to each other, but which are also perpendicular to the end planes of the molecules. If we were to look end-on at the chains they would appear to have a cross-section of hexagonal symmetry reminiscent of looking end-on at a clump of pencils.

The β' and β polymorphs show considerably more order in their crystal packing. Both display an angle of tilt relative to the end plane of

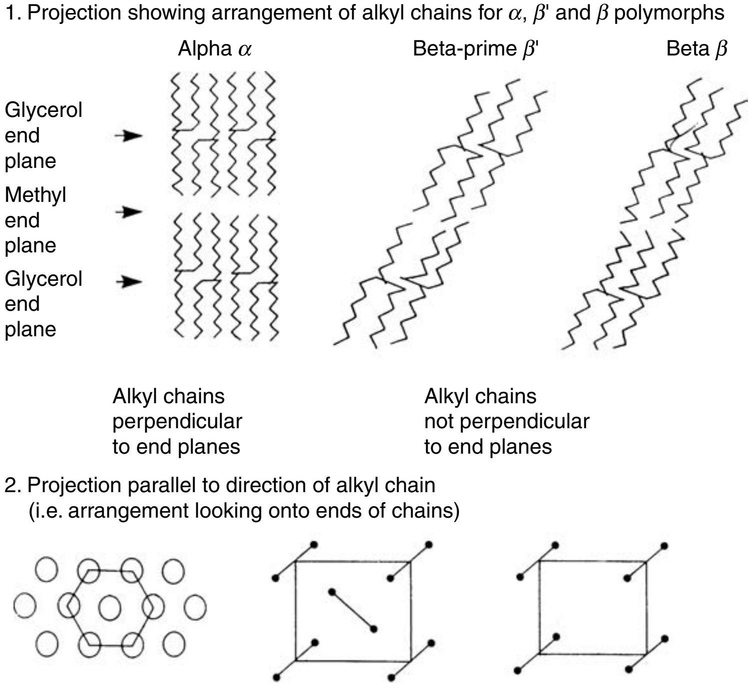


Figure 12.2 Crystal packing of triglycerides. (a) Projection showing arrangement of alkyl chains for α, β and β' polymorphs. (b) Projection parallel to direction of alkyl chain (i.e. arrangement looking onto ends of chains). Reprinted with permission of Loders Croklaan.

the molecules. This angle is slightly greater (i.e. closer to perpendicular) in the β' form than in the β form. In the β' form the chains pack in an orthorhombic sub-cell in which adjacent zigzag fatty acid planes are mutually perpendicular when viewed end-on. In the β form the chains pack in a triclinic sub-cell with all the zigzag fatty acid chains being parallel to each other.

These polymorphic forms can be characterized by X-ray diffraction and, particularly, by their X-ray short spacings, i.e.

α – Single strong line at 4.15 Å
β' – Two lines at 3.8 Å and 4.2 Å
β – One strong line at 4.6 Å.

More subtle differences are observed in the X-ray diffraction patterns of the various sub-forms, for example β_2 and β_1. Both these forms show four smaller peaks in addition to the strong peak identified above. In the β_2 form (or Form V in cocoa butter) these small peaks are of varying intensities, whereas in the β_1 form (or Form V1 in cocoa butter) they are of intensities which increase with diffraction angle (see Figure 12.3). Note that in the context of cocoa butter β_2 and β_{V} are now often used interchangeably as are β_1 and β_{VI}.

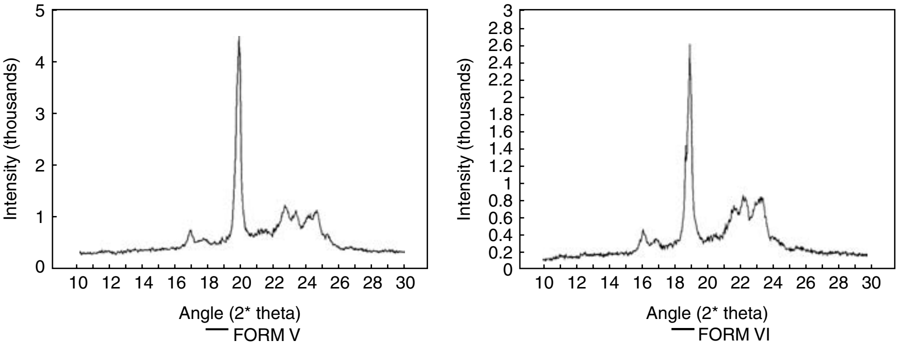


Figure 12.3 X-ray diffraction patterns of Form V and Form VI cocoa butter. Reprinted with permission of Loders Croklaan.

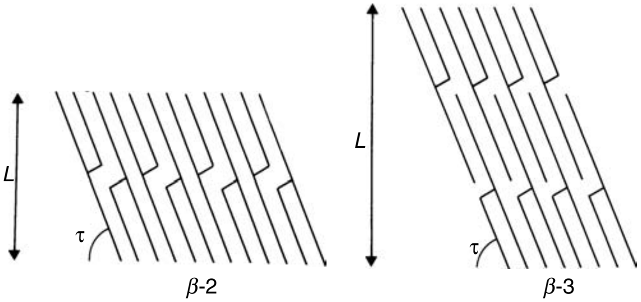


Figure 12.4 Schematic arrangement of triglycerides in the *β*-2 and *β*-3 crystalline phase. Reprinted with permission of Loders Croklaan.

In addition to these different polymorphic forms there is a further way in which different triglycerides can pack or crystallize together – the so-called double-chain length (denoted by '-2' after the Greek letter signifying the polymorphic form, e.g. *β*-2) and triple-chain length packing (denoted by '-3' after the Greek letter signifying the polymorphic form, e.g. *β*-3). Although such nomenclature can be confusing it should be remembered that β_2 and *β*-2 mean two different things – the former denotes the less stable of the two *β* forms, the latter denotes any *β* form in a double-chain length configuration. The molecules shown in Figure 12.2 are depicted in a double-chain system in which the distance from one methyl end plane to the next is approximately the length of two fatty acid chains. Double and triple systems are shown schematically in Figure 12.4.

The two forms differ, therefore, in that the distance from one methyl end plane to the next is approximately the length of two fatty acid chains in the *β*-2 system and of three fatty acid chains in the *β*-3 system. X-ray long spacings will define in which of the two ways a particular fat is packed. The long spacing of *β*-3 *is* approximately 50% greater than the long spacing of *β*-2.

Whether a fat crystallizes in a double or triple chain form is usually dictated by its triglyceride composition and, particularly, by the positional distribution of fatty acids on the triglyceride. The triglycerides in cocoa butter are predominantly of the SOS type, i.e. with the unsaturated oleic acid in the 2-position. The double bond in oleic acid causes an angular change in the fatty acid chain which means that it no longer has the 'straight' structure of a saturated chain. If such triglycerides were to crystallize in a double chain form or β-2 the unsaturated acid in the 2-position of one molecule would be adjacent to the saturated acids in the 1- and 3-positions of the next molecule. The stereochemistry would be such that close packing of the triglyceride molecules would not be possible. If, however, these triglycerides pack in the triple chain form or β-3, then the unsaturated chain in the 2-position of one molecule would lie adjacent to the unsaturated chain in the 2-position of the next molecule. It was long thought that they did this in such a way that the positions of the double bonds in the oleic acid chains were next to each other with the chains nesting together almost like spoons. Recent work by Peschar *et al.* (2004) suggests that this is not the case, but that only the end parts of the oleic acid chain (from the double bond to the methyl end group) are actually adjacent to each other. This enables much closer triglyceride packing and hence much greater thermodynamic stability. It has been shown that in Forms III and IV cocoa butter the triglycerides pack in a double-chain system, whereas in Form V they pack in a triple-chain system. The stereochemical problem of SOS triglycerides packing in a double-chain system accounts for the much lower thermodynamic stability of Form IV relative to the triple-chain Form V.

Whilst considering the structure of oleic acid in the cocoa butter molecule and how this might affect crystal packing, it is also worth mentioning some work carried out by Unilever Research in Holland on the structure of oleic acid (de Jong *et al.*, 1991). Several structures of oleic acid have been defined. Amongst these one has the 'conventional' bend in the chain where the unsaturated double bond occurs (between carbon atoms 9 and 10), whereas another has a further rotation of the chain around a carbon–carbon single bond adjacent to the double bond (see Figure 12.5). This rotation effectively straightens out the chain.

12.3 Relationship between polymorphism and chocolate tempering

What is the relevance of all this to the tempering of chocolate? As we have seen, the various polymorphic forms of a fat arise because the triglyceride molecules are able to arrange themselves in the fat crystal in different ways. This affects both the melting point of the fat and its physical volume in the solid mass. Which polymorphic form is produced is determined by the

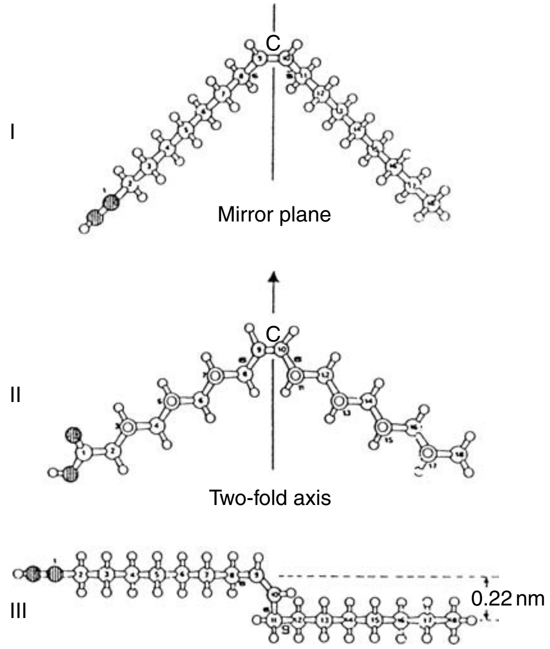


Figure 12.5 Alternative conformations of oleic acid. Reproduced from de Jong *et al.* (1991), copyright 1991 with permission from AOCS Press.

processing conditions used. Lower polymorphic forms are less stable and tend to transform to higher melting, more stable forms. This transformation results in a closer packing of crystals in the fat and hence in a decrease in volume. This can manifest itself in a number of ways – as an overall contraction of the fat, as a change in the physical appearance (e.g. smooth surfaces become rough), or as visible recrystallization (e.g. surface fat bloom formation).

The rate at which polymorphic changes occur depends on the relative stabilities of the various polymorphic forms and on the temperatures at which they are held. Rapid chilling of a molten untempered chocolate masse gives a relatively unstable polymorphic form of cocoa butter and hence a product which is difficult to demould and whose surface appearance rapidly deteriorates. Subsequent polymorphic transitions result in surface defects and, if they occur during demoulding, they may impede release from the mould because of re-growth of crystals. In the longer term they will shorten the shelf-life of the chocolate by promoting the formation of fat bloom.

The object of tempering is therefore to develop a sufficient number of seed crystals to encourage the total fat phase to crystallize in a more stable polymorphic form. This in turn will produce a better overall contraction and a more stable product.

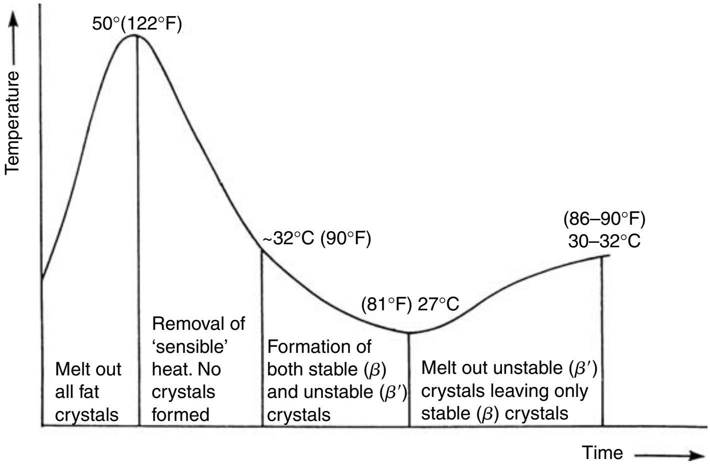


Figure 12.6 Milk chocolate tempering sequence. Reprinted with permission of Loders Croklaan.

12.4 Tempering

Tempering ensures that cocoa butter (and, indeed, cocoa butter equivalents) crystallize in the stable form. The most commonly used method of tempering involves the following steps:

(1) Complete melting
(2) Cooling to the point of crystallization
(3) Crystallization
(4) Melting out of unstable crystals.

The tempering sequence for milk chocolate is shown in Figure 12.6. Temperatures for dark chocolate would be 2–3°C (3–6°F) higher than those indicated. However, precise temperatures can vary depending upon recipe, tempering equipment and even the purpose for which the chocolate will be used.

Chocolate should first of all be heated to approximately 50°C (112°F) to ensure complete melting of the fat and no attempt should be made to proceed to the next stage until all the chocolate is completely liquid. The melted chocolate is then cooled and mixed to induce crystallization. Before the invention of tempering machines, this process was carried out by pouring the chocolate on to a marble slab and mixing it with a flexible spatula until it began to thicken. At this point both stable and unstable polymorphic forms were crystallized, and the thick 'mush' was mixed into a bowl of warm chocolate to melt out the unstable crystals prior to use. At this stage the chocolate was tempered. Although this method is still used by chocolatiers producing very small quantities of hand-made confections, many different tempering methods have been developed over the years and continuous

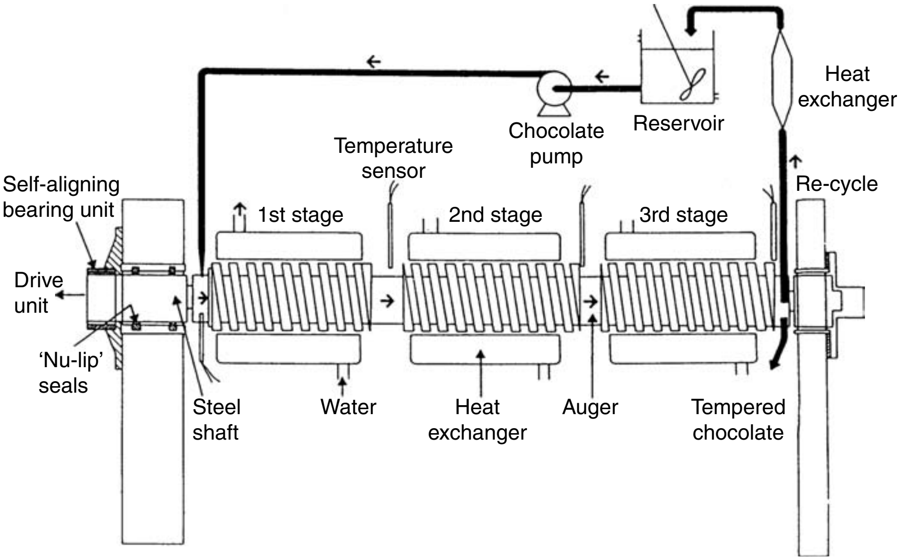
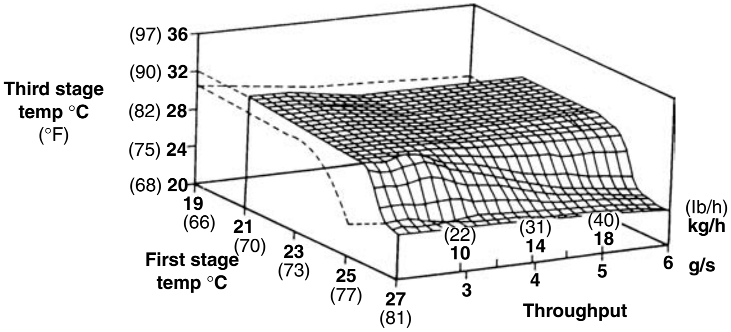


Figure 12.7 Three-stage tempering unit. Reprinted with permission of Loders Croklaan.

automatic tempering units are now widely used. These are usually multi-stage heat exchangers through which the chocolate passes and their use is described in detail in Chapter 13. The temperature of the stages are set to follow the type of profile shown in Figure 12.6 so that crystallization is first induced in both stable and unstable forms and, subsequently, the unstable form is melted out by raising the final chocolate temperature. The varying throughput of these units makes it difficult to give standard tempering conditions. Indeed there is probably not a unique set of conditions needed to achieve temper with a given chocolate in a given tempering unit, but a wide range of conditions, all of which will result in tempered chocolate. This was confirmed by studies carried out by Cebula *et al.* (1991) using a laboratory continuous 3-stage tempering unit. This unit is shown schematically in Figure 12.7. It consists of three swept-surface heat exchangers in series. Chocolate is pumped into the unit and a worm screw drives the material through the heat exchangers. Coolant temperatures and flow rates can be accurately set so as to achieve any desired variations in heat transfer capacity. Sensors are located at important points in the apparatus to measure the temperature of both the chocolate and the coolant fluid.

The temperatures of each of the three stages can thus be set and controlled independently of each other. To reduce the number of variables, a second stage temperature 1.5°C (2.7°F) below the first stage temperature was used. The experimental method used was to set the first and second stage temperatures and the flow rate and to vary the third stage temperature until 'temper' had been achieved. By subsequently varying the first (and second) stage temperatures and redetermining the required third

(a) Cocoa butter 95%, butter fat 5%



(b) Cocoa butter 75%, butter fat 25%

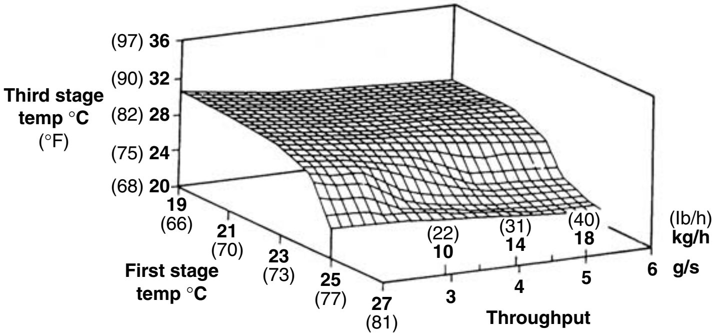


Figure 12.8 Three-stage tempering unit 'surface of temper'. Reprinted with permission of Loders Croklaan.

stage temperature to give temper, a 'temper surface' can be defined for the range of temperatures at which the chocolate will be tempered. This can be further extended by repeating at different throughput rates to give a three-dimensional temper surface such as that shown in Figure 12.8. In this experiment, temper was defined according to the measured temper curve, where all the samples showed a plateau (Figure 12.9). On each 'surface' all samples are at temper. Above the 'surface' products will be under-tempered and below they will be over-tempered. Thus there is no unique set of processing conditions to produce tempered chocolate. Instead a rather complex, but evidently general, relationship exists between the various temperature and flow rates.

Two regions are evident. Firstly, at lower first stage temperature (T_1) settings, the final stage temperature (T_3) required is practically independent of either the first (and second) stage temperature or the flow rate. The actual value of the third stage temperature attained for the plateau temperature is probably governed by the melting point of Form V of the fat phase.

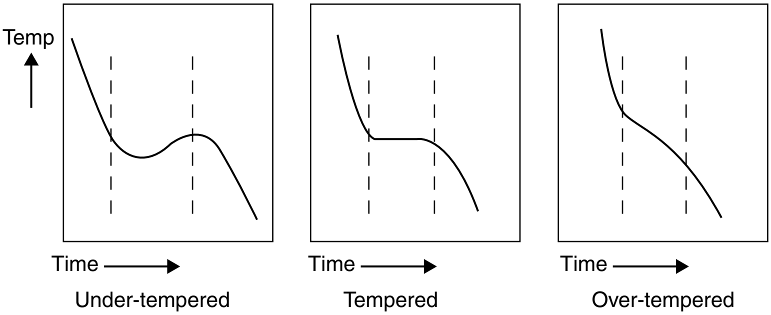


Figure 12.9 Typical tempermeter curves.

Secondly, at much higher first stage temperatures, there is a sharp drop in the final stage temperature required. This happens because when T_1 is not very low, nucleation rates of unstable fat crystals are considerably reduced. To compensate for this effect, a much lower T_3 is required. The T_1 value at which the drop appears is probably governed by the melting point of the unstable fat crystals.

One of the many series of experiments which have been carried out using this apparatus compared the tempering characteristics of a chocolate whose fat phase was composed of 95% cocoa butter +5% milk fat with one whose fat phase was composed of 75% cocoa butter +25% milk fat. The temper surfaces of these two chocolates are shown in Figure 12.8. The differences between them, in processing terms at least, are the positions of the surfaces with respect to the temperature axes.

For the low milk fat chocolate the temperatures are a degree or so higher at each stage and the 'plateau' region extends to higher temperatures. In some respects the low milk fat chocolate might be considered as easier to temper. Less undercooling is required to induce the production of the required stable polymorph in the fat and moreover, the 'plateau' region, at constant third stage temperatures, extends to much higher first stage temperatures.

For ease of comparison the edge of the temper surface for the 75/25 cocoa butter/milk fat system (Figure 12.8b) is shown as a dashed line on the diagram for 95/5 cocoa butter/milk fat (Figure 12.8a).

12.5 Measurement of temper

Although traditionally chocolatiers have been able to tell whether chocolate was in temper by subjectively observing the cooling effect of a 'dab' of chocolate on the lip, more scientific, instrumental methods are now used by industrial chocolate manufacturers. The instruments or tempermeters all rely on the measurement of a cooling curve of the chocolate, as the fat in the chocolate cools in a specified way. This cooling curve is printed on a chart recorder and the degree of temper is determined by the shape of the curve. Tempermeters such as those produced by Greer and Sollich (see Chapters 13 and 22) rely on the operator′s experience in judging the shape of the resulting curve. More recently, Tricor Systems in the United States have produced a tempermeter which uses a built-in algorithm to calculate the degree of temper in CTUs (Chocolate Temper Units) which can then be used numerically to define the state of temper (Chapter 22). Although there are some differences between the two types of apparatus the basic principles are the same.

In the Sollich/Greer equipment a thermistor probe is inserted in a chocolate sample contained in a metal tube, which is placed in an ice-water bath to give a constant cooling rate. In the Tricor system the temperature probe is integral in the instrument and a disposable sample cup containing the chocolate is inserted in the instrument. The temperature probe punctures the cup so that it is always centralized in the sample. Cooling is by means of a thermo-electric cooler rather than an ice-water bath.

Both methods produce the same shapes of temper curves. Figure 12.9 illustrates the degrees of crystallization which can be developed during the tempering process. This diagram illustrates curves relating to three states of temper – undertemper, temper and overtemper. The curves can be considered in three parts.

The first part is similar in all cases and simply registers the cooling of liquid chocolate prior to solidification. The second part is the most important in defining the state of temper and is therefore the one which shows the greatest difference between the three curves. As the fat solidifies it releases heat of crystallization which is shown on the curve as a change in slope. If the fat is undertempered (i.e. insufficient stable fat crystals have been produced in the temperer to induce further stable crystallization in the masse) the chocolate cools to quite a low temperature before crystallization begins. The low temperature then causes crystallization to proceed quite rapidly and thus the rate of heat released as the chocolate solidifies is high. The rate of heat released is greater than that at which it can be removed by the coolant bath, because the temperature differential between the chocolate and the ice/water bath is relatively small (Smith, 2006). Therefore, during the second part of the temper curve the temperature rises. Conversely, if the fat is overtempered more crystallization has already occurred before measuring the temper curve and hence there are many more seed crystals. When chocolate is overtempered it cools less in the tempermeter before crystallization starts compared with the undertempered case. This means that the temperature differential between the chocolate and the cooling bath is greater at this earlier stage than with an undertempered chocolate. The combination of this increased temperature differential and the slower crystallization (due to the higher temperature) means that the latent heat of crystallization can be more easily removed and so the temperature of the chocolate continues to decrease, albeit at a slower rate than in the initial phase before crystallization starts.

In a perfectly tempered chocolate, the rate of heat released by crystallization is exactly balanced by the rate of heat removal by the ice-water bath and a plateau is observed on the tempermeter curve.

The third part of the tempermeter curve is again similar in all cases and shows further temperature reduction as the ice-water cools the sample further.

It must be remembered that tempered, and under- and over-tempered are just terms to describe the curves. When operating a plant, any one of these may be the correct one for the product concerned. It will strongly depend upon the temperer and recipe of chocolate used.

12.6 Tempering by seeding

During the previous description of the events which take place during the tempering of chocolate, the importance was stressed of having sufficient polymorphically stable cocoa butter seeds to nucleate the bulk of the remaining fat in the stable β form. However, great reliance is placed on the ability of tempering machines to achieve sufficient numbers of these polymorphically stable seeds by basically a process of temperature changes. The fact that chocolate has been tempered in this way for many years shows that it is successful, but a potentially simpler and more reliable way would be to positively 'seed' untempered chocolate.

During the tempering process there are three major groups of triglycerides which can crystallize from cocoa butter. In chocolates which contain a small but significant level of long-chain trisaturated triglycerides (SSS), these will start to crystallize first from the molten mass (Figure 12.10). These triglycerides do not contribute to the 'temper' of the chocolate. Indeed, the only effect they have is to increase the viscosity of the tempered chocolate, because their crystallization reduces the amount of liquid fat in the chocolate. Then the

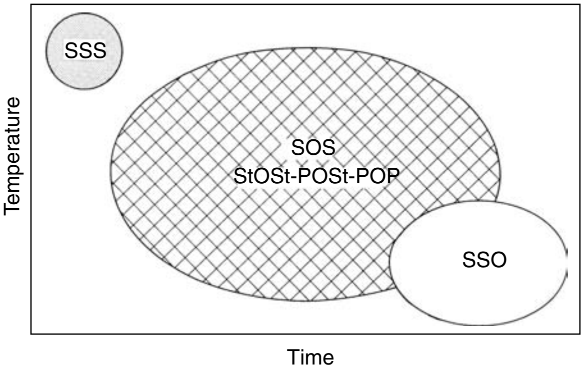


Figure 12.10 Crystallization of triglyceride groups during tempering.

SOS triglycerides (the StOSt, POSt and POP of the cocoa butter) will begin to crystallize. It is these triglycerides which give chocolate its 'temper' and which will seed the bulk of the chocolate in a polymorphically stable form. If the temper in the chocolate is allowed to build up, then the asymmetrical form of the SOS triglycerides, the SSO (saturated–saturated–oleic) group, which is present at a much lower extent in cocoa butter, can begin to crystallize.

If a finely powdered fat, which is rich in SOS triglycerides and which is already in a polymorphically stable form, could be added to chocolate then this would have a number of advantages:

- the correct amount of the correct seed would be assured in the chocolate;
- the viscosity increase associated with trisaturated triglyceride crystallization would be prevented;
- the equipment needed would potentially be simpler, being a simple mixing pump and a simple heat exchanger.

This is the basis of a patent from Loders Croklaan (Cain, 1991), which describes the seeding of untempered chocolate with SOS-rich crystals slurried in a liquid oil carrier and proportioned into untempered chocolate.

A variation of this method has been developed by the Fuji Oil Company in Japan. In this case the triglycerides used in the seeding material are rich in BOB (1,3-behenoyl, 2-oleoylglycerol). This triglyceride contains two behenic (C22) acid groups, which raise the melting point of the triglyceride to about 53°C (127°F), i.e. well above the melting point of the chocolate. Thus, if the chocolate is raised to a temperature above its normal melting point, but below the melting point of the BOB seeds, it is claimed that the chocolate does not bloom. This is because the residual solid BOB is able to re-seed the chocolate in a stable polymorphic form (Koyano *et al.*, 1990).

Summary

Because cocoa butter (and cocoa butter equivalents) are able to crystallize in a number of polymorphic crystal forms, it is necessary to temper chocolate containing these fats in order to promote crystallization in a thermodynamically stable polymorphic form.

Tempering in general involves reducing the temperature of the chocolate to induce crystallization of both stable and unstable polymorphs. The temperature is subsequently raised to a point where the unstable polymorphs melt leaving only polymorphically stable crystals, which can then 'seed' the crystallization of the bulk chocolate in a stable polymorphic form.

The actual temperatures needed to temper chocolate vary depending both on the equipment being used and on the fat phase composition of the chocolate, for example milk chocolate needs lower tempering temperatures than dark chocolate. However, it has been found that there is not a unique set of conditions for tempering a given chocolate, but different combinations of tempering temperatures and flow rates can result in equally well-tempered chocolate.

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Chapter 13
TEMPERING

E.J. Windhab

13.1 Introduction

Chocolate tempering is a process in which chocolate masse is thermally treated to produce a small fraction of homogeneously dispersed, highly stable fat crystals of the correct type and size. These crystals then seed the masse and grow to form a micro-homogeneous solid fat crystal network during the cooling stage following moulding or coating/enrobing.

The important effects of tempering the liquid chocolate masse are:

(1) adjustment of the yield value and viscosity for moulding, coating or enrobing (Chapters 10, 11 and 14).
(2) long-term stability of the chocolate flow properties under moulding, coating or enrobing conditions

and also results in the final solidified product having:

(3) good surface gloss and colour
(4) good snap
(5) smooth and fast melting
(6) good heat stability.

When considering the strong impact of tempering on these very important quality characteristics, there is an obvious need to quantitatively understand the effect of the tempering process on (a) the fat crystal structure (b) the chocolate itself and (c) the relationship between the two. The temper-related properties are determined by the fat micro-structure, which can be tailored by the tempering process.

From a fundamental research point of view, it is important to understand and characterize both the process–structure and the structure–property relationships.

Major *processing aspects* that have to be considered are:

(1) the fat/chocolate masse pre-heating
(2) the thermal and mechanical (flow) history of the chocolate masse in the tempering device

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(3) the post treatment of the tempered chocolate masse in pumps, moulding devices, coating devices/enrobers
(4) the cooling and solidification process
(5) post tempering and storage temperature conditions
(6) the factory environmental conditions.

Tempering-related *structural aspects* are:

(1) the fat crystal fraction
(2) the fat crystal size distribution
(3) the fat crystal polymorph distribution (the relative amount of each type of crystal present)
(4) the fat crystal network density (total amount of crystal) and its homogeneity
(5) the crystallization kinetics (how fast the fat will set)
(6) the polymorph transformation kinetics (how fast one type of crystal changes into another) and
(7) the migration kinetics of liquid components through the fat crystal/particle network (how fast the liquid fat components move through the solid network formed by the fat crystals and the other solid components).

13.2 Physics of cocoa butter crystallization (see also Chapter 12)

Chemically fats are triglycerides with three fatty acids connected to a glycerine molecule. Most fat systems form crystals with several different polymorph (same chemical composition different molecular arrangement) structures. For fats containing only a small number of triglycerides like cocoa butter (with SOS, POP, SOP triglycerides; S denoting stearic acid, P palmitic acid and O oleic acid) up to six different polymorphs have been identified (γ, α, β_{III}, β_{IV}, β_{V}, β_{VI}). Different crystal types are formed depending upon the steric (ability to fit together because of shape) or energetic compatibility of the molecules, the temperature/temperature gradients they are submitted to and for how long this takes place. The higher the temperature and the longer the crystal formation time, the denser and more perfect molecular ordering occurs, i.e. the individual molecules can pack more closely together giving higher crystal density. This is demonstrated in Figure 13.1. and Table 13.1.

Different forms of nomenclature for the polymorphs are shown in Table 13.1. Within the chocolate industry and the scientific community it is accepted that the β_{V} cocoa butter crystal polymorph is the most preferable in chocolate with respect to giving the best overall surface gloss, colour, hardness/snap, smooth melting and shelf-life (heat shock) characteristics.

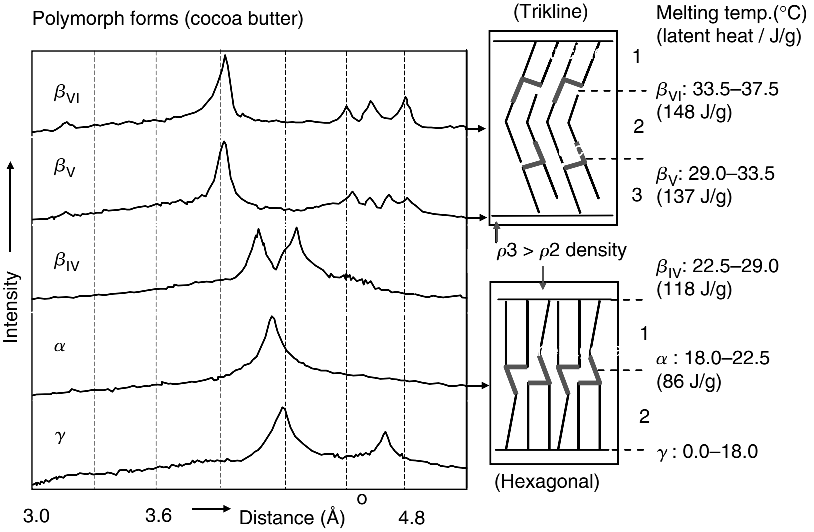


Figure 13.1 Cocoa butter polymorph characteristics.

Table 13.1 Melting temperatures/melting temperature ranges of cocoa butter polymorphs °C (°F in brackets).

Vaek (1951)	**Duck (1963)**	**Wille and Lutton (1966)**	**Lovegren *et al.* (1976)**	**Dimick and Manning (1987) Onset peak max.**	**Windhab and Zeng (1998) Melting range**
γ 18.0 (64)	γ 18.0 (64)	I 17.3 (63)	VI 13 (55)	13.1 (55) 17.6 (63.5)	γ 13.0–18.0 (55–64)
α 23.5 (74)	α 23.5 (74)	II 23.3 (74)	V 20 (68)	17.6 (63.5) 19.9 (68)	α 18.0–22.5 (64–72)
		III 25.5 (78)	IV 23 (73)	22.4 (72) 24.5 (76)	III 22.5–27.0 (72–81)
β'' 28.0 (82)	β'' 28.0 (82)	IV 27.5 (81.5)	III 25 (77)	26.4 (79) 27.9 (82)	β_{IV} 27.0–29.0 (81–84)
β 34.4 (94)	β' 33.0 (91)	V 33.8 (92)	II 30 (86)	30.7 (87) 34.4 (94)	β_{V} 29.0–33.5 (84–92)
	β 34.4 (94)	VI 36.3 (97)	I 33.5 (92)	33.8 (93) 34.1 (93.5)	β_{VI} 33.5–37.5 (92–99.5)

13.3 Chocolate tempering technology

Chocolate and similar coatings are produced according to many different recipe formulations (Chapter 20), but all contain a mixture of finely milled solids (cocoa, sugar, milk crumb or powder), suspended and well dispersed in cocoa butter with or without milk and substitute fats, which at normal processing temperatures is the liquid carrying medium.

For conventional tempering machines, it has been reported that 2–4% of the fat solidifies during tempering according to the type of temperer and hence an increase in viscosity can be seen, because there is now significantly less liquid fat present. As a general rule for such tempering machines, the viscosity increases by a factor of about two from the incoming chocolate to that leaving the tempering unit, although this may be greater if cooling conditions are exceeded. 1.5–3 Pa s (Casson plastic viscosity) has been reported to be a typical increase (Windhab *et al.*, 1991).

New tempering processes, like seed tempering, produce very finely dispersed cocoa butter seed crystals contained in a cocoa butter melt. Such suspensions contain about 10–20% of solid fat and if 0.2–1% of this is added to untempered chocolate (equivalent to 0.02–0.2% of solid crystals) it still guarantees a good temper and gives excellent product characteristics (Windhab and Zeng, 1998). Recent work on conventional chocolate tempering with improved analytical instrumentation (NMR, DSC) has also demonstrated that there can be less than 1% of fat in crystallized form after 'good' tempering (Padar and Windhab, 2007).

Owing to the fact that tempered chocolate is not in a thermodynamic equilibrium, another factor, time, has a crucial influence on the temper state or quality. Time and temperature are the key parameters and of paramount importance when designing tempering systems.

In chocolate tempering literature the need of maturation of fat crystals after tempering and before moulding or enrobing is frequently emphasized. This related to the fact that tempering in many conventional tempering processes was insufficient, particularly for chocolate systems with formulation-related slow crystallization kinetics, such as those containing a high level of butter fat. For such systems it was found that some residence time under temperature-controlled conditions was required (e.g. in the connecting pipe between tempering machine and enrober) in order to keep a satisfactory temper during enrobing or moulding, particularly if slightly increased temperatures were applied. This so-called maturation of the fat crystals is essentially post-tempering, which is needed because of insufficient capacity or mixing power of the tempering device being used.

Incomplete, or bad tempering, results in unstable crystal growth (α or β_{IV} polymorphs instead of β_{V}) and as a consequence in poor solidification, contraction and setting characteristics, as well as differences in colour and even whitish surface spots or a streaky grey-white finish known as 'fat bloom' (see also Chapter 12). Chocolate prior to coating or moulding, therefore, must be tempered to contain sufficient stable fat crystal nuclei of the β_{V} type in order to generate more than about 90% of β_{V} in the resulting product. In optimum conventional tempering processes all the seed generated within the chocolate masse is in the β_{V} form after tempering.

New seeding techniques however use seed crystals consisting of 30–95% β_{VI} polymorphs in addition to the β_{V} leading to optimum tempered chocolates and high-quality finished products (Windhab and Zeng, 1997).

Beside the total seed fat crystal fraction, the polymorph distribution of the seed crystals is of major importance, particularly for an optimized process with the fastest possible solidification–crystallization kinetics obtained under the lowest possible cooling temperature conditions, whilst avoiding the formation of unstable polymorphic forms. In conventionally tempered chocolate systems the fat crystal size distribution cannot be properly analysed. Mean crystal diameters are occasionally found by microscopic techniques to be in the range of 10–30 μm, depending on the volumetric mechanical power or energy input in the tempering machine. For the new seeding-based tempering techniques using seed crystal suspensions, optical analysis of the mean fat crystal size can be easily carried out and provides seed crystal mean sizes in the range of about 2–5 μm (number distribution). For a constant total crystal fraction, smaller crystals lead to an improved temper, accelerated crystallization kinetics during cooling and eventually an increased structure density in the final product.

For conventionally well-tempered chocolate systems the temper (= tempering degree) is related to crystal fraction and crystal size distribution of the β_V crystal polymorphs. As demonstrated in Figure 13.1 and Table 13.1, the melting temperature range of cocoa butter in the β_V form is about 29–31.5°C (84–89°F) Following conventional chocolate processing in the temperature range of 30–31°C (86–88°F) subsequent to tempering (e.g. coating/enrobing, depositing or moulding) the temper of the chocolate will be affected by a temperature fluctuations as small as +/− 0.5–1°C (1–2°F) occurring in the process. As a consequence conventional tempering has to produce a well-developed temper (eventually even slightly over-tempered) equivalent to a crystal mass volume fraction of up to 1%, or even more, in order keep sufficient seeding crystals throughout the post-tempering processing. The temperature to which a chocolate can be raised for a certain time, without losing the good degree of temper correlates with the amount of crystal seed present in a particular chocolate.

From this it can be shown that if β_{VI} polymorphs with a melting temperature range of 34–37.5°C (93–100°F) can be produced in the tempered masse, they are not significantly affected by subsequent processing, so long as the temperature does not exceed about 33.5°C (92°F), i.e. 2.5–3°C (5–6°F) above the typical processing temperature (Bolliger *et al.*, 1998; Windhab and Zeng, 1998).

13.4 Measurement of temper and its related characteristics (see also Chapter 22)

How do we know if chocolate is correctly tempered and ready to be used? There are four basic analytical methods which indicate the degree of temper: (1) temper curve measurements using a calorimetric tempermeter; (2) heat flux curve or melting enthalpy measurements by differential scanning calorimetry (DSC); (3) solid fat content (SFC) measurements by nuclear magnetic resonance spectroscopy (NMR) or (4) temperature-dependent flow curve measurements by thermo-rheometry.

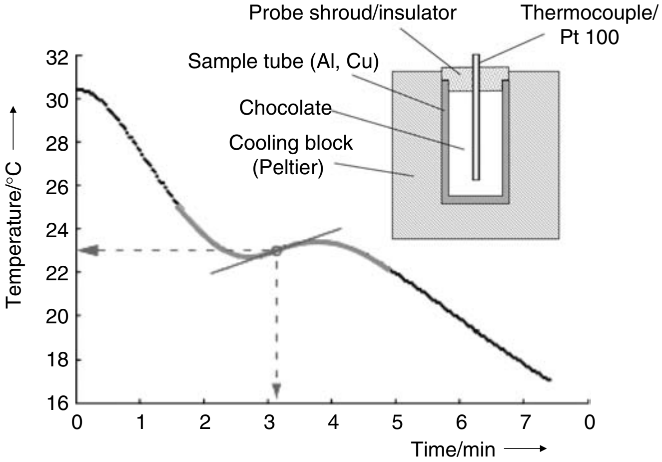


Figure 13.2 Schematic diagram of tempermeter.

13.4.1 Tempermeters

Figure 13.2 illustrates schematic details of a *tempermeter* (1), which consists of (a) a cooling block (Peltier element) to hold a constant temperature (isothermal cooling) of 0–10°C (32–50°F), (b) the sample tube made from highly conducting aluminium or copper; (c) a probe shroud and insulator; and (d) a thermistor/thermocouple probe as well as (e) a recorder or computer to store and plot the temperature versus cooling time data. An optimum cooling temperature depends on the geometry, heat capacity and heat conductivity of sample and sample cup. Using 25 ml aluminium tubes/cups, an optimum of 8°C (46°F) was found for a large number of chocolates and fillings. Different types of cooling curves are illustrated in Figure 13.3.

In Figure 13.3a it can be seen that the chocolate sample cools with about a constant gradient for a period of time, then levels off producing different tangent slopes at the inflection point, depending on the degree of temper. This is due to crystal growth, with the latent heat being released and thus generating sufficient heat to retard cooling. The sample is in a

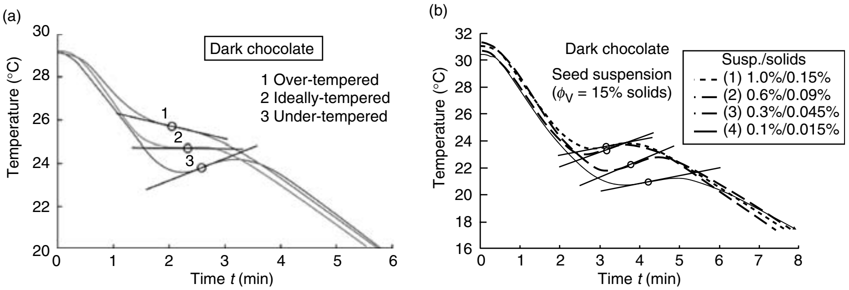


Figure 13.3 Selection of typical tempercurves (a) conventionally tempered; (b) seed tempered.

semi-solid state at this time. Once most of the latent heat has been liberated, cooling continues until complete solidification occurs. Graph 1 in Figure 13.3a shows an over-tempered sample which cools slowly with a negative tangent slope in the inflection point. Graph 2 in Figure 13.3a shows a well tempered sample according to conventional tempering, which cools faster than the previous sample 1 and shows a horizontal slope of the inflection point tangent indicating a slightly delayed, but more pronounced increase in crystallization heat release. Graph 3 represents an under-tempered chocolate sample, which first cools quickly due to the lack of crystals generating crystallization heat, but followed by a further delayed and more intensive release of crystallization heat leading to some reheating and a related positive slope of the inflection point tangent. Setting for sample 3 takes place over a longer period of time.

Beside fat composition, the rate of crystallization and setting are also influenced by a number of additional factors such as the type and amount of emulsifier used. This can be investigated using the tempermeter cooling curve.

The tempermeter cooling curve serves only as a guide, because it varies according to the type of tempering process, i.e. depending on residence time, temperature and mechanical treatment. In Figure 13.3b temper curves for β_{VI}-seed-tempered dark chocolates are demonstrated, which indicate that good temper curve shapes are process specific. According to the conventional scale for the degree of temper, all seed-tempered samples from lowest to highest crystal seed suspension fractions of 0.1–1% (equivalent to about 0.015–0.15% of solid crystal mass in the chocolate) would be classified as under-tempered if originating from a conventional tempering process. However, product quality was demonstrated to be optimum if ≥0.3% wt. of seeding crystal suspension (equals ≥0.06% crystal mass, related to total masse) were added.

Figure 13.4 shows the inflection point tangent slope values (m_{IP}) as a function of the inflection point temperature (T_{IP}). This relationship can be interpreted as crystallization intensity (m_{IP}) as a function of supercooling (T_{IP}) of the fat melt. The fewer crystal nuclei present in the tempered masse, the greater the supercooling before massive crystallization will start and lead to an increased m_{IP}. Below a certain critical supercooling temperature, T^*, crystallization kinetics is expected to slow down due to a dominating increase of viscosity, which greatly reduces the diffusion-controlled mechanisms. From Figure 13.4 such T^* value is shown in the range of about 22°C (72°F). Furthermore it has to be expected that an increased fraction of less stable polymorph crystal nuclei forming during supercooling within the tempermeter will also accelerate the release of heat of crystallization and thus increase m_{IP}. This effect is also seen for the conventionally crystallized samples. It is expected that the major reason why these conventionally tempered samples form a larger fraction of unstable polymorph crystals during supercooling than the seed-tempered ones is due to the diameter

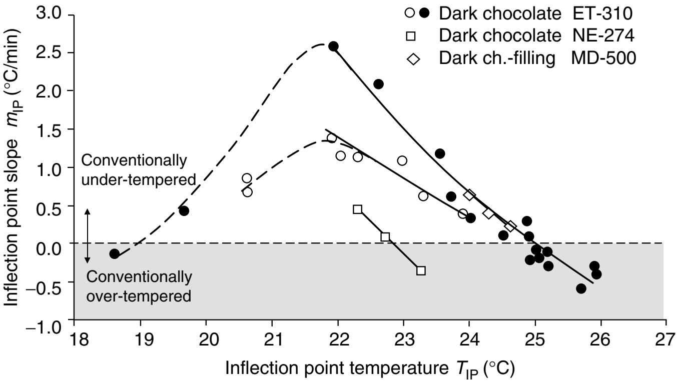


Figure 13.4 Relationship between the tangent of the slope in temper curve at the inflection point (m_{IP}) and the inflection point temperature (T_{IP}) – open symbols: seed tempered; closed symbols: conventionally tempered.

being 10 times larger than the stable β_V fat crystals generated in the conventional tempering devices. As a consequence, even at a higher fraction of pre-crystallized total fat, the mean distance between the crystals increases leading to 'wildly crystallizing' melt domains between the existing nuclei in which mainly α or β_{IV} crystals are forming.

In addition the function $T_{IP}(m_{IP})$ will vary according to the chocolate recipe (milk or plain), types of cocoa butter or other fats present and any emulsifiers that are used.

When comparing conventional tempering machines using the same recipe chocolate, a higher T_{IP} value can be taken as an indicator for more stable crystals being present. Both the shape of the curve and the temperature of the inflection point should be recorded when taking cooling curve measurements, which is done by most of the commercial tempermeter instruments (see Chapter 22).

13.4.2 Differential scanning calorimetry (DSC) (see also Chapter 22)

DSC measures phase transition heat during cooling (crystallization) or heating (melting) with controlled temperature/time gradient applied to a small sample volume (in order to provide near homogenous temperature conditions). The so-called direct DSC method developed by Breitschuh and Windhab (1998) makes it possible to measure the crystal fraction and the polymorph distribution within a tempered chocolate masse. This method involves sampling in DSC-aluminium pans for short sampling times ($\leq$60 s), under isothermal conditions (e.g. $T \approx 28$°C (82°F) for standard milk chocolate standard; 30°C (86°F), dark chocolate) and with a constant sample weight ($\approx$5 mg). If these requirements are met, reproducible measurements

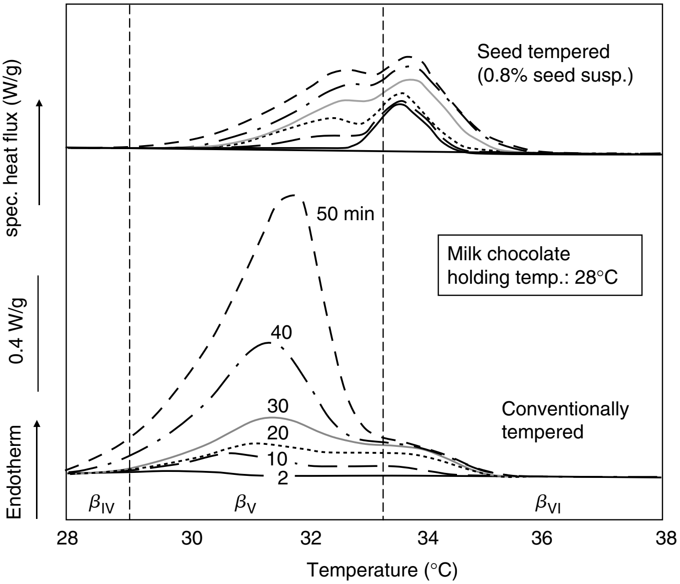


Figure 13.5 Differential scanning calorimetry (DSC) measurements: Melting curves measured by the DSC-direct method according to Breitschuh and Windhab (1998) for milk chocolate held at 28°C (82°F) under constant moderate stirring – for different residence times.

of the crystal nuclei (generated or added/seed) in the tempered chocolate system can be obtained.

Figure 13.5 shows DSC measurements for differently tempered (conventional and seed-tempered) milk chocolate held at 28°C (82°F) for different mean residence times. This simulates processing conditions for chocolate masses for example being kept in the depositor of a moulding or enrobing machine. The different starting conditions for the conventionally and seed-tempered chocolate masses enable their respective total crystal fraction and polymorph distribution to be calculated. The development of the crystalline component is also shown as a function of residence time at 28°C (82°F) (Figure 13.5). For the conventionally tempered milk chocolate there is a significantly faster increase in total crystal fraction with time and a clear dominance of the β_V polymorph, whereas the β_{VI} seeded system increases in β_V and β_{VI} fraction in a more balanced manner, but with a clearly lower total crystal fraction.

13.4.3 Thermorheometry

Thermorheometry is a complementary technique for temper evaluation with the advantage of dynamic measuring conditions, which can be adjusted to come close to the conditions within a tempering machine. In general the (apparent) viscosity is measured as a function of time for constant

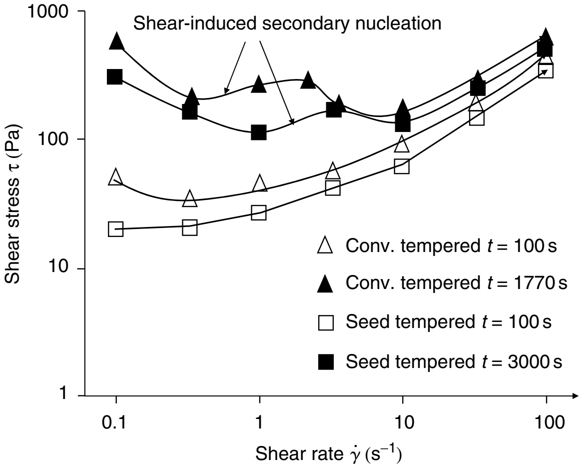


Figure 13.6 Thermorheometry (TRH) measurements: Transient development of flow functions (shear rate range: 0.1–100 s^{-1}) for conventionally (i) and seed tempered (ii) milk chocolate under holding conditions (temperature: 28°C (82°F); shear rate: 1 s^{-1}) –rheometer: Paar/Physica UM 300 with concentric cylinder geometry.

(apparent) shear rate. After distinct residence times under constant shear (e.g. at 1 s^{-1}) shear rate sweeps preferably between 0.1 and 100 s^{-1} are carried out. Flow functions $\tau(\dot{\gamma})$ for a milk chocolate masse shear pre-treated at a shear rate of 1 s^{-1} for 100, 1700 and 3000 s at 28°C (82°F) are shown in Figure 13.6 for two different tempering processes: conventionally shear-tempered in an AMK 50 (Aasted Mikroverk ApS,) tempering unit (conv.) and seed tempered using a Seed Master Cryst Mix (Bühler AG) (seed). After 1700 s (conventionally tempered) and 3000 s (seed tempered) both systems have reached 3 wt.% of crystallized fat fraction.

13.4.4 Nuclear magnetic resonance (NMR) (see also Chapter 22)

NMR spectroscopy measures the proton spin relaxation, which in chocolate systems provides a signal correlating with the solid fat fraction and can consequently be used for the solid fat content measurements (SFC). To obtain sufficient accuracy at solid fractions ≤1% (relevant for tempered chocolates) requires optimized temperature adjustment of the NMR magnet as well as a defined sampling routine, such as is described for direct SFC measurements by Breitschuh and Windhab (1998). Figure 13.7 demonstrates the SFC of a milk chocolate masse as a function of holding time at 28°C (82°F) over a time period of about 370 s. This simulates again solidification behaviour under processing conditions for example in the depositor of a moulding or enrobing plant. As can be seen in Figure 13.7, an equilibrium solid fat content of about 25% is reached after about 350 s.

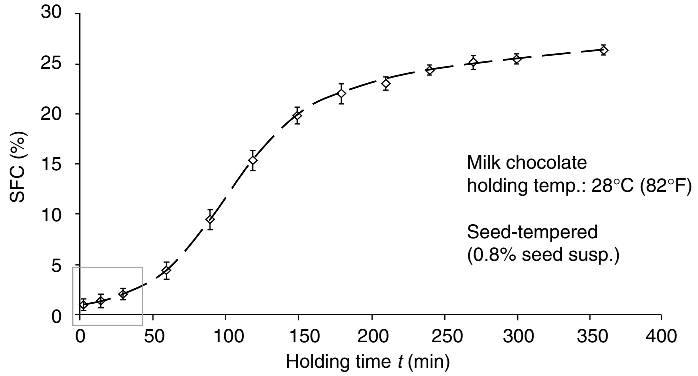


Figure 13.7 Nuclear magnetic resonance (NMR) measurements: Increase of solid fat content (SFC) in seed tempered (0.8% cocoa butter seed suspension containing 15% solid seed crystals) milk chocolate during holding at 28°C (82°F) and stirring at 1 s^{-1}.

13.5 Tempering processes

There are several ways to temper chocolate, known as ‘hand’, ‘batch’ or ‘continuous’ processes. This chapter is primarily concerned with continuous machinery relevant for industrial chocolate production, although the principles involved are applicable for all methods.

13.5.1 The principle of conventional continuous chocolate ‘stir/shear-tempering’

Conventional stir/shear-tempering is carried out in a continuous flow through stirred vessel systems, generally divided into three temperature zones (1) pre-cooling, (2) cooling and (3) reheating. The chocolate passes in the order 1–3 and with the stirring elements normally designed in such a way that shear gaps are formed between stators connected to the vessel walls and rotating sections attached to a central shaft, as is shown schematically in Figure 13.8. The higher shear rates are mainly applied in the shear gaps between the rotor- and stator elements or between the rotor and the inner vessel wall. In addition wall scraping blades may be added onto the rotating stirrer parts. The residence time distribution (RTD) of the chocolate within the temperer is planned to be as narrow as possible (all the chocolate spends approximately the same time within the machine).

There is a wide range of different tempering devices commercially available with widespread combinations of shear rate, temperature and residence time distributions.

The following sections discuss the most relevant factors (i.e. temperature, shear and time) and how they influence tempering quality in conventional stir/shear-temperers.

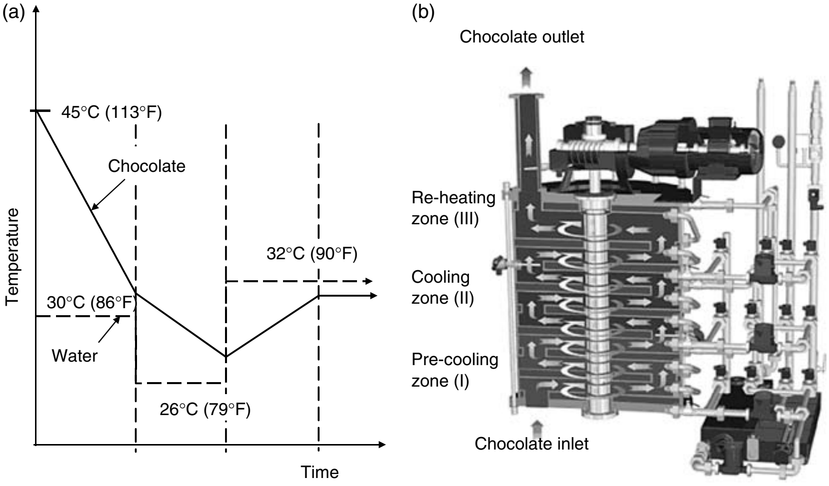


Figure 13.8 Schematic drawing of continuous stir-/shear-tempering device (a) and characteristic temperature versus time plot during conventional tempering treatment in device (b).

13.5.2 Impact of temperature/temperature control

Controlled tempering generally assumes that the continuous chocolate in-feed to the temperer is completely free of fat crystals. However this chocolate is typically at about 45°C (113°F), and may even be lower for energy conservation reasons (e.g. 41–42°C (106–108°F)). At this temperature there are a number of high melting triglycerides contained in cocoa butter, as minor fractions, that are still solid. The amount depends upon the source of the cocoa butter and this means that the nucleation potential may differ between different chocolate masses.

The major goal of tempering is to gently cool the warm chocolate through a multistage tempering machine, gradually reducing the temperature to 'strike seed' and initiate the first stages of nucleation and crystal growth.

Primary nucleation is performed at cooled walls (or shearing elements) in the cooling section of the tempering machine from which fat crystals are scraped off and mixed into the chocolate suspension, where secondary nucleation takes place. This is mostly due to fat crystals/fat crystal agglomerates being broken down between the solid particles (sugar, cocoa and milk powder particles) in the fat-based suspension. The cooling wall temperature determines the type of fat crystal formed at the wall. At temperatures below 22°C (72°F) in the cooling section, these are mainly unstable α, whereas between 22°C and 27°C (72°F and 81°F) unstable β_{III}-/β_{IV}- polymorph nuclei are formed as well as a small fraction of the stable β_V- polymorph. During mixing into the chocolate masse the unstable polymorphs get gradually transformed into the β_V type due to the applied shear stresses and the temperature increase in the subsequent reheating section. The reheating happens gradually via the heat exchange at the wall of the tempering device and in addition by the latent heat released from the fat that is crystallizing.

In some systems there is a subsequent holding (retention) stage within or after the tempering machine with associated temperature and mixing control. This is a crystal 'maturation' step, in which the fat crystal nuclei polymorph- and size distributions develop further by crystal growth and ongoing polymorph transition from unstable forms to the stable β_V- form towards an equilibrium, which is almost never reached – often the temper is very far from optimum. Some 'maturation' may also occur, but generally in an uncontrolled manner, within subsequent moulding, enrobing or coating process steps. In the case of a new type of seed crystallization process (see Section 13.6.3 and Chapter 17) such maturation produces between 30% and 95% of β_V to β_{VI} within a pure cocoa butter fraction or within a mixed fat fraction containing a minimum of about 10% of cocoa butter. This crystal suspension is subsequently used for seeding the bulk of the chocolate. When added and homogeneously mixed into the non-tempered chocolate a well controlled 'matured' degree of temper is achieved.

13.5.3 Impact of shear

Since the 1980s, many authors have demonstrated that higher shear in tempering equipment is a 'prime' consideration for producing high nucleation rates, with more stable crystals at higher temperatures than normal (Ziegleder, 1985; Windhab, 1986; Windhab *et al.* 1991; Zeng and Windhab, 1999; Windhab and Zeng, 2000). From empirical tempering experience, it was found that there is a difference between what is described as optimized tempering in a low residence time temperer (4–6 min) and a fully matured stabilized tempered chocolate (12 min to 2 h) and that claims that a fully matured chocolate, milk or plain, can be obtained from a low residence time (<6 min) temperer merely by shear rate and water temperature are simply incorrect.

Twenty years later we are now able to interpret or revise such statements based on improved insight into the crystallization mechanisms and the process–structure relationships taking place during tempering: The tempering degree of a chocolate masse depends on the *structure-parameters* (1) crystal fraction, (2) crystal size distribution and (3) crystal polymorph distribution. In addition (4) the viscosity of the pre-crystallized suspension system has to be taken into account, because it is desirable to reach an optimum tempering degree with the lowest possible increase in viscosity. The following relationships can be used in order to get the lowest viscosity increase compared with the non-tempered state: The lower the solids crystal fraction, the smaller size of the crystals is required and/or the more the crystal polymorph distribution has to be shifted to the stable β_V. The *process-parameters* providing adjustment to get such an optimum include a lower residence time and lower wall cooling temperature for higher and more homogeneous shear. Figure 13.9 demonstrates qualitative 'optimum spaces'

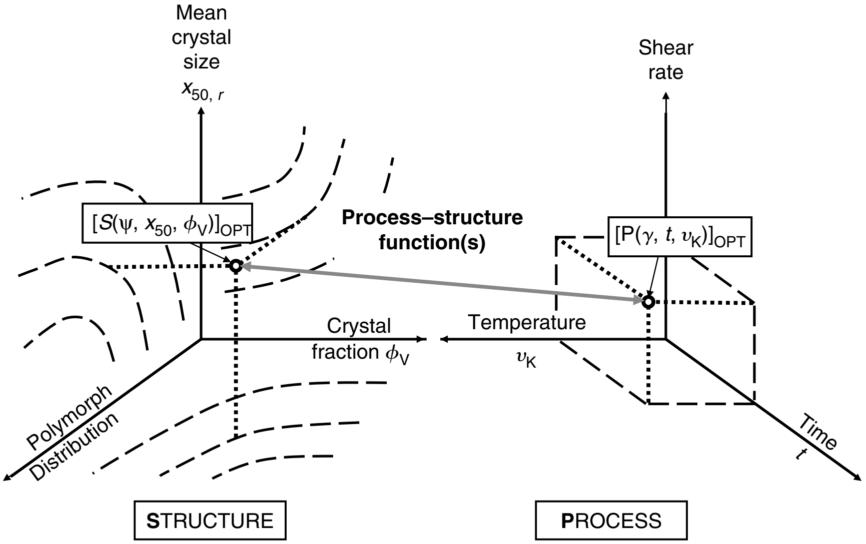


Figure 13.9 Process–structure relationship: Correlation between qualitative 'optimum spaces' for the structure $[S(\psi, x_{50}, \phi_V)]_{OPT}$ and the process $[P(\gamma, t, \upsilon_K)]_{OPT}$ (ψ, ξ_{50}, ϕ_ς r, x_{50} mean diameter/size, ϕ_V volume fraction, γ shear rate, t time, υ_K cooling temperature).

for the structure $[S(\psi, x_{50}, \phi_V)]_{OPT}$ and the process $[P(\gamma, t, \upsilon_K)]_{OPT}$ parameters to be quantitatively correlated for each specific fat/fat–mixture system. Figure 13.10 illustrates the relationships between the fat crystal structure characteristics, related physical characteristics of a chocolate system, resulting processing characteristics and the final product quality properties.

A good temper, as measured by conventional tempermeters (e.g. Sollich-, Tricor-, Systech-, Analytics tempermeters) can be generated by a crystal nuclei fraction of less than 0.5–1% of the total cocoa butter fat with more than about 75% of β_V-polymorph crystal nuclei produced under higher homogeneous shear crystallization conditions ($\geq 750\,s^{-1}$) within a residence time period of as short as <60 s and cooling wall temperatures between 5°C and 15°C (41°F and 59°F) (Windhab and Zeng, 2000).

However, as was stated earlier, a temper state reached under conventional tempering conditions will generally not be completely stable if typical temperature fluctuations of +/− 0.5–1°C (1–2°F) occur during further processing treatment of the tempered chocolate masse. This is certainly due to the fact that the typical temperature range for tempered chocolate processing is about equal to the outlet temperature of the tempering unit, which also lies in the melting temperature range of the β_V cocoa butter crystal nuclei (29.0–33.5°C (84–92°F) and which in the case with about 10% added milk fat (milk chocolate) reduces due to mixed crystallization to about 26–30.5°C (79–87°F)).

Shear rates affect mixing and heat exchange rates in a tempering machine. There are limits to the amount of shear that can be applied to chocolate in the

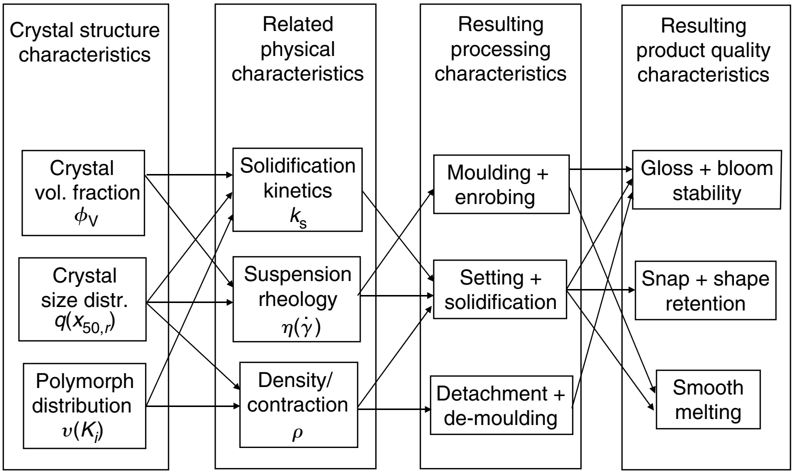


Figure 13.10 Relationships between the (i) fat crystal structure characteristics (ii) related physical characteristics of a chocolate system (iii) resulting processing characteristics and (iv) the final product quality properties for a system with given fat/triacylglycerol (trigyceride) composition.

tempering phases. Too much shear will produce heat, too little, poor mixing and poor heat exchange.

From experience local maximum shear rates acting in tempering machines vary from about 500 to 12 000 s^{-1}. However it has to be noted that the highest shear rate values are in general only applied in a very small part of the flow gaps. Thus an average shear rate can be significantly (up to 2 orders of magnitude) smaller. Typical maximum shear rates in tempering equipment are given in Table 13.2.

The maximum shear rates are usually measured at the outer periphery, where the clearance gap between the heat exchanger wall and the rotor or scraper flight can be accessed. The highest shear rates given in Table 13.2 relate to the narrowest gaps between scrapers/stirring elements and the

Table 13.2 Approximate maximum local shear rates in tempering machines.

Type of tempering device	Maximum shear rate (range/ s^{-1})	Producer of tempering device[a]
Kettle-type scraped	500–12 000	
Screw type	500–3000	Hosokawa Kreuter
Stacked plate multizone	3000–6000	Aastedt, Sollich
Stacked plate multi-chambered	4000–8500	APV

[a] The producers of tempering machines mentioned here are only examples and a more completed list of manufacturers is given in the Appendix.

cooled wall. In the case of a rotating disc or scraper arm the radial dependency of the shear rate has to be considered, and the apparent shear rate can then be calculated by dividing the local circumferential velocity by the respective shear gap width. For more precise calculation the viscosity dependant local velocity field has to be known. High shear crystallizers with narrow concentric cylinder shear gaps as are used in the generation of seeding suspensions (see Chapter 17) apply highest average shear rates in the range of 1000–3000 s^{-1}. This value is however very constant throughout the machine.

In order to avoid confusion in shear rates quoted by manufacturers, it is necessary to look at the different mixing/scraping tools and calculate the local ratio between tool-velocity and respective gap width. From this it can be seen that many manufacturers of tempering machines give maximum shear rates, which may act only in a small volume, thus being not representative. Some tempering machines also contain undesirable features such as: (1) Intermittent and variable shearing/mixing flow, (2) some chocolate can bypass the shear going directly from the inlet to outlet of the machine. This type of feature means that different parts of the chocolate is treated to different amounts of shear for different times, so that it is impossible for the bulk of the masse to be homogenous at the microscopical scale.

The relatively high fluid viscosities of chocolate masses lead to low Reynolds (Re) numbers (denoting the ratio of inertia to viscous forces). Consequently flow in tempering devices is generally laminar. The fat crystal primary nucleation starts at the cooled walls, where there is the strongest cooling. Crystal growth normally takes place along the temperature gradient direction, thus forming dendritic (needle-like) crystals, which are scraped off or detached by flow shear stresses and mixed into the chocolate masse. In a tempering machine the action of shearing/mixing scrapes these needle-like crystals from the walls and breaks them up to form more seed. The higher the acting shear, the more efficient the process becomes. As this secondary nucleation action is continuous, this results in the formation of many more crystals, and increases the crystal growth rate provided that the heat exchange and cooling temperatures are able to remove both the mechanical heat input and that generated by fat crystallizing.

Following the first phase of striking seed, which generally consists of a semi-stable form (mostly α-type), a transition occurs when semi-stable crystals re-crystallize into a more stable mature form (mostly a α–β_V transformation). During this transition, further latent heat is generated. This transition is an important indicator for degree and efficiency of the tempering process. From the kinetics of latent heat generation the confectionery engineer can derive information for process optimization (see Section 13.4.1). The shear rate or mixing action in a tempering machine is a function of the type of machine and the speed/design of the mixing elements. If the tempering machine is of the screw type, then the shear rate range along the mixing elements is narrowly distributed, with the first in first out principle being nearly fully effective as the chocolate passes down the screw and back-mixing is negligible.

If however the tempering machine is of the stacked plate design, then the shear rate distributions are intermittent and vary from the centre to the peripheral parts of the machine. If the machine has a rotary Archimedes disc (e.g. APV Baker Figures 13.16 and 13.17) mixing element, then there is continuous increase of the shear rates applied to the chocolate masse from the centre to the periphery during progression through the machine. The 'contact' time at the higher shear rate at the periphery is only a few seconds during the tempering cycle.

A kettle-type tempering device can be considered to be a stirred vessel reactor in which complete re-mixing can be achieved, depending on the number and type of scraping/stirring elements and the throughput rate. This principle requires in general a long residence time to reach a homogeneously tempered state of the chocolate and this is seldom applied in practice.

13.5.4 Importance of residence time distribution (RTD)

For conventional tempering it has been shown to be important to make the chocolate contain only the highest melting crystal polymorphs. For typical tempering times, the most stable cocoa butter polymorphs are the β_{V} although some fraction of β_{VI} is possible for the longest tempering times. It was shown by Nelson (1999) that the mean residence times in conventional tempering required to ensure good product quality characteristics from moulding and enrobing processes are:

(1) 10–12 min for moulding plants.
(2) 20–360 min for enrobing.

The reasons for these differences between moulding plant and enrober plant requirements were described as follows: The *moulding plant* generally needs less fluidity and can make up for a higher viscosity by more intensive shaking and cooling systems. *Enrobers* should have the highest practical coating temperature that can be obtained from the tempering machine and from the enrober tank (to give the minimum viscosity – see Chapter 14). This requires a high maturity of the fat crystals, i.e. a long residence time. Defects easily show up in enrobed pieces and are less visible in a 'moulding plant' where the product takes its shape and some gloss from the mould.

If a 'matured' (e.g. long enough tempered) chocolate masse is produced by conventional tempering, then it is possible to raise the temperature in further processing without losing any crystals. As the temperature rises the viscosity falls, making it easier to coat the centre of a product. This means that, for any fat content, the thinnest chocolate is obtained at the highest temperature, which in turn requires a long tempering period. These temperature differences can be as much as from 31°C to 32°C (88–90°F) to one of 34–35°C (93–95°F) for dark chocolate with full maturation. In this case a substantial content of the β_{VI} polymorph has to be assumed. Specific operating conditions and product advantages have been reported for products coated with the 'fully matured' seed-tempered chocolate coating (Windhab and Zeng, 2002). From experience for optimum conventionally tempered chocolates with low viscosity the following aspects have been reported (Nelson, 1999):

(1) Good decorative markings, especially on chocolates of high milk fat content that require extra time during tempering.
(2) When bloom-resistant additives such as sorbitan tristearate and polysorbate 60 are used in a coating, time is essential to introduce stable nuclei in sufficient quantities to ensure a high coating temperature.
(3) The improved flow at the higher temperature gives better weight control.
(4) A 'mature' chocolate with stable nuclei is not easily affected by adverse conditions, such as a high ambient temperature and varying centre temperatures.
(5) Large masse of 'well-seeded' chocolate held at a high temperature, but under the melting point of the stable nuclei and being well agitated, remains very stable over long periods of time.
(6) The high-temperature coating contains only stable crystals, and with correct cooling, good colour and gloss characteristics will be found.
(7) Better shape for example good bases, are a by-product of the thinner chocolate produced.
(8) A harder, more heat-resistant chocolate is produced, which gives a longer shelf-life.
(9) Better contraction is obtained in moulding plants.
(10) The better hardness and heat resistance results in fewer finger-marks during packing; or fewer wrapping machine problems and down time.

13.5.5 'Recipe factors' influencing tempering quality

Chocolate recipes have changed over recent years particularly with respect to substitute fats, viscosity-reducing agents and other additives. Changing the recipe can have an effect on the tempering procedure required, as ingredients may affect the crystal type, shape and the rate that it is formed. For example milk chocolate has a proportion of animal fat (butter), which contains a wide spectrum of low melting triglycerides. When mixed with cocoa butter this gives a type of 'eutectic effect' due to mixed crystals or co-crystallization. This is useful on one hand (bloom-resistant) and detrimental on the other (lower melting point, softer, slower in tempering and set in a cooler). Mixed or co-crystallization of cocoa butter with milk fat lower the melting point of the mixture and hence the temperature to 'strike seed'. Therefore in conventional tempering more time is necessary to create the mature crystal growth (see Chapter 12).

A group of additives generally influencing the crystallization behaviour of the fat phase are the emulsifiers used in chocolate manufacturing. According to their molecular nature, emulsifiers interact with the surfaces of solid particles as well as with fat crystal interfaces thus slowing down crystallization kinetics. This normally means that residence time under crystallization conditions must be increased.

13.6 Types of tempering machine

13.6.1 Chocolate tempering kettles

Kettle tempering has been used in batch form for very many years, but is no longer seen in modern large-scale chocolate manufacture, although it is sometimes used by small confectioners. However due to its exemplary role, the stirred vessel type of reactor with its pronounced back-mixing properties is still of interest for comparison with other temperers. When it has good wall scraping and radial/axial mixing rotor-/stator elements, it is an almost-ideal homogenizing crystallizer, although a rather long residence time is required.

The kettle is basically a stirred tank whose temperature can be controlled within the appropriate range. It is even possible to adapt kettles to work continuously, by metering chocolates in at the base and overflowing out at the top or vice versa. Additional control can be gained by feeding into a second kettle, once again in at the top and metering the chocolate out at the base. The 'time period' is determined by the volume of the kettles and the volume flow rate. It can have major advantages over some other types of temperer, probably the most important being the maturity 'time period', which can be from one to two hours, resulting in a high-temperature usage chocolate. Further advantages are as follows:

(1) Simplicity of all mechanical parts.
(2) A simple, easily maintained agitator.
(3) Bearings are mounted outside the product contact area, hence do not have wear or contamination problems associated with pressurized systems.
(4) As there is no pressure in the equipment and no seals are required (they are, however, advisable in order to retain the lubrication oil).
(5) Kettles are easy to drain and clean (and can be seen to be clean), which is a prime consideration when changing different colours of chocolate or non-compatible coatings.
(6) Particulate ingredients can be added (nuts, raisins, crystals of sugar) at a suitable point, provided the exit pump is slow-running with a large swept volume designed for particulate matter (Chapter 11) (in fact chocolate kettle tempering embodies most of the criteria needed for high-quality tempering).

Major disadvantages are a longer start-up time and a greater floor space requirement, when compared with vertical tempering machines. The trend for modern continuous tempering machines during the past two decades has gone towards speeding up crystallization kinetics by applying higher shear rates and also slightly lower cooling temperatures in order to achieve higher throughput rates. Consequently there tends to be shorter residence times. It is certainly a challenge to the manufacturers of tempering machines to try to match the good mixing homogeneity and 'maturation'-capability achievable in kettle-type units and this has not always been met with some designs of temperers.

13.6.2 Types of continuous industrial tempering machines (Nelson, 1999)

This section describes examples of some of the different types of tempering machines that are available. Some older forms of temperers are included to show how different developments have taken place. It is not intended to give a complete market overview of existing tempering machines.

13.6.2.1 Hosokawa Kreuter

It is interesting to consider an early temperer of Hosokawa Kreuter, because it probably has the longest theoretical 'residence time period' for the chocolate of any commercial machine. This is the Kreuter Interval Pre-crystallization procedure, which is illustrated in Figure 13.11. The Interval design consists of a 'batch' stock tank of chocolate that is first pre-cooled and then super-cooled until seed formation takes place. An outboard pump recirculates the chocolate, further enhancing the mixing from top to bottom in the tank. In addition a stirrer creates light mixing to give good heat exchange at the vessel walls, for both cooling and heating to take place. Once the machine strikes seed in the super-cooling period, temperatures have to be raised gradually over a period of time. This time period induces mature crystal growth. Up to this point, this is the mode of operation of most tempering kettles. In these, however, too long retention time will result in over temper. Hosokawa Kreuter on the other hand have made use of the fact that there is a higher temperature that will prevent further solidification and still retain maximum fluidity from the resulting stable mature chocolate (equilibrium). This is possible since the batch system allows for time to create crystal growth. All this sounds too good to be true and there is of course a trade-off between advantages and disadvantages.

Advantages are:

(1) It is possible, with a designed time period, to create the optimum maturity in the chocolate.
(2) This in turn produces a high-temperature coating giving good handling characteristics and long shelf-life; fat may possibly be removed from the recipe due to lower viscosity.
(3) It is suitable for all types of chocolate.

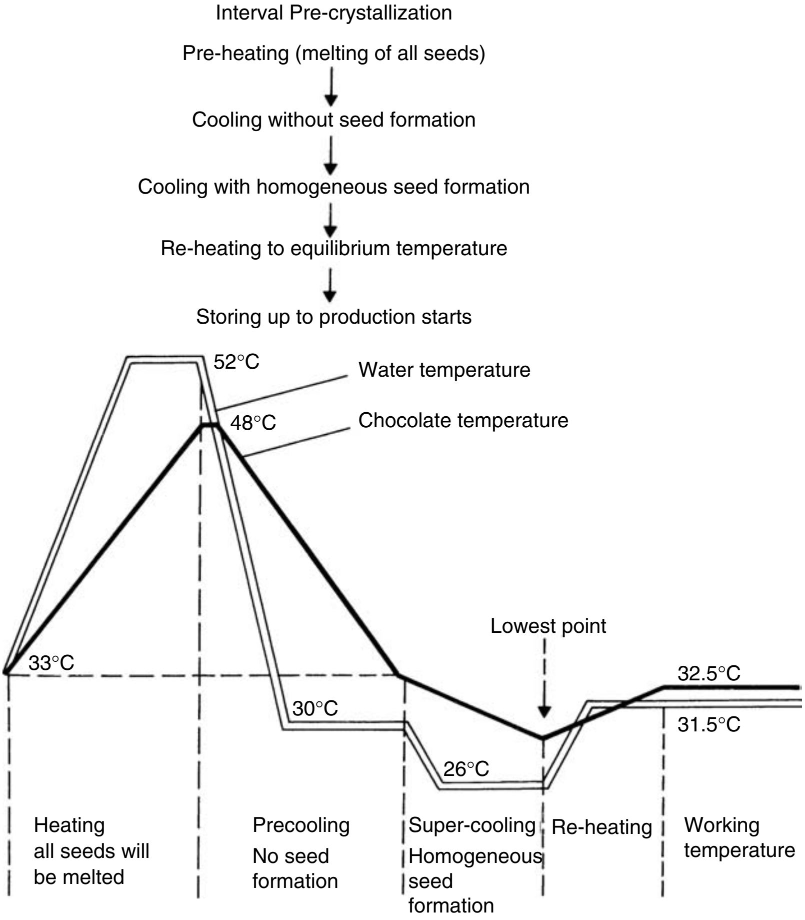


Figure 13.11 Kreuter interval pre-crystallization procedure.

(4) Since no more crystal growth can take place at the control temperature, a state of equilibrium exists.
(5) Energy savings are claimed, since there is no need to reheat and de-temper excess chocolate feeds that many other systems demand; the user plant takes only what it requires and no return piping is necessary.
(6) Prepared tempered chocolate can be stored ready for immediate use, thus reducing start-up times.

The disadvantages of this system are:

(1) The system relies on keeping the seeded chocolate at the pre-determined control temperature to within very close limits; this could affect the readiness for usage.

(2) As this is a batch system, a large storage tank would be necessary to suit the high usage rateof a wide enrober plant – one day's usage may require a 16-tonne tank, or several smaller tanks, which could create space problems.

Hosokawa Kreuter nowadays preferably provides the 'K-procedure', a screw tempering device. This is a short-residence time machine with what is claimed to be a fast-revolving screw capable of working at high pressures and generating high shear. The high pressures may be due to the remote location of the tempering machine from the user plant, viscous chocolate, or both. This type of machine falls into the short residence-time period category. The application of screws gives a narrow residence time distribution of the tempered chocolate. Combined with the locally applied high shear rates this provides short process-time and conventionally well-tempered chocolate.

13.6.2.2 Aasted

The Aasted tempering device is a vertical unit, consisting of a stack of interchangeable heat exchange plates scraped continuously to give efficient cooling and mixing. Because the heat exchange plates/discs have a chamber-like space, each one has a retention zone in its own right, and once stacked together they have a sufficient 'time period' to temper the complete range of chocolate recipes. It has a range of zonal temperature controls to enable it to match the requirements of a wide range of recipes. Such is the range of capacities and models available that any change in flow rate can be matched to the required adjustment to the retention time (Figure 13.12). This tempering device is well suited for moulding plants or enrobers and takes up minimal floor space.

The Aasted temperer operates in the following manner. Chocolate is gently metered through the machine. Aasted, recognizing the fact that inadvertent accidents can happen, have fitted a heat-jacketed relief valve to protect the pump and temperer from high-pressure damage (pumps can break down at 14 bar, 200 psi). The chocolate rises up through the control zones, of which there are three in current models, although older ones may have more. The cooling controls in the first zone strikes seed and initiates crystal growth, allowing the remaining zones to be adjusted to give the best conditions. The chocolate leaves the temperer, after being reheated to the user required temperature.

13.6.2.3 Sollich

Sollich is a company who have probably made the most ingenious varieties of tempering machines, ranging from very short residence times, through to the present-day systems. These include single-stream, double-stream and multi-stream systems. 'Streams' are blends of previously seeded masse, or may represent the new untempered feed into the tempering worm. Sollich have manufactured a range of combined temperer/enrobers (see Chapter 14).

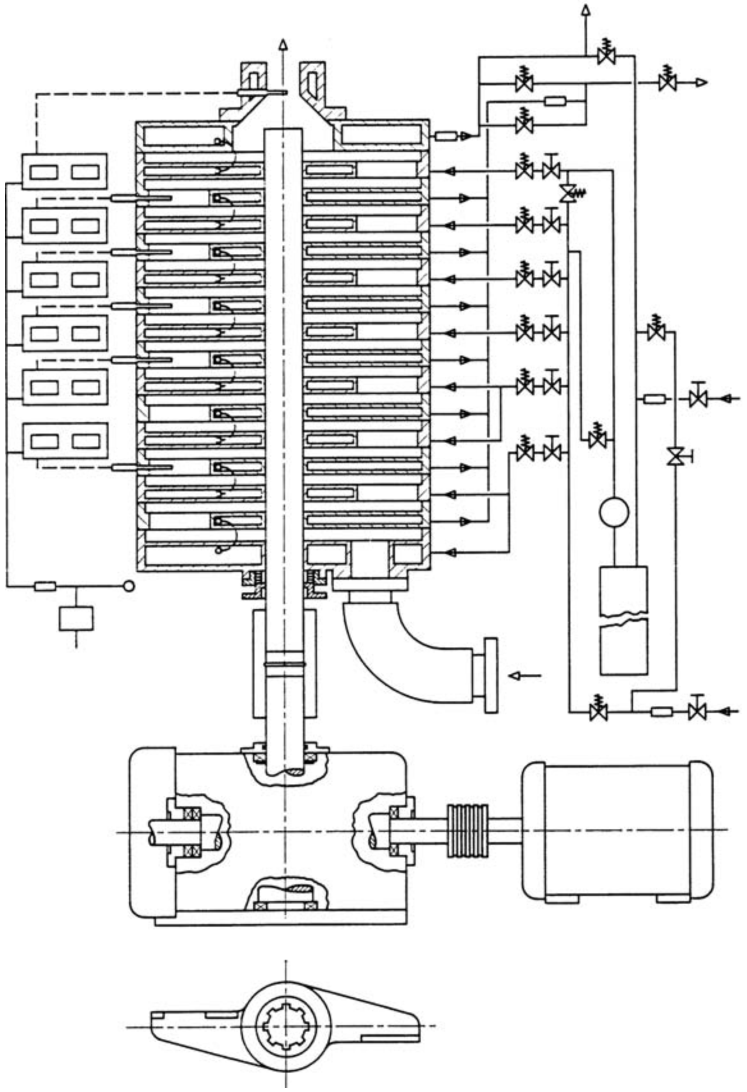


Figure 13.12 The Aasted temperer.

Their separate or outboard temperers include the Solltemper MST-V and the current popular MSV Turbo.

With the Solltemper MST-V (Figure 13.13), Sollich have developed a plate-type heat exchanger for tempering chocolate, which claims to have more residence time, 'microcrystalline growth' and thermo-cyclic conditioning, through the use of special scrapers. For this machine a residence time of 5 min is needed to create seed (Figure 13.8). This temperer has proved to combine well with enrobing machines to produce a good temper. The

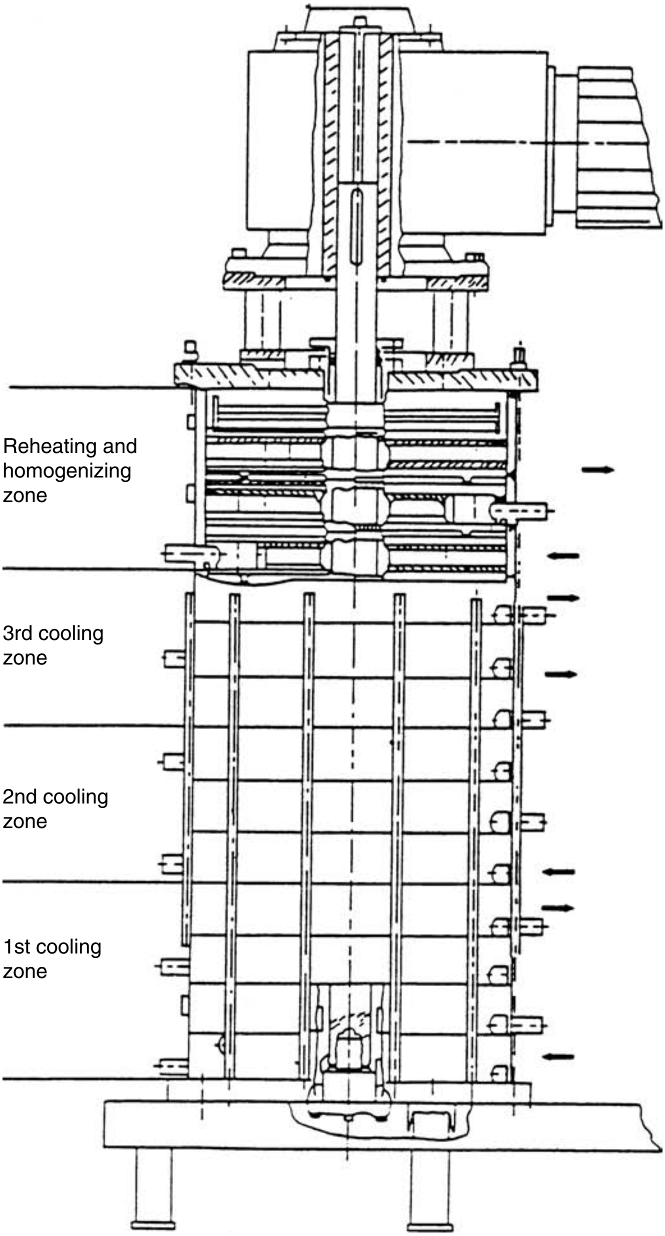


Figure 13.13 The Sollich Solltemper MST-V.

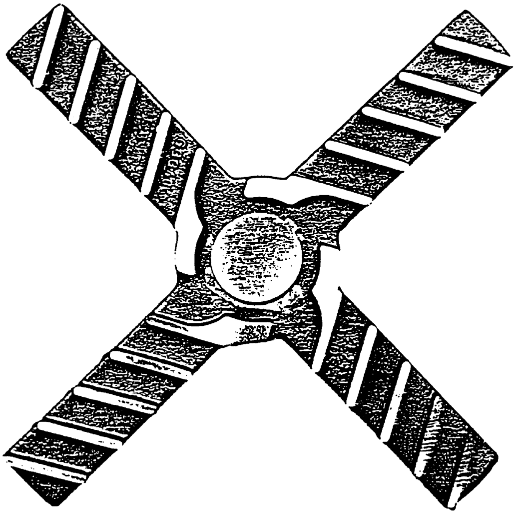


Figure 13.14 Sollich Cruciform Scraper: MSV Turbo Temperer.

enrobing temperature is, however, lower than could be achieved with a longer residence time in the enrober tank.

In the MST-V temperer, metered chocolate is fed in the base of the machine and rises through heat-exchange plate elements, which are divided to create three cooling zones, and which have spring-loaded scraper blades in order to provide efficient heat exchange. The required 'strike seed' temperatures occur in the later stages of the cooling cycle. A further zone reheats as necessary and extends the residence time period. The chocolate now passes through to the user plant. It is also claimed that water at 16.6°C (62°F) can be used effectively as the cooling medium.

This model has been largely superseded by the Sollich tempering machine designated the MSV Turbo. This machine has a stacked plate design like the MST V. Major changes have taken place however in the method of scraping the cooling plates and water circulating systems. The previous spring-loaded scrapers have been replaced by a semi-scroll cruciform design (Figure 13.14). Water cooling and circulation is now improved and is continuous. This is achieved by a circulating pump passing water through redesigned cooling or heating zones. A modulating control valve system for precise temperature control admits heating or cooling water. An automatic capacity control system adjusts the cooling surface area as required, when variations of flow rate or incoming chocolate temperature occur. This ensures an almost uniform degree of temper at all times.

13.6.2.4 Carle and Montanari

A wide range of tempering machines have been produced. These started with the 'Tan' worm screw types, followed by the 'BETA' stacked plate-type

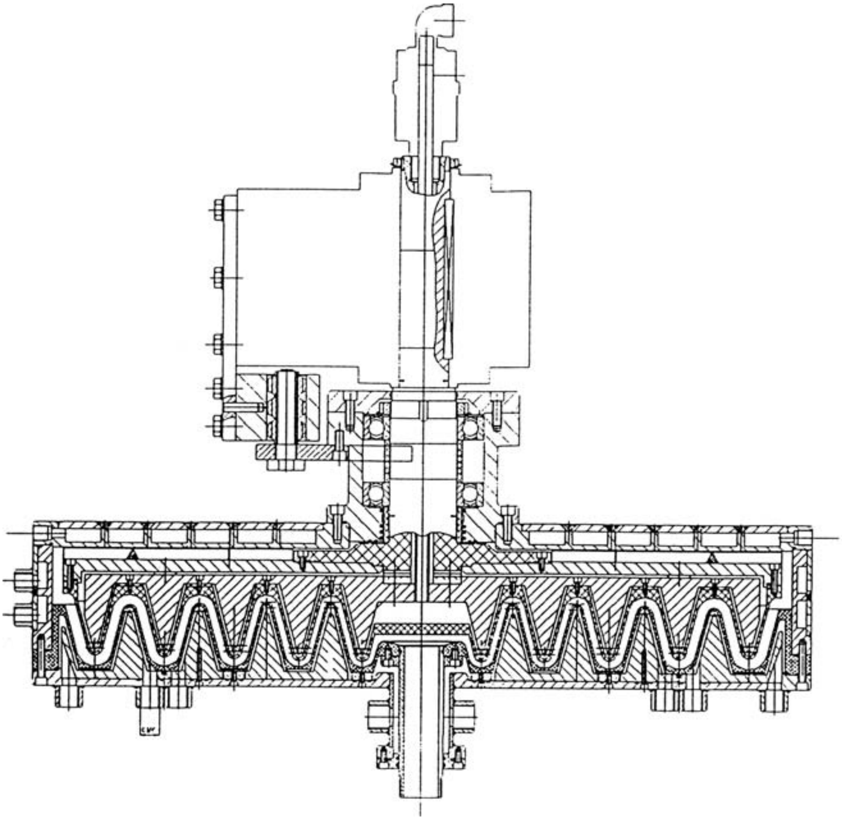


Figure 13.15 Section of a ‘τ’ tempering system (Carle & Montanari S.p.A.).

temperer and a very novel design, the ‘τ’ (‘Tau’) intensive shear machine (Figure 13.15), which was introduced in 1996.

This machine was designed to be opened like a clam shell. The intention of the designers was not only to allow easy clean out, but also to follow the theories related to relatively high shear tempering. The ‘τ’ *Tempering Machine, as* can be seen in Figure 13.15, is made up of two circular bodies, both of which present a corrugated surface, forming a series of concentric round chambers. The profile of the two bodies is such that, in the final arrangement of the system, there is an interpenetration of the crests of one element’s corrugated surface into the chambers of the opposite facing element. In this way a product passage gap is created in the space left between these two bodies.

One of the two bodies rotates (rotor), whilst the other is fixed (stator). Both elements contain cavity walls for the passage of the cooling medium and temperature-controlled fluids. This cooling/heating fluid system has been designed so as to give two areas of different controlled temperature in the stator, each one having 50% of the heat exchange surface. A further independently controlled temperature zone exists in the rotor element, with a further zone positioned in the core of the tempering elements. The key advantages of this machine are:

- A large surface area in a relatively small space.
- The formation of a passage/gap for the product, which is of constant dimension and controllable at every point. This applies to a homogenous and continuous shearing action, whereas in conventional tempering systems this effect is limited only to the areas of close proximity between the mixers and the heat exchange walls.
- The possibility of getting into the inside of the machine by simply uncoupling the tempering elements. This is made possible by the fact that the machine consists of only two tempering elements within a housing, thus forming a unit which is easy to open.
- The rotor is driven by a variable speed drive.

The product flows from the centre of the system to the periphery, so that as the cooling area increases with distance from the centre, so too does the volume available to contain the chocolate. This means that the system is not very sensitive to the increase in viscosity of the product during tempering and as a result only very low pressures are present within the machine. In addition, the relative speed between the rotor and stator increases with the distance from the centre. This results in an increasing shear rate and hence a higher shearing stress being applied to the product as its viscosity also increases. This means that the maximum shear stress is applied to the cooled product, where it is able to increase the rate of crystallization and encourage the formation of stable β_V polymorph crystals.

Currently, Carle and Montanari produce a four-section vertical temperer based on scraped heat exchangers.

13.6.2.5 APV Baker

In the late 1950s, Baker Perkins were licensed to produce their own version of the Sollich built-in tempering techniques. These were designed into enrobers as integral units. Early designs had the problems associated with low residence time systems. Baker Perkins solved these problems in the mid-1960s by using a large enrober seed bed with a variable retention time between 15 and 60 min. This was shown to be enough time, together with efficient agitation, to create the most stable high-temperature coatings. In this machine the principle of seed maturation has been applied to the tempering machine itself, rather than just to a holding tank or the enrober. This has led to the development of the Baker Perkins 105 TU ACS tempering machine (Figure 13.16) with a ‘real’ retention zone, located approximately midway through the temperer. Advantageous features of this model are:

(1) High-pressure chocolate metering pump.
(2) Safety features on start-up.

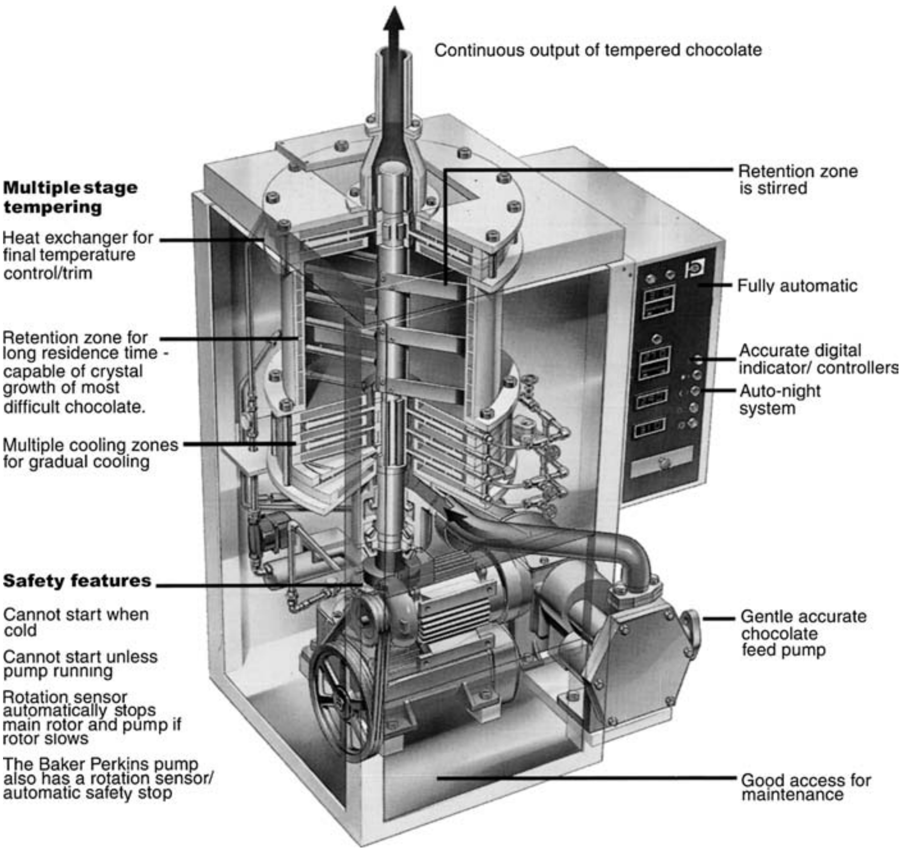


Figure 13.16 The Baker Perkins 105 TU tempering machine (Baker Perkins BCS Ltd).

(3) High shear rate Archimedes cooling discs (8500 s^{-1}).
(4) Water plates with high-velocity turbulent flow.
(5) Transition maturation mixing zone giving significant improvement in final crystal hardness (timed residence mixing zone).
(6) High shear rate Archimedes control discs controlling temperature to user point.
(7) Chocolate zonal temperature control is by autotune electronic instruments operating chilled water modulating valves, effectively holding temperatures to 0.1°C.
(8) Where the de-seeded chocolate temperature is unreliable, extra preheating plates or cooling plates are available on a modular machine.
(9) Savings in fat (cocoa butter) are documented to take place because of the higher temperature of the chocolate at use.

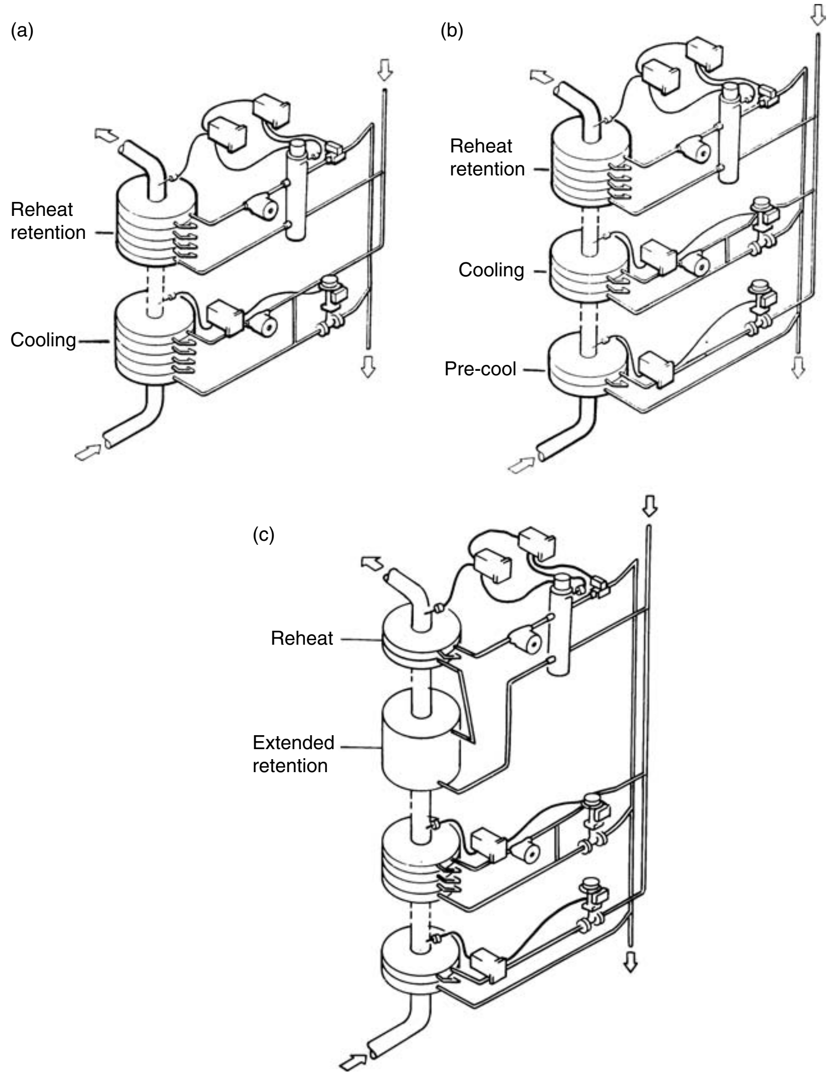


Figure 13.17 Schematic diagrams of the APV Baker (a) two-stage system; (b) three-stage system and (c) with extended retention.

The operation of the APV Baker tempering machine is as follows (see Figures 13.16 and 13.17). A high-pressure metering pump takes de-seeded chocolate from bulk storage and meters it into the first zone of the tempering machine. This zone is filled with Archimedes mixing discs mixing and spreading chocolate in a prescribed continuous path from the centre of the machine to the outside and back again. At the same time the chocolate progresses upwards through the machine due to the pumping action of the discs. During the passage through this first zone, sensors regulate the chocolate temperature. At the end of the first zone, at approximately 27°C (81°F), chocolate seeding is initiated, giving rise to very fast and fine crystal growth. If this state was allowed to proceed solidification would result.

On entering the second zone there occurs the transition from the unstable crystalline states to the β_V form and a natural temperature rise of 2°C (3.6°F) is observed. This 'transition'is not seen in other machinery and is the early stage of maturing to the more stable crystal form. As the chocolate, now being rewarmed, progresses within the second zone it is intensively mixed. This shear, together with the time element, provide the necessary maturation conditions required to produce a more highly tempered chocolate. This zone has a retention time of 12–20 min depending upon flow rate.

The next part of the machine is a disc-type heat exchanger which is capable of precisely controlling the exit temperature. This machine has been designed with the necessary prerequisites to handle the most difficult eutectics as well as, of course, the easier recipes. The ACS temperer can fill the dual role of feeding enrober plants or moulding systems. As mentioned earlier, this machine recognizes the *latent heat temperature rise* in the retention zone by sensor probes, and can be pre-set to attain a pre-determined cooling curve. Although highly tempered, this chocolate exhibits a higher melting point and a lower viscosity, with the temper cooling curve showing a higher than normal (temperature) inflection point.

With the increasing demands due to new recipes and fat systems coupled with the need to minimize costs, APV Baker have introduced a concept of modular designs. These vary according to customer and product preferences, and have a high hygiene standard with total all round access for cleaning and maintenance. The modular design can take one of the following forms:

(a) Two-stage systems comprising nucleation cooling and reheat/retention for basic recipes (Figure 13.17a).
(b) Three-stage systems comprising pre-cooling, nucleation cooling and reheat/retention (Figure 13.17b).
(c) Two- or three-stage systems incorporating extended retention (Figure 13.17c).

13.6.3 Continuous industrial seed-tempering

13.6.3.1 Summary of the principles

In conventional tempering, the crystal seeding is performed by scraping seed crystals from a cooled wall. Whereas these needle-like seed crystals are in a semi-stable polymorph form (mostly α-form), a new methodology has been developed in the past ten years of seeding by continuously adding pure, fully matured β_{VI} or $\beta_V + \beta_{VI}$ cocoa butter seed crystals in concentrated suspension into temperature-controlled, untempered chocolate. Currently, commercial industrial temperers based on this principle (Seed Master tempering machines) are manufactured by Bühler AG of Switzerland.

Control of crystallization processes by seeding is used commercially to make many different products for example sugars (Kleinert, 1980), vitamins, drugs (Bollinger *et al.*, 1998) and fine chemicals (Cebula *et al.*, 1991). The idea of seeding chocolates with well-defined crystals has also been reported within a number of scientific and patent applications either based on specific cocoa butter crystals (e.g. Windhab and Zeng, 1998; Bollinger *et al.*, 1998; Pate, 1983; Dieffenbacher, 1986) and a system based on BOB seeding, which is used in Japan, but is not legal in most other countries. Such seed crystals are added to the chocolate in crystal powder form, or by the confectioner's 'handcraft methodology' of adding small amounts of solid chocolate pieces/ powders into an untempered chocolate melt. The use of the former seeding concepts for continuous industrial chocolate manufacture was not significantly implemented, since they did not have the consistency or robustness to fulfil one or more of the following required aspects: (1) good control of the tempering state with respect to resulting polymorph distribution; (2) stable active seed crystal fraction and seed crystal size distribution; (3) homogeneity of seed distribution; (4) thermal stability of the seed and (5) a method of handling continuous seed powder dosing and homogeneously mixing it into a chocolate stream.

Many of these problems are overcome by adding the seed (containing a majority of β_{VI} crystals) in a concentrated suspension within liquid cocoa butter. The seed crystal suspension containing cocoa butter crystals is continuously added to the pre-cooled chocolate stream in quantities from 0.2% to 1% and homogeneously mixed using a specially designed static mixer system. The cocoa butter seed crystal concentration in the seed suspension is fixed between 15 and 25% wt with a β_{VI} fraction of up to ≥95%. This gives the possibility to pre-crystallize and further process the chocolate at temperatures at least 3–4°C (5–7°F) higher than in conventional tempering technology, leading to an improved processability during moulding and enrobing. Other advantages include improved fat bloom stability, accelerated solidification, ability to crystallize mixtures of vegetable fats and cocoa butter down to only 10% of cocoa butter fraction and diminishing the crystallization inhibiting effects of added milk fat or other fats without reducing their positive contribution to support anti-bloom.

These advantages are based on the fact that stable cocoa butter crystals are externally generated and introduced into the various chocolate and chocolate-like systems in suspension form with:

(a) controlled polymorph distribution (preferably with fixed β_{VI} fraction in the range of 50–95%);
(b) controlled seed crystal size/size distribution (adjusted by the degree of shear treatment and residence time in the seed crystal suspension processing within a mean crystal size range of about 2–10 μm); and

(c) controlled fraction of active seed crystals (0.02–0.15% crystals equivalent to 0.2–1% suspension per total chocolate masse) by precise dosing and micro-homogeneous mixing of the seed crystal suspension into the chocolate.

Consequently, a large number of nuclei controlled with respect to aspects (a)–(c) is present in the seed-tempered chocolate providing the basis to form a dense and finely structured fat crystal network with fast solidification kinetics.

It has been found that the triclinic crystalline structure of the β_{VI} seed crystals makes the chocolate solidify in the triclinic β_V state, if the cooling and solidification kinetics is faster than that of a $\beta_V \rightarrow \beta_{VI}$ polymorph transformation (Mehrle *et al.*, 2007). This condition can easily be fulfilled, because in the chocolate the $\beta_V \rightarrow \beta_{VI}$ transform may take from about half to several hours even at elevated temperatures of 32–33°C (90–91°F).Typical industrial cooling conditions (10°C (40°F) for 20 min) produce an insignificant amount of additional β_{VI} crystal fraction. This is what is needed however, because the β_V solidification provides the desirable smooth texture and melting, and avoids a waxy mouth-feel that is commonly associated with the β_{VI} state.

13.6.3.2 The seed-tempering process

The new industrial seed tempering process consists of three processing steps:

(1) Chocolate feed and cooling unit
(2) Cocoa butter crystal suspension forming stage
(3) Dosing and mixing unit.

These process steps are shown schematically in Figure 13.18.

Chocolate feed and cooling unit. The unit consists of a heated container and a conventional plate heat exchanger to cool the untempered chocolate from >45°C (>113°F) to 32–34°C (90–93°F) in the case of dark chocolate. The units (2) and (3) are specially designed and are described below.

Cocoa butter crystal suspension (CBCS) processing. Two different process methods have been developed and successfully tested for cocoa butter crystal suspension preparation.

Set-up A is illustrated by a quasi-continuous process with two separated devices for seed crystal nucleation (A1) and seed crystal maturation (A2) (Figure 13.19).

A1 is represented by a high shear crystallizer, in which a rapid nucleation of α-crystals and their almost complete transformation into the β_V polymorph form, which takes place within a residence time period of about 20–100 s. This unit is in principle a Narrow Annular Gap Scraped Surface

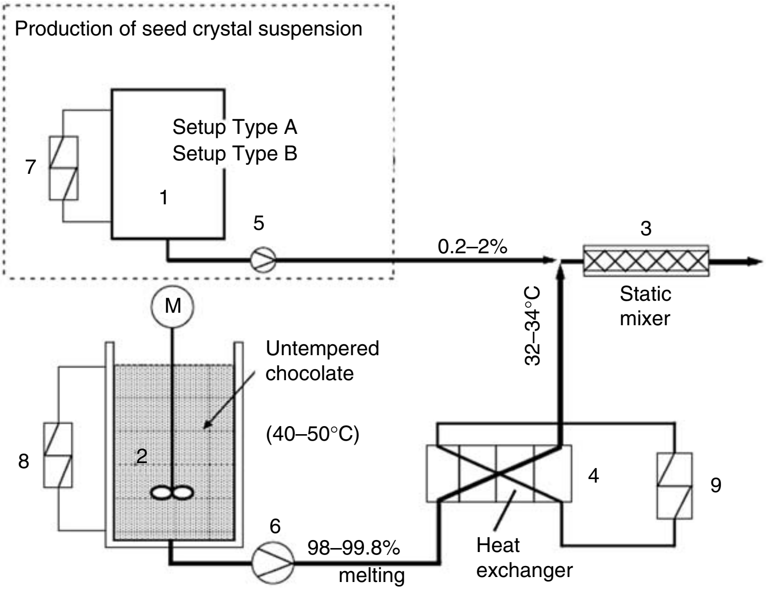


Figure 13.18 Schematic process of chocolate seed tempering with 1: seed suspension (CBCS) production unit, 2: untempered chocolate masse container, 3: static mixer, 4: heat exchanger, 5: CBCS pump, 6: chocolate pump, 7, 9: cooling circuit, 8: heating circuit.

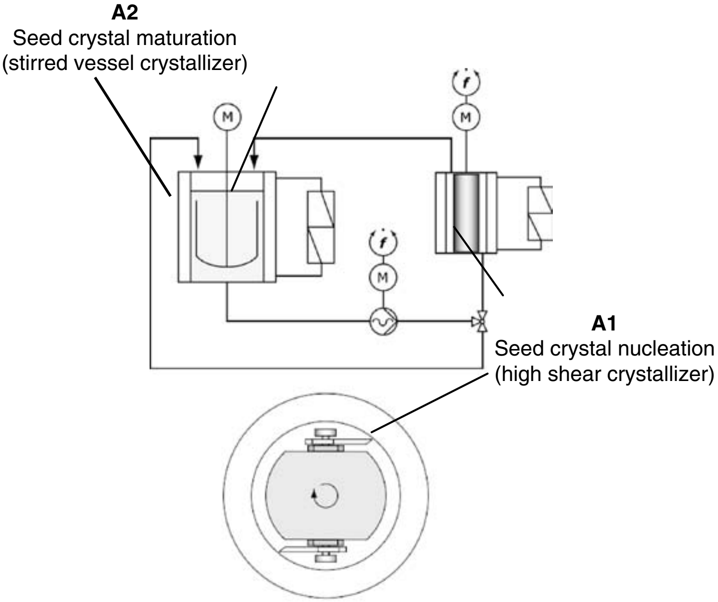


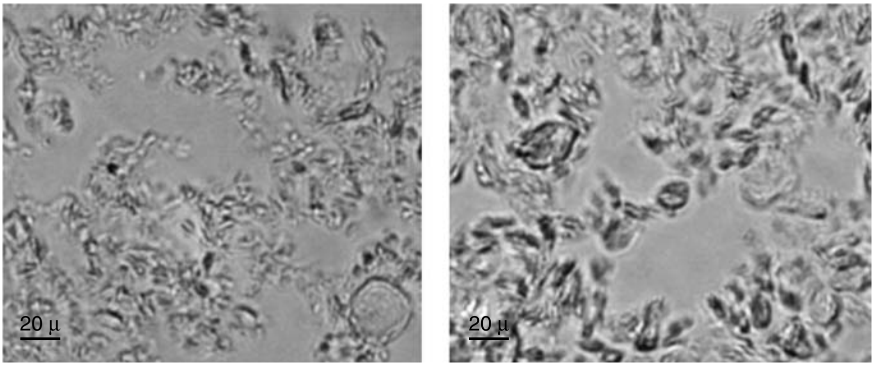
Figure 13.19 The seed tempering process (STP) in set-up A (SeedMaster Cryst/Mix (®Bühler AG)).

Crystallizer (NAG-SSC) which has a very homogeneous shear flow field and narrow residence time distribution. This fast α-crystal nucleation and complete $\beta \rightarrow \beta_V$ transformation under homogeneous high shear (1000–4500 s^{-1}) has been an object of detailed studies involving in-line small angle X-ray scattering (SAXS) monitoring. Published results include molecular/structural interpretations of the shear-induced transform mechanism (Windhab *et al.*, 1991; Cebula and Ziegleder, 1993; Padar *et al.*, 2005; Mehrle *et al.*, 2007).

A2 is a stirred vessel crystallizer in which the β_V seed crystal suspension containing about 10% vol. of crystal solids when entering from the high shear crystallizer (A1) increases in solids fraction up to about 15–20% vol. and simultaneously a $\beta_V \rightarrow \beta_{VI}$ transform takes place. This $\beta_V \rightarrow \beta_{VI}$ transformation has been shown to be diffusion controlled and not significantly influenced by shear forces. More detailed studies led the β_{VI} polymorph form being described as a 'purified' or 'optimized' β_V form (Windhab, 2003; Van Mechelen *et al.*, 2006 a,b; Mehrle *et al.*, 2007), which also basically agrees with previous related published work (Vaek, 1960; Sato *et al.*, 1989a,b; Koyano *et al.*, 1990, 1991; Metin and Hartel, 1998)). Under elevated temperature conditions of about 32–34°C (91–93°F) and moderate but homogeneous stirring more than 95% of the β_V transform into β_{VI} which takes about 45–60 min under homogeneously stirred/mixed conditions. The mean seed crystal diameter of the number distribution $x_{50,0}$ has been detected in the range of about 7–10 μm (Figure 13.20).

Set-up B is a fully continuous process with an integrated device for seed crystal nucleation (B1) and seed crystal maturation (B2) (Figure 13.21).

The functions of the two integrated sections B1 and B2 are similar to those of the units A1 and A2 in the quasi-continuous process set-up A described previously. However what clearly changes is the residence time in the



SeedMaster compact B
SeedMaster cryst/Mix A

Figure 13.20 Cocoa butter seed crystals in seed suspensions produced with set-up B (SeedMaster Compact (®Bühler AG)) and set-up A (SeedMaster Cryst/Mix (®Bühler AG)). See Plate 7 for the colour image.

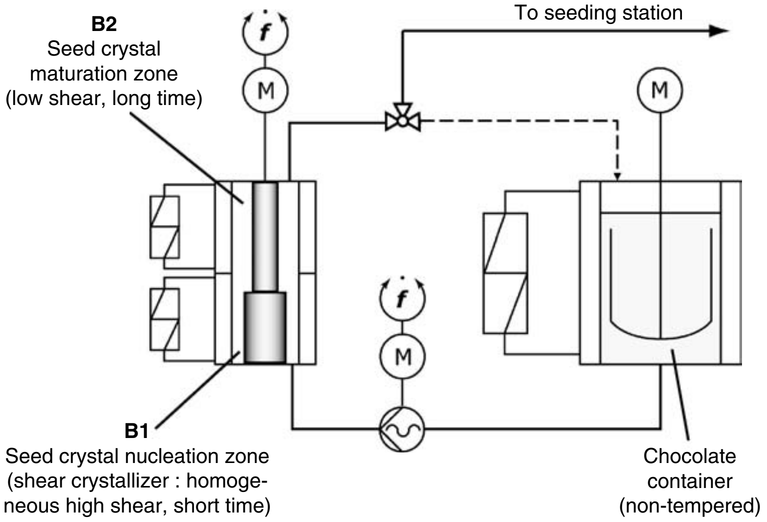


Figure 13.21 Processing unit comprising the 'Seed Tempering Process (STP)' in the process set-up B (SeedMaster Compact (®Bühler AG)).

section B2 (5–8 min) compared to the stirred vessel crystallizer A2 (45–60 min). This makes a major difference in the polymorph distribution of the seeding suspension, which now contains only up to about 30–50% of β_{VI} polymorphs. On the other hand the final seed crystal mean size is clearly reduced by up to a factor of 2–3 compared to the A process product. This was shown to lead to an improved seeding efficiency and thus to lower seed suspension dosage required (≤0.5% seed suspension equivalent to ≤0.05–0.075% of seed crystal mass fraction per total chocolate masse), but still provided sufficient β_{VI}-based high-temperature stability.

In the high shear crystallizer units (A1 or B1) the fat phase is partly crystallized at wall temperatures of 5–15°C (41–50°F) (temperature of cooling water). Owing to the shear field rapid α-crystal nucleation, the shear-induced transformation into the β_{V} polymorph, as well as an initial $\beta_{\mathrm{V}} \rightarrow \beta_{\mathrm{VI}}$ transformation leads to a mixture containing mainly β_{V} and some few β_{VI} polymorph crystals with a total crystal fraction of about 8–10%. This crystallized cocoa butter suspension is then fed into the A2 unit or the B2 section with wall temperatures between about 28°C (82°F) and 32°C (90°F).

In set-up A the cocoa butter suspension is circulated through the stirred vessel 'maturation' crystallizer (A2) and the shear crystallizer (A1) for a certain time required (≈45–60 min) for final conditioning with ≥95% β_{VI} fraction in the crystal seed. During this time further crystals are formed in the shear crystallizer, which grow further and finally transform into the β_{VI} form in the stirred A2 unit. The design of the stirred vessel 'maturation' crystallizer (A2)

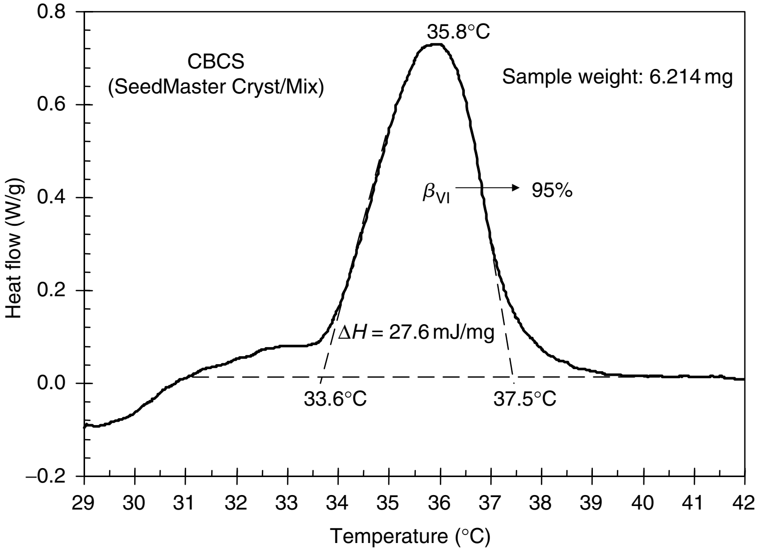


Figure 13.22 DSC melting curve for cocoa butter seed crystals in suspension (CBCS) from set-up A (SeedMaster Cryst/Mix (®Bühler AG)).

and the way the product is stirred are also critical to produce the correct size, type and concentration of cocoa butter crystals. The melting properties of a sample of cocoa butter crystal suspension measured by differential scanning calorimetry is shown in Figure 13.22.

In set-up B the cocoa butter suspension received at the outlet of section B1 is directly transferred only once through section B2, therefore only partially allowing for the $\beta_V \rightarrow \beta_{VI}$ transformation (between 3 and 65% for residence time between 5 and 8 min). The final cocoa butter crystal suspension is then added to chocolate in quantities ranging from 0.2% to 2% w/w which equals a seed crystal content of 0.02–0.3% (according to the solid crystal fraction of 10–15% in the seed suspension).

Dosing and mixing CBCS into chocolate. The cocoa butter crystal suspension (CBCS) that has been made can be easily handled due to its high stability in a temperature range between 32°C and 33.5°C (90–92°F). The CBCS can then be pumped through a thermally controlled ring mainly from which dosing pumps continuously feed it according to requirement (usually in the range of 0.2–1% suspension of total masse) into the main streams of untempered chocolate. A larger number of chocolate production lines, that is a whole factory can be supplied with the appropriate seed suspension. This is followed by micro-homogeneous in-line mixing in a static mixer. Instead of the ring main, the suspension can be directly fed to one or more chocolate production lines. Owing to the good compatibility of the CBCS to a wide range of chocolate and filling recipes (only 10% of cocoa butter must be present in the recipe), only

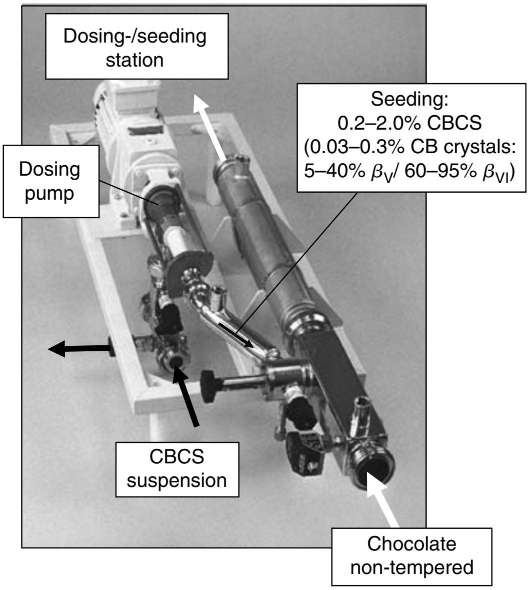


Figure 13.23 Seeding station for dosing/mixing of CBCS into an untempered chocolate stream.

one CBCS production unit can provide the seed for many different product lines. Figure 13.23 illustrates a typical CBCS 'dosing/mixing station'.

13.7 Properties of CBCS-tempered chocolate

13.7.1 Pre-crystallized liquid state

The influence of chocolate temperature on the measured temper for constant amount of added seed crystal suspension is illustrated in Figure 13.24 for a dark chocolate. Although temperature is increased from 31°C to 34°C (88–93°F), the degree of temper and therefore the quality of pre-crystallization remains unaffected and the chocolate has been made stable against these temperature variations. In conventional tempering, variations in temperature greatly affect the quality of pre-crystallization and most importantly for temperatures above 31°C it is almost impossible to generate crystals of any temper, as is illustrated in Figure 13.25.

The new seed-tempering process thus opens the opportunity to deposit and mould or enrobe at significantly higher temperatures than possible for conventionally tempered chocolates. This greatly affects the flow properties of the chocolate, because chocolate viscosity reduces significantly as the temperature increases. This lower viscosity often produces better coating and weight control, particularly during enrobing. Alternatively lower fat chocolates can be used, yet maintaining the same flow properties.

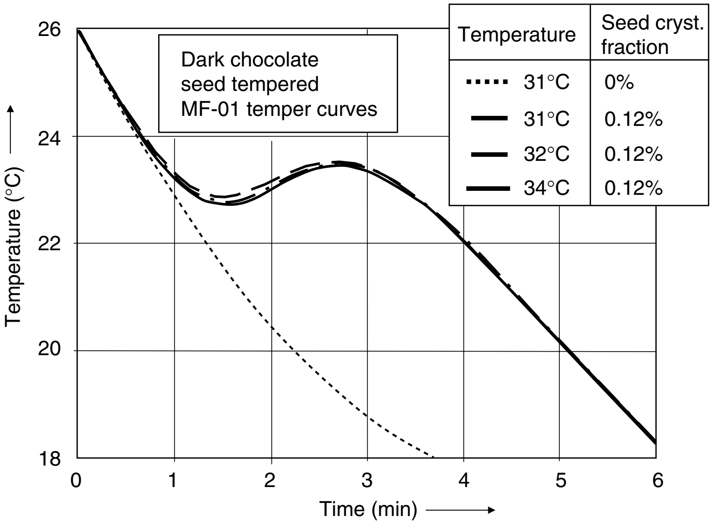


Figure 13.24 Temper curves for seed-tempered dark chocolate treated at different temperatures (31–34°C) (88–93°F) (Source: Zeng, 2000).

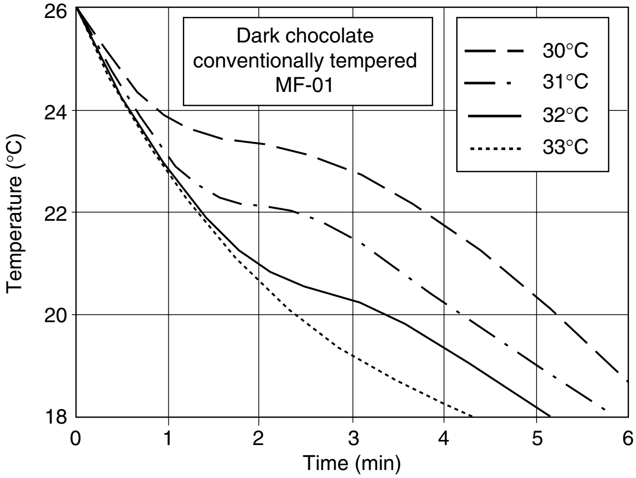


Figure 13.25 Temper curves for conventionally tempered dark chocolate treated at different temperatures (31–34°C) (88–93°F) (Source: Zeng, 2000).

13.7.2 Semi-solid and solid state

The speed of setting of moulded chocolates during cooling depends on the fraction of seed crystals and their size distribution. Although conventionally tempered chocolates contain more solid fat (0.5–1% compared to about 0.02–0.3% for seed tempered) and would therefore be expected to set

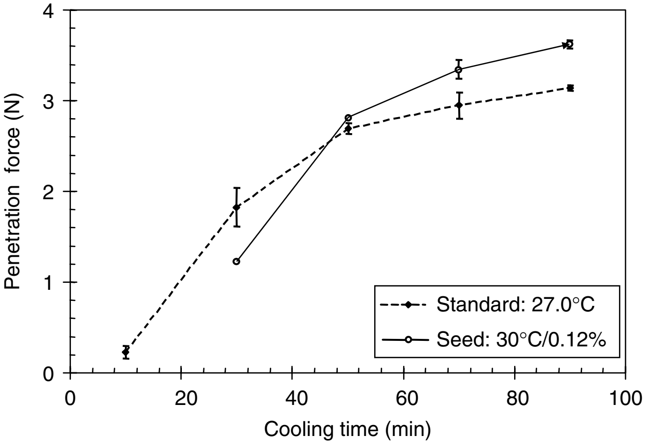


Figure 13.26 Effect of the type of tempering on the snap/hardness of milk chocolate as measured by needle penetrometry (Source: Zeng, 2000) – during cooling (12°C, 54°F).

faster, normally the effect of the more finely dispersed seed crystals (seed tempered 3–7 μm, conventionally tempered >15–20 μm estimate) overcomes this and the seed-tempered chocolate sets faster.

The improved size distribution of the seed crystals also explains the characteristic increase of hardness and improved 'snap' for seed-tempered products (Figure 13.26) and their significantly improved bloom stability. The latter is particularly pronounced in the case of filled products for which both the filling and the coating have been seed-tempered (Figure 13.27). Here the liquid fats in the centre for example trioleins, find it harder to diffuse through the more dense structured fat phase produced by the seed tempering.

A slight, but systematic tendency of increased final contraction (density) for seed-tempered systems particularly when cooled more rapidly, is assumed to indicate the overall solidification in the stable β_{V} polymorph form, compared with 10–20% of less dense β_{III} or β_{IV} polymorphs forming in conventionally tempered chocolates. However, it might also be due to a systematic difference in micro-dispersed gas between the two types of tempering.

Research on long-term storage trials with seed-tempered chocolates of different fat composition indicates that the local inclusion of finely dispersed β_{VI} crystals improves stability of the chocolate system against further $\beta_{\mathrm{V}} \rightarrow \beta_{\mathrm{VI}}$ transform, which could cause the undesirable structure effects known (but not yet clearly understood) as the non-controlled β_{VI}-bloom (Van Mechelen, 2006 a,b) with visible re-crystallized β_{VI} crystals.

In Section 13.6.3 it was explained how the seed contained a high proportion of β_{VI} crystals and yet the chocolate was almost entirely β_{V} because of the relatively slow transformation to β_{VI}. From Figure 13.28 it

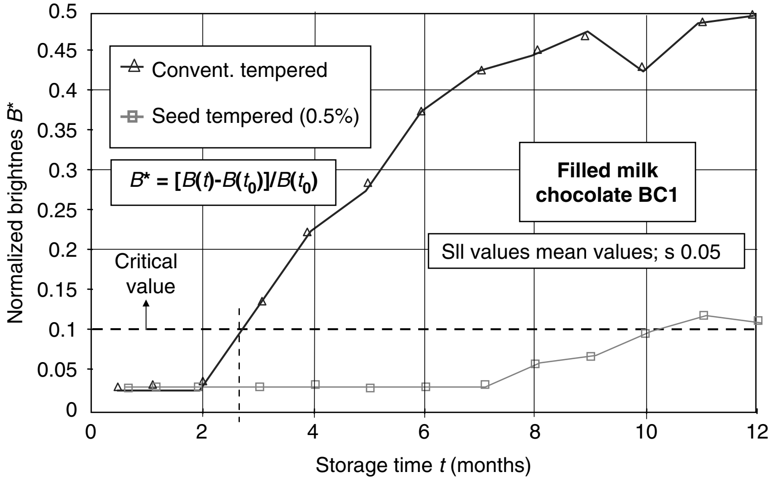


Figure 13.27 Effect of the type of tempering on the surface gloss of a filled milk chocolate product; surface brightness measurements by LAB-colormeter (Source: Zeng, 2000) – brightness versus storage time (19°C, 66°F).

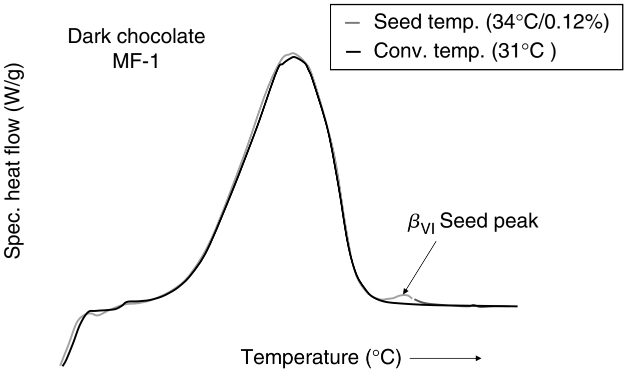


Figure 13.28 Melting behaviour of conventionally and seed-tempered dark chocolate as measured by DSC.

can be seen that both, conventionally and seed-tempered dark chocolate samples show a very similar type of melting behaviour which is typically dominated by β_V crystals. For the seed-tempered chocolate a small peak at 36°C (92°F) can still be seen, which is the melting peak of the β_{VI} seed crystals. The fact that the chocolate solidifies largely in the β_V state explains why the sensorial perception – no waxy mouth-feel as would be expected for β_{VI} crystals – of the seed-tempered chocolate is practically equivalent to the conventionally tempered chocolate.

13.8 Other methods of tempering

There is a variety of other tempering methods and machines found, particularly in patent literature. Many are of historical interest and no longer relevant for modern industrial production of chocolates and it is not possible to mention them all here. Some types of these 'historical' tempering systems described by Beckett (1995) are listed below:

(1) *Cooling drum.* Multiple or single layouts condition chocolate before it is trickle-fed to the enrobers.
(2) *Drip feeding of untempered chocolate* where the material already in the enrober tank seeds new incoming chocolate.
(3) *Screw-type tempering machines*, some horizontal, some vertical with different screw geometries and arrangements.
(4) *Lehmann multi-roller* for cooling and tempering highly viscous paste systems and delivering it into suitable trays at the end of the machine.
(5) *Bauermeister pressure tempering,* a high-efficiency, scraped cylindrical, horizontally disposed, heat exchanger, fitted with an adjustable relief valve at the exit to maintain a cylinder pressure between 1.7 and 10.5 bar.
(6) *Thermocyclic/cyclothermic tempering* with 4–5 subsequent cooling–heating steps to stepwise generate highly stable seed, but long residence time and large volume equipment are required.

Conclusions

There are many types of tempering machines available to the chocolate manufacture, each having its own advantages and disadvantages. To obtain good processing and a high-quality product however requires accurate control of the mechanical and thermal history of the fat crystals generated in the melted chocolate. This can in principle be done by precisely adjusting the temperature, shear rate and residence time. This requires homogeneous shear flow fields with short characteristic lengths to provide good heat transfer and frequent detachment of material from wall boundary layers. In addition, an understanding of the processing and final product from the molecular via the mesoscopic/micro-crystalline to the macro-disperse level is very helpful in optimizing the tempering process, particularly with respect to raw material variations, new product developments/optimizations and process scaling. It is expected that new analytical methodologies, such as those based on X-ray and neutron scattering, as well as on improved in-line instrumentation to monitor chocolate's rheological and calorimetric characteristics, will be the key drivers for ongoing and future improvements in the tempering of confectionery.

Acknowledgements

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Appendix

Machinery manufacturers

Aasted-Mikroverk APS, Bygmarken 9 – 17, DK-3520 Farnum, Denmark.
APV Baker, Manor Drive, Paston Parkway, Peterborough PE4 7AP, UK.
Bühler AG, CH-9240, Uzwil, Switzerland.
Carle and Montanari S.P.A., Via Trebbia 22, Loalità Quinto dè Stampi, 20089 Rozzano, Milan, Italy.
Hosokawa Kreuter Gmbh, Essener Strasse 104, D-22419, Hamburg, Germany.
Lehmann Madchinenfabrik Gmbh, Daimierstrasse 12, 73431, Aalen, Germany.
Sollich Gmbh & Co. KG, Siemenstrasse 17 – 23, 32105 Bad Salzuflen, Germany.

Chapter 14

MOULDING, ENROBING AND COOLING CHOCOLATE PRODUCTS

M.P. Gray

14.1 Introduction

Previous chapters have discussed the manufacture of liquid chocolate, its ingredients, and how to handle and temper it. This chapter deals with ways of forming chocolate into a finished product ready for wrapping.

There are two principal ways of doing this. The first is to form the final shape using a mould into which tempered chocolate is poured. This can be a simple dosing operation if making solid tablets, or can include forming a shell of chocolate and adding various fillings to create a more interesting eating experience. Enrobing is the other method and uses a pre-formed centre over which chocolate is poured to produce a coating. The thickness and form of the coat are controlled by blowing off the excess mass using air and then vibration.

Moulding gives a more obvious gloss to the finished product, whilst enrobing can cope with complex shapes and gives a soft and pleasing finish to the article.

In both cases, subsequent cooling is required to prepare the sweets for immediate wrapping. If chocolate is used as the coating, then good temper is a necessary prerequisite, though if a vegetable fat-based compound coating is used, this may not be necessary.

14.2 Moulding

14.2.1 Background

Moulding of chocolate has been used to make sweets since the nineteenth century. Initially it was carried out entirely by hand, but over the intervening years, automation has gradually taken over. Early moulding lines still

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required a lot of people to move the moulds from one stage to the next and to carry out operations such as inversion of moulds, topping up depositor hoppers, and even scraping off excess chocolate from the moulds. Further automation was gradually introduced until, during the last quarter of the twentieth century, advances in electronics and automation techniques allowed the number of operators to be reduced to one per plant, and sometimes even one between two plants.

At the same time, the metal moulds which were originally used, have been replaced by plastic, normally polycarbonate ones, resulting in a significant reduction in noise in the production areas. The easier handling of these lighter moulds has allowed the introduction of automatic mould changers, both for complete changes of moulds and for the removal of individual moulds, which have undemoulded items left in them. Polycarbonate moulds are also more flexible, so they can be twisted to aid demoulding.

Plant speeds have increased from just a few moulds per minute (mpm) to around 70 mpm for solid items, and plant widths from 275 mm to 1800 mm (12–75 in.) are now available with capacities of up to 10 000 kg/h (10 ton/h). This has all meant that outputs have steadily increased, whereas labour requirements have fallen. In general, reliability has also improved, though some of the earlier automated lines in particular, continue to give problems unless heavily modified.

Other recent improvements include easier cleaning and attention to hygiene; with construction methods using solid supports to eliminate hollow bodies, components being installed with a clearance to the floor to allow easy inspection and cleaning underneath, and electric cables being routed away from dirty areas or made easily accessible for cleaning. Wood and plastic cladding have been replaced by clear polycarbonate so that all the components are visible, and leaks and spills can be seen and eliminated.

14.2.2 Loose and fixed mould plants

Fixed mould plants are those with moulds attached to continuous motion conveyors, usually chains, and are well suited to large production volumes, as they can reach speeds of more than 60 moulds per minute when moulding solid chocolate and 40 or more moulds per minute when producing filled articles. Intermittent motion and crowding (pushing the moulds together to prevent chocolate falling underneath during depositing) are possible for short sections, generally by using hydraulic mechanisms to slacken the drive chains. Fixed mould lines are usually arranged vertically with the return leg from the demoulding to the mould heater being above or below the depositing leg to minimize the area they occupy.

Loose mould plants have a higher degree of flexibility in terms of the variety of products that can be made on one plant (sometimes simultaneously) and in their ability to change from one product to another rapidly. They are linear and modular, and can easily be adapted to users' requirements.

The moulds are moved by a variety of chains and conveyors, and can switch rapidly from a continuous to an intermittent motion and vice versa, as required. Modern technology, in particular the servo motor, allows each section to be independently controlled electronically, and has revived interest in loose mould plants, as they now have the potential to operate at much higher speeds than lines using older technologies. Conventionally, lines have had one or possibly two central motors with lengthy shafts being used to drive the individual components.

14.2.2.1 Circuit description

Simple loose mould lines are usually laid out in a square, though a figure of eight (8) layout is often adopted to allow sections not being used to be bypassed for cleaning or changeover, or just to save wear and energy. More complex layouts with parallel legs can be found on ultra-flexible plants used to make a wide variety of assortments. The various components may be independent or combined according to the age and design purpose of the plant. A typical layout of a loose mould line capable of manufacturing filled chocolate bars is shown in Figure 14.1. A picture of the turning point on such a line is shown in Figure 14.2.

Fixed-mould lines require the same components, generally in the same sequence, as those of the loose mould line: smaller or older lines are sometimes also laid out in the form of a square, but normally the return leg will be above or below the depositor leg.

The necessary components are:

- Mould conditioning
- Depositing
    - There can be several depositors according to the number of products made.

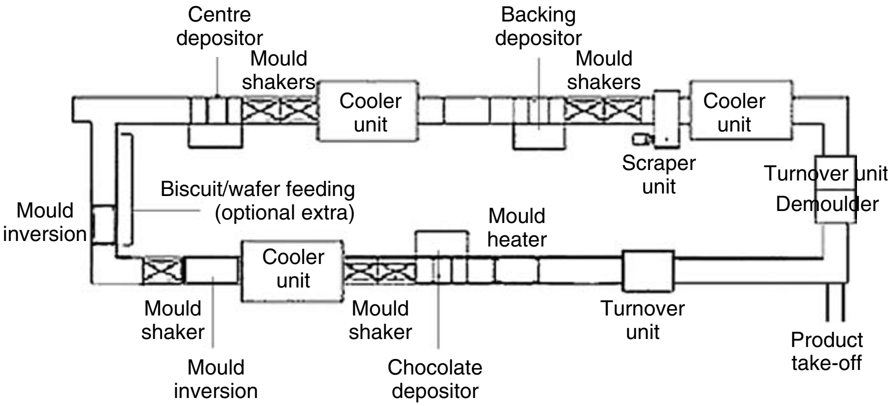

Figure 14.1 Layout of loose mould moulding plant.

Figure 14.2 Picture of turning point on loose mould moulding plant (OPM Italy).

- Shelling forming and cooling*
  - The cooler can be vertical or horizontal, and continuous or intermittent in operation.
- Centre filling and cooling*
  - Again, there may be several depositors, often used simultaneously to produce all the components of an assortment at the same time.
- Backing off*
  - Can be flood, deposited or sprayed according to the type of centre.
- Main cooler
- Demoulding.

Note: Sections marked with arterisks are not required for the manufacture of solid tablets.

14.2.2.2 Prerequisites

Other chapters in the book cover temperers and tempering, chocolate recipes and the handling of masses before they reach the moulding line. It is imperative that the chocolate is well tempered before reaching the depositors and that its temperature is as high as possible to maximize fluidity. Surfactants such as lecithin and PGPR must have been optimized for moulding and the viscosity must not only be suitable for the purpose, but be consistent. Without these requirements being met, it is impossible to always produce glossy items of the correct weight and shape. Such defects will not only result in poor sensory attributes, but may well lead to problems in the wrapping area, where wedge or banana-shaped items will slow down or jam wrapping machines, especially at high operating speeds.

14.2.3 Mould conditioning

If tempered chocolate is put into moulds that are not at approximately the same temperature (ideally +/– 1°C) problems will arise:

- If the moulds are too warm, detempering can occur resulting in product sticking in the impressions at demould, poor gloss, and bloom.
- If they are too cold, poor gloss and sticking in the mould can result. The flow of chocolate in the mould can also be affected, and can result in markings on the finished product as well as an increased number of air bubbles.

Moulds returning from the main cooler are usually at around 12–15°C (54–60°F) and so must be re-heated. If they have just been introduced to the plant, or there has been a long stoppage, they are likely to be at room temperature and will require less heating. The conditioner will take some time to adapt to these changes, and there will usually be a gap in production as a result.

Mould heating may be direct or indirect. Indirect systems use air heated by steam coils or electric heaters which is blown across the mould surface. This has the advantage of giving a precise and even control of mould temperature, but the disadvantages include higher capital cost and greater space requirement, the need for a longer heating zone (more moulds in the circuit) and a higher energy requirement. The air is diverted during stoppage periods to prevent overheating.

Direct systems use a radiant heat source, usually an electric heater mounted above the moulds and shining down onto their top surface. Advantages include energy efficiency (as it only acts on the mould surface), simplicity, and a shorter conditioning time, which in turn leads to fewer moulds in the circuit. Disadvantages are that the temperature is never completely even and it is difficult to get heat into the bottom of a deep mould cavity. The reflectors are normally moved through 180° during a stoppage to reflect the heat away from the moulds.

An optical pyrometer, infra-red (IR) thermometer or a conventional one with a contact probe can be used to check that the temperature is even across the moulds – usually an IR thermometer is fitted above the line, but this only measures at one point across the mould.

14.2.4 Depositors

There are several types of depositor, which will vary depending upon age, manufacturer and purpose. Piston depositors (Figure 14.3), of which

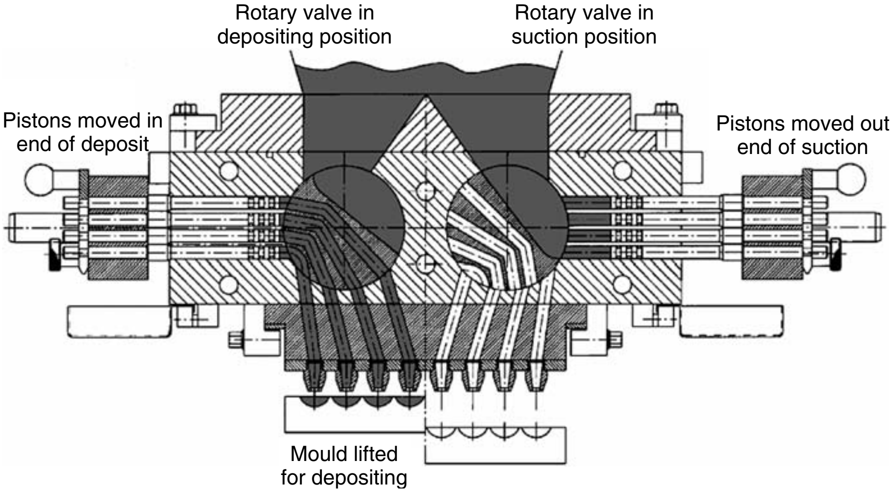

Figure 14.3 Typical piston depositor.

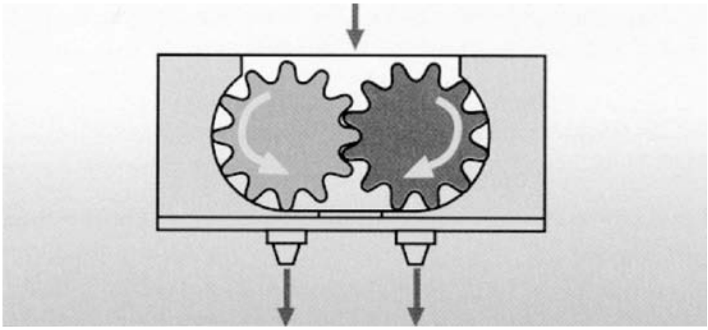

Figure 14.4 Typical gear depositor.

there are many different models, are the more accurate. Their layout can be either linear or rotary. As plants have become wider and faster, so the drive mechanism has been improved with mechanical drives being replaced by hydraulic ones. Various different solutions have also had to be found to ensure that all the different pistons provide an even distribution of chocolate in every mould cavity all the way across the plant, with the degree of success depending on the manufacturer and on the product. Checking the weight variation across a moulding line should be part of each new product start-up.

Rotary gear depositors (Figure 14.4), which tend to be more compact and somewhat cheaper, are also used for tasks requiring less accuracy such as shelling and biscuit applications.

The depositor has three basic components: a jacketed hopper, usually stirred slowly to distribute the masse evenly and minimize variations in temper and temperature: the piston block, where the masse is metered by being drawn in to the bore, and then in the next part of the cycle pushed out into the third component, the depositor plate. It is this complex and heavy device that directs the chocolate into the various cavities in the mould. The depositor plate is interchangeable to adapt the depositor to the layout of the various moulds used on a plant. More than one piston can be used for each cavity, if the product being made is large. The plates on wide plants may have more than one hundred nozzles and frequently there are two rows of depositors per plant filling alternate moulds to enable higher operating speeds. The pressure applied to the plate can be as much as 18 bar (260 psi), which is why it has such a massive construction (see Figure 14.5).

On some plants, the moulds are lifted up so that they are closer to the depositor and then rapidly dropped back to their normal height: This is done

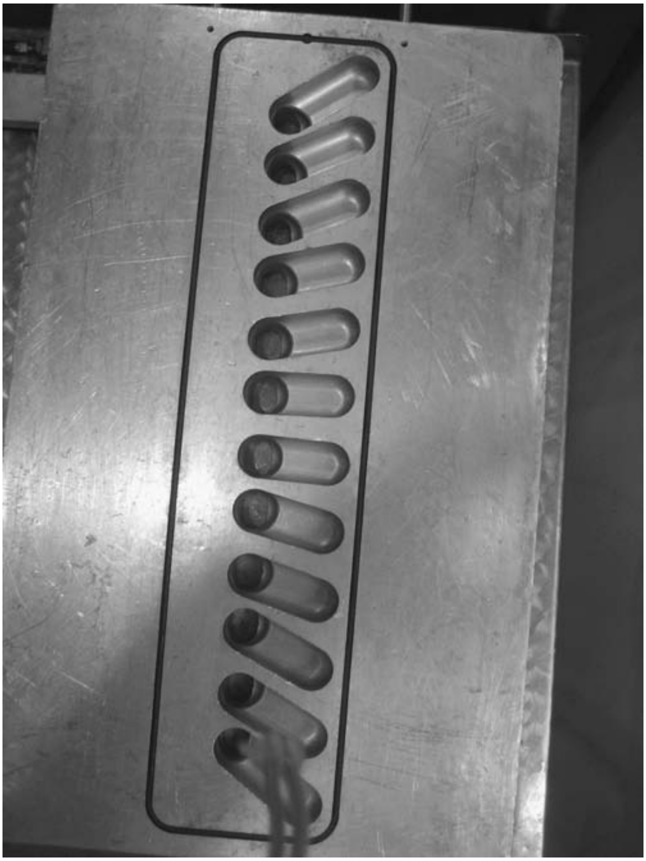

Figure 14.5 Typical depositor plate.

to break any tails that might form when depositing stringy materials such as caramel. The whole depositor may move backwards and forward at the same speed as the moulds, or may swing whilst depositing. This is done to allow more accurate positioning of the material being put into the cavities.

Many modern depositors can be slid away from the line to allow cleaning whilst the line itself is still running, resulting in a significant reduction in downtime during changeovers.

14.2.5 Adding inclusions

Small-diameter nozzles are generally fitted to a depositor plate for dosing liquids, whether it is chocolate or a product centre. However, this approach does not work when there are inclusions, such as nut pieces or crispies (cereals) mixed into this liquid/paste. In this case the openings must be large enough to let two inclusions travel through side by side. If the inclusion is 3 mm (0.1 in.) long then the outlet needs to be at least 6–8 mm (0.25–0.3 in.) diameter. With such a large opening dripping can occur, so a shut-off knife or valve is usually fitted to the underside of the depositor plate to physically close the outlet after depositing is completed. Some depositors are fitted with a suck-back mechanism to reduce dripping and strings of chocolate falling onto the moulds.

Figure 14.6 shows a typical worm conveyor/mixer for inclusions, which can be mounted on a swivel to allow for cleaning whilst the plant continues to run.

Alternatively double hopper systems make it possible to change very easily between different types of inclusions. There are many machines that can be used to add nuts and fruit accurately. With all of them however accurate weighing, good temperature control and homogeneous mixing mean

Figure 14.6 Screw mixer conveyor system as manufactured by Aasted (Denmark). Reproduced with permission of Aasted Mikroverk.

better weight control. Adding inclusions to the chocolate in a mixer before pumping to the depositor hopper gives a more homogeneous result and allows better deposit and weight control.

Defects from incorrectly adding inclusions show the following:

Grey marks over inclusions: due to poor temper or inclusions being too warm.

Badly shaped bars: inclusions should ideally be near to the temperature of the chocolate, and should at least be stored in a warm room for several hours before use.

Poor weight control: non-homogeneous mixing either of inclusions with chocolate or if using more than one inclusion, of the inclusions themselves.

14.2.6 Removal of air bubbles

Air bubbles can spoil the appearance of a chocolate tablet and in extreme circumstances may give rise to weight variations. They can be minimized by choosing the correct mould temperature prior to depositing. Some mould designs will inherently trap bubbles, and this must be addressed during their design.

It is important to begin vibrating to remove trapped air bubbles as quickly as possible after the chocolate is deposited into the moulds. Most vibrators act vertically; the mould is pushed a set distance (amplitude) at a given frequency by an eccentric cam or an air cylinder. Ideally both the frequency and amplitude should be adjustable.

Horizontal vibration can be used to spread a small amount of chocolate over a large distance in a thin piece. Orbital shaking is a special application used to ensure even coverage of a chocolate shell during traditional shelling method, once the mould has been inverted.

Vibrating times should be a minimum of 30 s and are ideally 55–60 s. The moulds must make sufficient contact with the shaker rails to allow effective transfer of energy between the two: if they are not well restrained, they will bounce and little energy will transfer.

14.2.7 Shell forming

The traditional method of forming a shell that is later filled and backed off, wherein mould cavities are filled almost to the top, the moulds are shaken to remove air bubbles and are then inverted. The inverted moulds are shaken immediately to drain out all but a thin shell of chocolate. The viscosity of the masse must be adjusted so as to make this the controlling step. Too low, and the chocolate will run out irrespective of the shaker setting, too high and the shell will be thick and uneven, and so heavy. The moulds are then returned upright and when cooled the centre is added then back or seal as required.

If a biscuit or similar item is to be placed in the shell, the chocolate may be left uncooled to make good contact and to prevent the formation of air pockets between the chocolate and the inserted item.

Other methods of shell forming are described in Section 14.2.15.

14.2.8 Centre filling

Centre filling is crucial to the quality of the finished item. Overdosing leads to leaking sweets and can contaminate the backing-off chocolate. Under-filling gives a poor eat due to a thick back and not enough centre. If the filling is too warm it can detemper the shell, leaving a grey colouration and possibly leading to bloom, as well as sticking in the mould. If the centre is too cold it will not flow uniformly to form a flat surface. This leads to poor sweet backs, possible leaking sweets and contamination of the backing off chocolate. Air bubbles can also be trapped around cold (viscous) centre giving weight control problems.

The centre may cost more (nut pastes, ganaches) or less (fondants, frappés, caramels) than the chocolate, so over-filling can be expensive. If the centre is less expensive the correct proportions must still be maintained for quality reasons.

The centre may be more (fondant, caramel, syrups) or less (whipped or fat-based cremes) dense than the chocolate, or almost the same (pralines, gianduja). It is important to be aware of the effect of each of the filling masses used on a line.

There are contraction differences between fat- and fondant-based centres. Generally, fondants will contract less than fat-based centres. This can cause problems in shell moulding since pressure may build up in the centre during cooling resulting in cracks in the chocolate and possibly leakage of the water-based centres.

14.2.9 Backing off

There are several ways to put a back on a product. Ideally, a separate temperer is used to supply the backing off chocolate, to avoid contamination from any returns (e.g. some of the centre material may be scraped into this chocolate), to avoid pumping the tempered masse a long distance and also to allow a lower degree of temper or a slightly higher fat content, which will make producing a flat back easier. If the backs are uneven, problems can appear downstream, particularly in high-speed wrapping machines where good contact between the back of the sweet and the conveyor belts is essential for consistent acceleration.

14.2.9.1 Flood backing off (Figure 14.7)

This is the cheapest method, as there is no need to meter the chocolate. Weight control depends on viscosity and scraper efficiency. Soft centres can be pushed

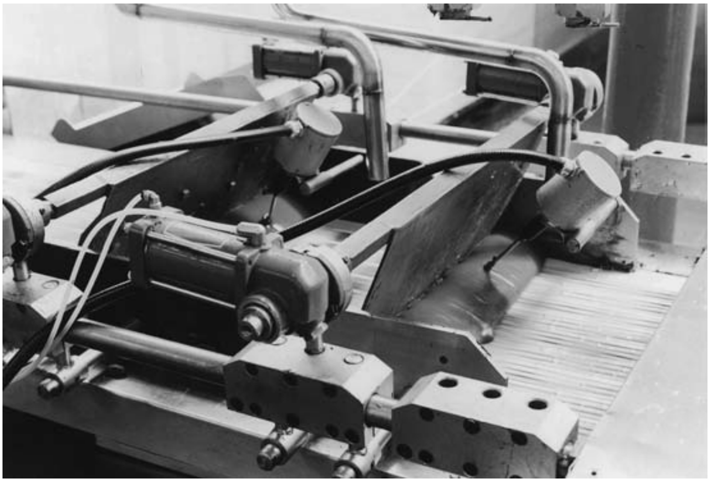

Figure 14.7 Flood backing off. See Plate 8 for the colour image.

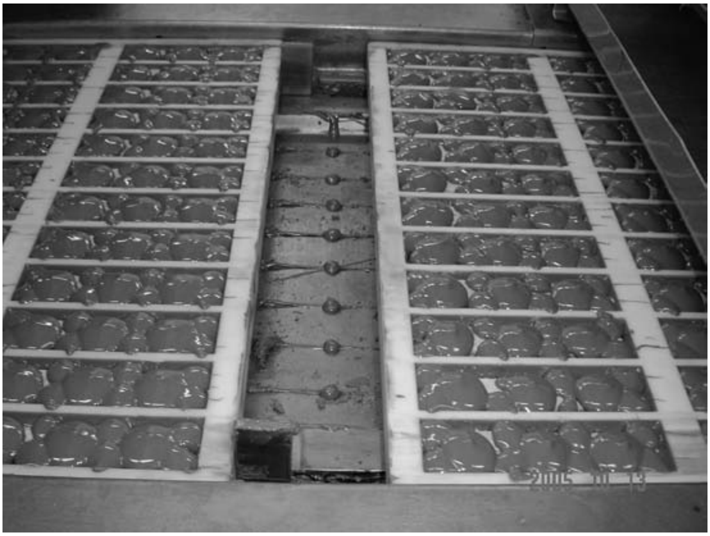

Figure 14.8 Deposit backing off. See Plate 9 for the colour image.

out of the shell and contaminate the chocolate and it is difficult to avoid incorporating air bubbles. A static knife across the mould is used to control the flood, with a second one to clean the moulds and improve accuracy. It is essential to use the correct material for the blades, and not to apply excess pressure.

14.2.9.2 Deposited backing off (Figure 14.8)

This is more expensive to install than the flood system. An accurate volume is applied, but the chocolate viscosity needs to be low enough to enable the chocolate to spread into the corners during the brief period of vibration. Cold centres can be difficult to cover. Mould surfaces usually need cleaning to spread the chocolate properly and to remove any excess; this is usually done with a licking roll or scrapers running at right angles to the plant.

14.2.9.3 Sprayed backing off

Spraying chocolate onto a sweet is an expensive and potentially messy way of adding a back, but it is good for very liquid centres such as liqueurs and is sometimes used to form a first thin untempered coating before being followed by a flood or deposited back. The chocolate viscosity must be low, and extra fat normally has to be added. The mould surface in between the cavities will need cleaning as it is difficult to direct the spray only onto the sweet.

14.2.10 Cooling

When cooling and then crystallizing any fat containing product heat has to be removed from two sources:

- *Specific heat* has to be removed to cool it.
- *Latent heat* is given out when the fat crystallizes, and as can be seen below this is the more significant of the two when solidifying chocolate.

Specific heat of fat	2.0 J/g
Latent heat of crystallization of fat	157 J/g
Specific heat of milk chocolate	1.6 J/g
Latent heat of crystallization of milk chocolate	44 J/g

To cool 1 g of fat from 28°C to 12°C (82°F to 54°F) requires the removal of 32 J, whilst 157 J will need to be removed due to crystallization. Conduction or contact cooling is the most efficient because of the intimate contact with the product. Forced convection is the next most efficient form of cooling for enrobed products since the top and sides of the product are in the air stream. This is analogous to 'wind chill' and high-velocity air aids cooling. Radiation, the third method of heat extraction removes a much smaller amount of heat.

The need to crystallize fat as small crystals in Form V limits the rate of cooling that can be applied. Low cooling temperatures or short cooling times, give less stable polymorphs such as Form IV and can result in a lack of stability and poor contraction (see also Chapter 12).

14.2.10.1 Intense cooling

Intense cooling is sometimes necessary when depositing a hot centre for example a caramel, at 55–60°C (131–140°F) into a chocolate shell. An intense shell cooler will prevent the centre from melting or detempering the chocolate. Typically, the shell is cooled to 10°C (50°F) prior to depositing the centre. Cooling continues immediately after depositing to ensure that the chocolate remains undamaged.

14.2.10.2 Cooler zoning

Older coolers tend not to be zoned, having one source of cold air that has to be directed in such a way as to optimize cooling, whereas the more modern ones usually have at least three temperature zones:

Zone 1 – specific heat removal with temperature settings of 12°C to 15°C (54°F to 59°F), and typically about 5 min residence.

Zone 2 – in which most of the latent heat is removed. It tends to be released suddenly as crystallization sets in. Typical temperatures are between 7°C and 10°C (45°F and 50°F) for 10–20 min. Very large tablets may require up to 30 min cooling.

Zone 3 – the product is warmed to just above the dew point of the packing room prior to exiting. The dew point is the temperature at which moisture begins to condense from the surrounding air and this would damage the chocolate surface and cause marks or sugar bloom. (Sugar bloom has an appearance similar to fat bloom, but is actually sugar crystals on the surface. Unlike fat bloom it does not melt under warm conditions.) The actual dew point can be measured using a wet and dry bulb thermometer in conjunction with a psychometric chart. Throughput times are typically the same as zone 1 though temperatures may be slightly higher.

Dark or low butterfat milk chocolates can be cooled at temperatures 2–3°C (3.5–5.5°F) higher than those given above.

The air speed in a cooler, needs to be high enough to give turbulent flow across the moulds, which is generally agreed to occur once it has reached 5 m/s (990 ft/min). Air should not blow directly onto the chocolate as it can cause ripples to form on the backs. Older coolers that use cold plates to cool and have low airflow require a much higher temperature differential and can result in condensation inside the cooler. All coolers require some sort of periodic defrosting unless supplied with dehumidified air. Traditionally this has been done during shift changes or during a forced stop for the purpose. Some more modern units are equipped with hot gas defrosting systems, which can defrost the coils without production being interrupted.

The position of the air temperature control probes in a cooler should also be checked. To give the correct value, they must be fully in the airflow they control and in a position not affected by outside conditions, i.e. adjacent hot rooms or strong sunlight. Older coolers and those moved around at various times are prone to suffer from this problem. Check where the cooling air is drawn from and ensure that it is not from a humid or hot zone, nor from a process area with strong aromas.

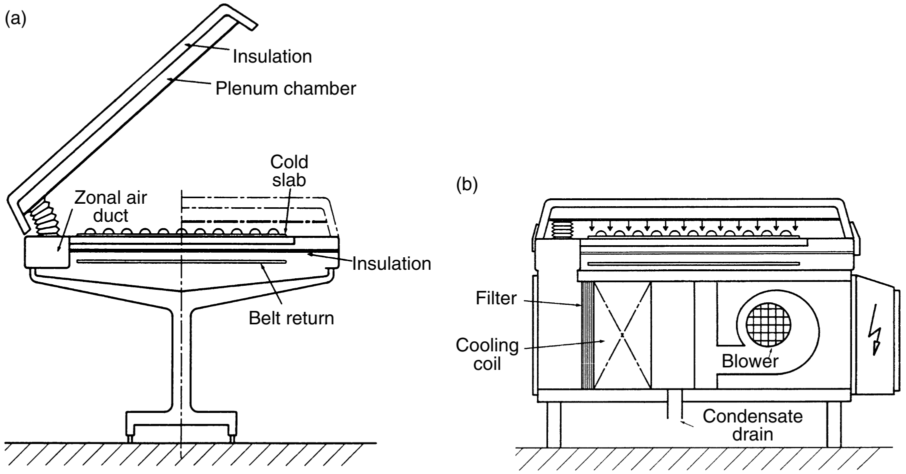

Figure 14.9 Sections through the Gainsborough cooler at (a) the centre and (b) the blower.

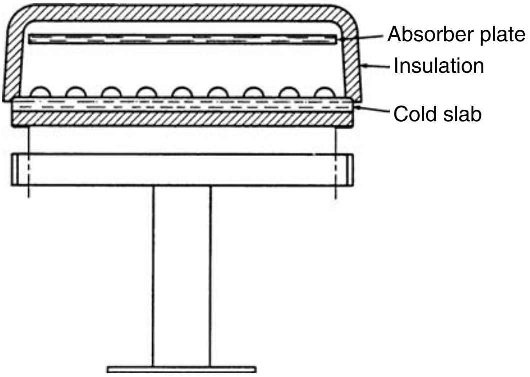

Figure 14.10 The Sollich cooler normally used with enrobers.

14.2.10.3 Cooler layouts

Two types of tunnel cooler are shown in Figures 14.9 and 14.10. These are the Gainsborough cooler and the Sollich contact radiation cooler. In a modern Sollich cooler, cold air enters the product space from the cooling unit via a duct and there is a brief initial cooling by convection. Air flaps in the covers divert cold air to the space above the conveyor where plates above the product are cooled, leading to radiation cooling which is gentler than convection. At the end of the first tunnel air returns to the conditioner via the space below the conveyor so that products in that area are cooled from the bottom (contact cooling). In the second section, cooling is by convection with air flowing with the product and warming up. Again it returns to the cooler below the conveyor.

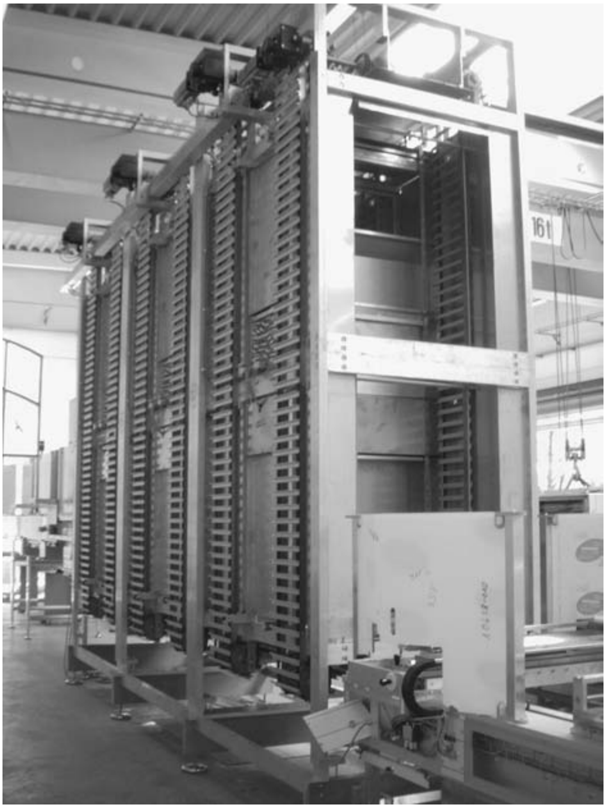

Figure 14.11 Multi-tier cooler.

Multi-tier coolers arose from the need minimize the floor space needed. For instance, a three-tier cooler is equivalent to a linear unit approximately six times its length. In early designs, chocolates were put onto plaques which were carried by hand to the cooling units, in which they were located on metal trays suspended from the carrier chain. The chain circuit ran continuously but could be stopped at will. This was the forerunner to the in-line multi-tier coolers now in use seen in Figure 14.11.

All tiered coolers require turning points or star wheels to guide the moulds and keep them upright as they are conveyed into the next layer. Such mechanisms are frequently a cause of jams and so need to be regularly cleaned and carefully maintained.

14.2.11 Demoulding

If tempering and cooling have been optimized, then demoulding is a minor part of the process with good quality product cleanly leaving moulds that are

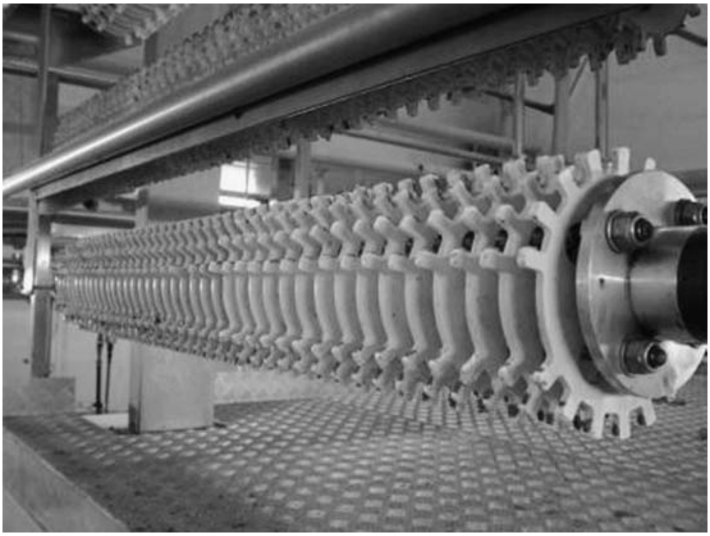

Figure 14.12 Sticker detector.

returned to the start of the process. As any user can testify, life is not always that simple!

A small amount of force is normally needed to part the product from the mould and this is usually supplied by a hammer, possibly aided by a mechanism that twists the moulds. Product is demoulded onto either plaques or a belt, depending on subsequent packing arrangements. Detectors are available to identify moulds containing sticking sweets (see Figure 14.12).

14.2.12 Troubleshooting demoulding problems

Poor demoulding should be tackled at once, as stickers can go back round the plant and cause further trouble. Check all the plant operations that might affect contraction in a sequential manner confirming that each is working within defined limits. The following hints can help troubleshooting.

14.2.12.1 Static

Product can be held in place by electrostatic charge, which is more of a problem with light or small units than moulded bars. A static discharge device can help.

14.2.12.2 Mould condition

Mould surfaces will roughen with use and washing, particularly if the products being moulded contain abrasive inclusions or centres such as wafer or grated hard boiled sugar. A lip can also form at the edge of the cavities if a scraper or knife is of the wrong material or if too much pressure is being applied.

14.2.12.3 Proportions

Very thin shells can result in less contraction, making good temper and optimized cooling essential to give good demoulding. Poor mixing with other ingredients can also result in increased sticking (Section 14.2.5).

14.2.12.4 Contraction

As cocoa butter crystallizes, its volume decreases slightly, resulting in contraction of items made using it. The presence of butterfat, or other soft fats or oils (e.g. nut oils) will reduce contraction.

To obtain good release from the mould, the degree of contraction needs to be maximized. This requires the amount of temper and the rate of cooling to be optimized. Compounds made using vegetable fats rely much more on contraction due to cooling, but the choice of the correct fat system will affect release.

Typical values for contraction of chocolate

Milk	0.3%
Dark	0.8%
Compound fats	<0.6% (high trans fatty acid or lauric).

For filled items, under-tempering will result in more contraction and give better de-moulding. Better flow from under-tempered masse (lower viscosity) helps distribution within the mould and will result in a more uniform wall thickness.

Non-cocoa-butter-based systems have less complex polymorphism and faster cooling rates are possible because at chocolate cooling temperatures only one polymorphic form is possible; however, over rapid cooling can result in the fat setting in a glassy amorphous state. Some lauric fats require very sharp initial cooling to get sufficient contraction to release.

14.2.13 In-line storage systems

Unless there is a considerable excess of wrapping capacity over moulding output, a flexible store or buffer can be used to avoid costly and potentially damaging traying-off of excess product during wrapping machine stops and then having to hand feed them again. These were traditionally paternoster type with product being pushed onto trays that move up and down a series of stacks until reaching the exit, but other formats are now available. A bypass is normally provided for use when the wrapping machines can handle the full line output.

Such systems (e.g. Figure 14.13) can also be used to allow a moulding line to run more shifts than the wrapping line, but however they are used, there is a possibility of the store hiding inefficiencies in the moulding line performance that line personnel must be aware of.

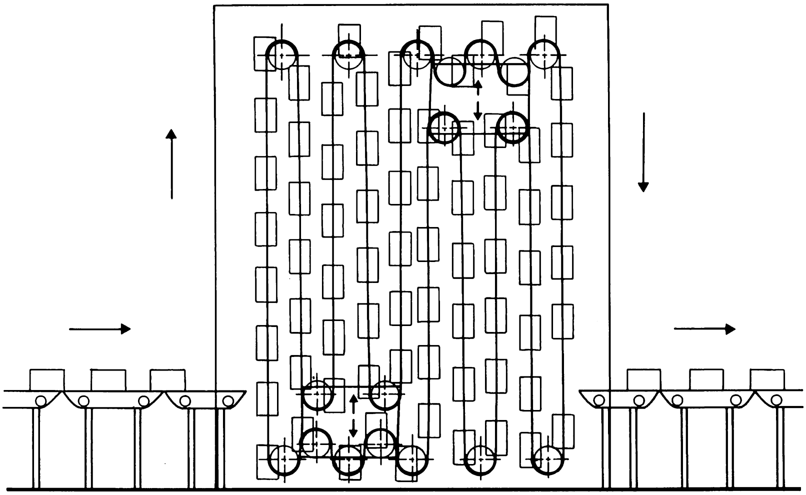

Figure 14.13 Schematic diagram of a flexible storage system. This example is 50% full.

14.2.14 Keeping moulds clean and changeovers

It is far more efficient to keep the moulds clean, rather than resort to scrapers or rollers to clean them up. Factors such as correct depositor timing to avoid depositing outside the impressions, making full use of any suck-back fitted to the depositor and avoiding drips from the depositor by good maintenance and using the correct nozzle diameter (the wider the nozzle is the more likely is the drip) can all help.

If dirtying of the moulds cannot be avoided, then a suitable combination of licking rolls (Figure 14.14), surface scrapers and edge scrapers can help avoid build-ups that shorten runs and cause contamination.

Changeovers will always be a part of running many lines, so it is essential that their efficiency is improved as well as minimizing their number. It is imperative that each line has its own Standard Operating Procedure (SOP) written and available locally. Analysis of downtime for changeover against stock levels from longer runs, should be carried out to ensure that the most cost-effective options are chosen. 'SMED' (Single Minute Exchange of Dies) is a useful tool: its aim being to systematically reduce the time lost in production for machine changeovers and set-ups.

14.2.15 Other methods for shelling forming

The traditional method of shell moulding was described in Section 14.2.7. Several other methods are available however.

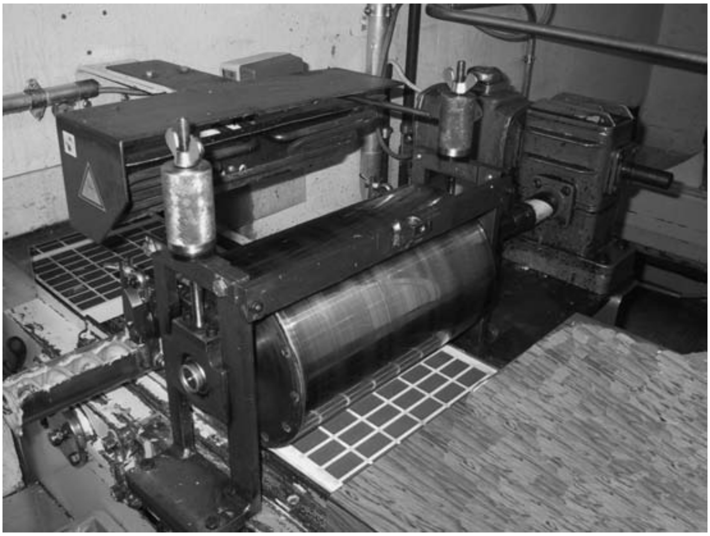

Figure 14.14 Licking roller. See Plate 10 for the colour image.

14.2.15.1 Book moulding

Initially similar to conventional shelling, but once the shell has been formed the two matching halves of the mould are pressed together like a book so that they seal, forming a hollow (or centre filled) shell. A shallow but continuous and even lip is needed to provide chocolate for the seal. Conventionally the lip is formed after shelling, whilst still inverted, by an extra shaking stage. The mould is re-inverted and the lip is reheated by infrared heaters before closing the book to form a seal. Closing can be done by turning one half of the mould pair through 180° whilst held in a frame, or on a loose mould plant by moving both moulds through 90° to the vertical. A plastic clip or a magnet holds the halves together.

14.2.15.2 One shot moulding

This is described in detail in Chapter 17 and is a method of depositing both shell and centre simultaneously.

14.2.15.3 Spinning

The liquid chocolate masse is placed inside one half of the mould, which is then closed and spun on two axes. Once the chocolate has set and contracted the mould is opened and the item taken out. Different coloured chocolates can be added to certain portions of the mould to give the item an attractive appearance (e.g. Santa Claus' beard in white on a milk chocolate).

14.2.15.4 Cold forming

This is described in detail in Chapter 15, but in the context of this chapter, it is a way of making very accurate shells wherein an exact amount of liquid chocolate is put into a cavity, and a plunger at around –20°C (–4°F) applies pressure to distribute and set the masse (Figure 15.1). This is very good in forming a lip for book moulding. It can also be added to a conventional tablet moulding line to enable it to make filled products (see Chapter 21, Figure 21.2).

14.2.15.5 Drop moulding

This is a specialized plant for making chocolate pieces such as buttons or chips for cookies. Depositing is done directly onto a cooled belt (see Figure 14.15). Such plant can also be used to make easily melted chips for the distribution of industrial chocolate masses.

14.2.15.6 Dragee moulding

A plant for making shaped chocolate pieces such as lentils for sugar coating, was originally developed by Erikson in the 1940s and is shown in Figure 14.16. Liquid tempered chocolate is poured between the two rolls, which are maintained below freezing point. A web containing the lentils comes out below the rollers. This web is then broken after cooling, to release the individual pieces. The remaining web crumbs can then be melted and reworked.

Figure 14.15 Drop moulding production plant. See Plate 11 for the colour image.

14.2.16 Troubleshooting moulded product faults

14.2.16.1 Weight variability

If there are significant weight variations between the shells of moulded articles it is helpful to build a 'map' by weighing individual shells from

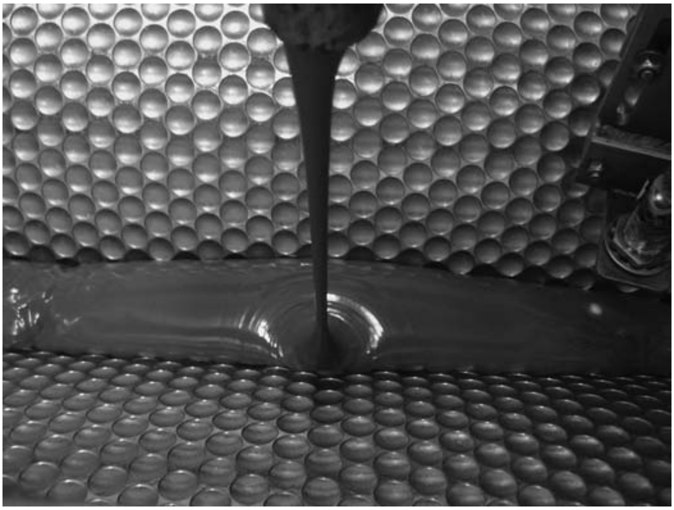

Figure 14.16 Dragee moulding plant. See Plate 12 for the colour image.

10 consecutive moulds. If there is a pattern within each mould or between moulds, there are several possible causes.

- Incorrectly adjusted shakers.
- Temperature variations across the mould, possibly from the conditioning zone.
- Temper or temperature variations across the depositor hopper.
- Poor mould restraint due to broken or worn lugs on the mould. (See Section 14.2.17 on mould construction.)
- If using book moulds, the clips that hold the mould into the frame are not properly adjusted.

14.2.16.2 Cracking of hollow figures

For hollow figures, solidification and shrinkage may result in stress cracks due to too much contraction. A higher pre-crystallization level (6–7 on a Sollich temper meter) should be used, and the moulds and the beginning of the cooling line should be run warmer.

14.2.16.3 Visual defects

Tablets with missing or bent corners

- Viscosity of the mass too high
- Temperature too low
- Overtempered
- Inclusion level too high
- Wrong deposit type – ideally need ribbon for inclusions

Curved bars

- Incorrect temper
- Cooling too rapid
- Inclusions or centre expanding or contracting more than the chocolate.
- Poor design of bar with plinth (base) too thick

Grey areas

- Local detempering due to incorrect mould or inclusion temperature, poor tempering or mixing in of untempered masse

Pale curvy lines

- Poor temper

Rub marks on bar sides

- Incorrect setting of demould belt height or speed, or hammer/mould twist not set correctly
- Demould not quite good enough, causing tablets to partially release
- Such marks can also often be caused by the wrapping machines

14.2.16.4 Breakage at demould

Breakage at demould can occur due to poor mould design, for example when the product sticks to the mould due to sharp corners, or there is too much flat, unengraved surface.

A shelled tablet with chunks or cubes, having a base or plinth that is too thin compared to its height, will break when dropping out of the mould. On a typical 10 mm (0.4 in.) deep 100 g (3.5 oz) tablet, the plinth should be at least 5 mm (0.2 in.) thick. A bar with an odd number of cubes is less likely to break. If a thinner plinth is essential, adding reinforcing ribs of chocolate between the cubes will help. The base and the cubes of such a tablet should have radii of 0.75–1 mm (0.03–0.04 in.) to get an even contraction. Sharp radii will cause the shell to have thin areas and result in leakage of the centre ingredients or breakage.

14.2.16.5 Formation of meniscus (Figure 14.17)

Feathering is a thin rim of chocolate or meniscus around the bottom of a chocolate product. It can be caused by the mould being too deep, or by shaking a solid product too much. Some additional depth is necessary to avoid spillage, but there should be no more than 0.5 mm (0.02 in.) in a small piece (less than 50 g (1.8 oz)) or 1 mm (0.04 in.) in a bigger item. When a meniscus occurs and breaks off during demoulding or wrapping, chocolate particles can dirty the wrapping machine or spoil the surface of the product.

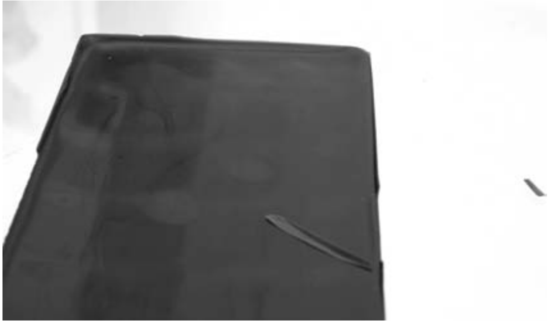

Figure 14.17 Meniscus on a chocolate bar. See Plate 13 for the colour image.

According to the Agathon company, this problem can sometimes be reduced by using an ionizing (anti-static) device.

14.2.17 Mould design, care and innovations

14.2.17.1 Mould design

Any reputable mould manufacturer will give advice on the basics of mould design. It is vital to follow such guidance to ensure good demoulding, with high gloss and a minimum of marks due to uneven cooling or sticking. Mould life will also be dependant on good design and competent injection moulding.

The following points are examples of the details that must be designed in to any successful mould.

- Impression tapers must be large enough to allow the product to be released from the mould, 8–10° is the minimum. Sharp angles should be avoided, otherwise air bubbles will remain in the cavities giving poor appearance and demoulding. External radii should be about 1.5 mm (0.06 in.).
- Engravings give a sweet, unique appearance and identify it. They also assist demoulding, as they enlarge the surface of the item and help contraction. They will reduce cool spots and demould marks. Engravings should be about 0.18 mm (0.007 in.) deep and well rounded with a taper of 15–20°.
- Engraving lines can be incorporated in the side walls of a flat thin item to avoid a vacuum forming and holding the product in the mould.
- For a typical 100 g (3.5 oz) bar, the base or raft should be at least 5 mm (0.2 in.) thick compared to the total height of the bar of approximately 12 mm (0.5 in.). If a thinner base is desired, there should be reinforcing ribs of chocolate, preferably around the outside of the bar between the cubes.
- Radii on the back of the mould are important. Any notched or non-rounded area will soon result in breakage of the plastic mould itself. For

those which undergo rough treatment radii of 0.5–1 mm (0.02–0.4 in.) should be specified to avoid early breakage.

- Flexibility is important. Should you make use of the natural property of the plastic material which is flexibility, or have a rigid mould leading to a longer life because of its frequent abuse on shaker tables? It is a balance between having a more rigid mould with more ribs and thus more material which could last longer and a flexible one that will cope with the stress imparted by the demould twister and the hammers. The shaking of a rigid mould is more even as vibration energy is transmitted, rather than absorbed as in a flexible one. The ribs are good channels for distribution of the polycarbonate in the injection moulding tool. They also act as connecting points between the outside frames and help keep the mould straight on the line.

14.2.17.2 Mould construction and care

Polycarbonate moulds are made by injection moulding of granules, which have been dried immediately before use. Moisture uptake continues for 24 h after moulding, from which point the moulds are stable. It is a naturally clear polymer, so white colour is normally added at 0.1–0.2% to make any broken pieces visible and look less like glass if they should get into a product. Other colours can be added at low levels, but the more is added the more the polycarbonate is weakened. There is not normally any premium payable for colour addition.

It costs more to make a mould with several injection points, but because the liquid plastic has less distance to travel inside, there is less stress and the mould is stronger.

Broken moulds should be examined and the reason for breakage logged. Action must be taken to find and eliminate the cause of any trend that is established, i.e. several moulds showing similar damage. Up to 1% breakage is normal: above that amount, the causes should be investigated. Avoid excessive hammering of the moulds, i.e. solve problems of poor demoulding. Twisting during demould shortens mould life, and should be adjusted to an effective minimum.

Mould breakage can be a significant source of foreign bodies in a product and there are currently no satisfactory means of detection or removal.

Common causes of breakage are:

- Poorly aligned turn points
- Plant components moving out of alignment and touching the moulds
- Badly adjusted or damaged scrapers
- Stickers being hammered out with metal or sharp objects.

Continuing to use cracked moulds is a false economy: they can distort under the backing-off knife and cause bad backs and over-weights and they are likely to cause jams at turn-points by breaking or becoming distorted.

Table 14.1 Recommended washing conditions for polycarbonate moulds.

Wash type	Recommended temperature	Water type	Contact time (s)	Detergent
Pre-wash (heavily soiled moulds)	60°C (140°F)	Soft	10+	None
Main wash	60°C (140°F) max	Soft	15+	Detergent
Re-circulating rinse	60°C (140°F) max	Soft	10+	None
Final rinse	60°C (140°F) max	Demineralized or reverse osmosis treated	Minimal	Rinse aid
Blowing off/air drying	105°C (220°F)	–	As required	–

14.2.17.3 Mould washing

The maximum recommended washing temperature for polycarbonate moulds is 60°C (140°F). Above this, moisture will be absorbed and weaken the moulds.

Detergents must be neutral (pH ~7) to avoid chemical attack. Rinsing may be done at temperatures of up to 75°C (167°F) if the residence time is only seconds. A rinse aid should be used to help drying. Water needs to be soft to avoid spotting due to dissolved salts being left on the surface after drying. A summary of the recommended conditions for washing and drying moulds is given in Table 14.1.

Solid chocolate must be removed from the moulds before washing, both to avoid contaminating the detergent solution and to prevent discharge of contaminated effluent which will be expensive to treat. There is a double cost saving, for lost chocolate and for effluent charges.

14.2.17.4 Mould innovations

Electronic chips have been sealed into moulds for various purposes

- measuring the hours the moulds have run,
- counting the times the moulds have been washed,
- signalling to the depositor the amount of chocolate to be deposited in each cavity when the next mould is different and requires more or less chocolate.

14.3 Enrobing

14.3.1 Background

Until the early 1900s chocolates were coated by hand, or by automated batch techniques copying hand-dipping methods. The traditional hand-dipping of chocolate, with batch tempering, results in an attractive finish that is difficult to copy. The first enrober is credited to Magniez (1901) and was produced by A. Savy Jeanjean et Cie. This machine, the 'Standard Enrober', was also supplied by the agents Baker Perkins and manufactured by the National Equipment Co. of America. Such was the advanced nature of the machine that many were sold throughout the world, and it became the basis for all future designs of enrober with the principles little changed to this day. The Savy enrober had many features, which are lacking on present-day enrobers, though often for reasons of simplicity. For example, all of the many rollers were driven and scraped, the blower to remove excess chocolate was of a turbo layout, the rotor in the blower being the same width as the belt and a sideways driven movement of the delivery belt produced zigzag decorative markings from a piping system.

Whilst the basic components of an enrober have not changed significantly over the years, the methods used to control their operation and the degree of precision possible have changed significantly, accompanied by a modest increase in throughput. Perhaps the biggest change though in the manufacture of chocolate enrobed sweets has been in the efficiency of the coolers.

Enrobers are provided for the smallest producer to the largest and there is a wide variety of different designs to meet all requirements. Belt widths from 125 mm to 2600 mm (5–110 in.) are available and the variety of accessories that can be added both before and after the enrober is vast and increasing.

Many modern enrobers have two or more curtains, either from one hopper or two. As long as all the coats of chocolate are added whilst liquid, they will blend together as one.

Double enrobing however, required two separate enrobers with a cooler in between them. This gives a discontinuity in the coating, which provides a better moisture or fat migration barrier. It also allows the second coat to bridge any discontinuities in the first, and gives the possibility of using different materials in the two layers, either having different colours, or different barrier properties.

14.3.2 Basic layout of an enrober (Figure 14.18)

The sweets entering the enrober are transferred from a plastic feed belt onto a wire mesh one and pass under one or more curtains of chocolate; there is a plate or a trough fitted with a roller underneath the mesh to ensure controllable coating of the underside of the sweet. The excess masse from the curtain falls through the wire mesh belt into a sump, and is recirculated. Part of the masse is diverted through a detemperer and is then retempered: blending of the freshly tempered and recirculated streams controls the overall level of temper in the enrober.

After the curtain, excess chocolate is forced off the product by an air blower and a licking roll is used to control the amount of masse left on the underside of the sweet. There is normally a vibrator after the blower to remove excess chocolate and to improve the appearance of the sweet; finally

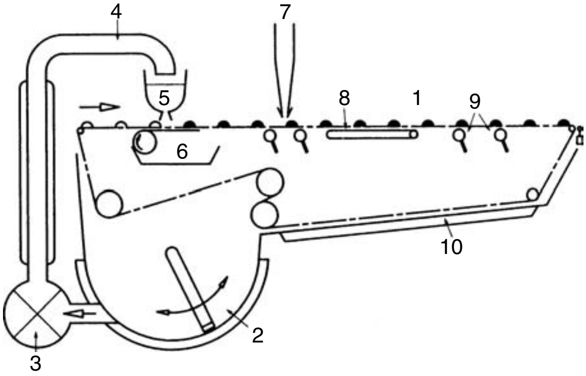

Figure 14.18 Components of an enrober. (1) Wire grid conveyor belt; (2) reservoir tank; (3) chocolate pump; (4) riser tank; (5) top flow pan; (6) bottoming trough; (7) air nozzle; (8) grid shaker frame; (9) licking rolls; and (10) heated extension trough.

there should be a detailing rod between the end of the wire belt and the start of the cooler belt.

14.3.3 Enrobers with inbuilt temperers (Figure 14.19)

Until the 1980s, enrobers generally had a built-in temperer and indeed many units still incorporate such a device today, though usually only those with a lower throughput. The main advantages are compactness, lower capital cost plus simple and rapid installation.

Tempering and detempering are done by worm screws which tend to have a limited throughput and are more difficult to zone and control accurately than conventional modern high shear temperers. Generally enrobers with internal enrobers use a ratio between 1:6 and 1:8 fresh to recirculated masse.

A masse temperature of 45°C (123°F) is required for detempering, but as the cylinder surrounding the detempering worm and the worm itself wear, the rate of heat transfer reduces and detempering becomes more difficult. Typically in a Sollich unit, the cylinder and worm each have a nominal diameter of 198 mm (8 in.) with a tolerance measured at the centre-point of +0.15 mm to +0.2 mm (0.006–0.008 in.) for the cylinder and –0.15 mm to –0.2 mm (–0.006–0.008 in.) for the worm: the gap is thus 0.3–0.4 mm (0.012–0.016 in). If this gap reaches 1 mm (0.04 in.), replacement is necessary.

14.3.4 Enrobers with external temperers

In these machines the chocolate supply from the temperer is pumped directly into the sump, where it mixes with the masse already there and with returns from the curtain (see Figure 14.20). It is then pumped up to the curtain trough, generally mixed at a ratio of between 1:4 and 1:6 with recirculated masse.

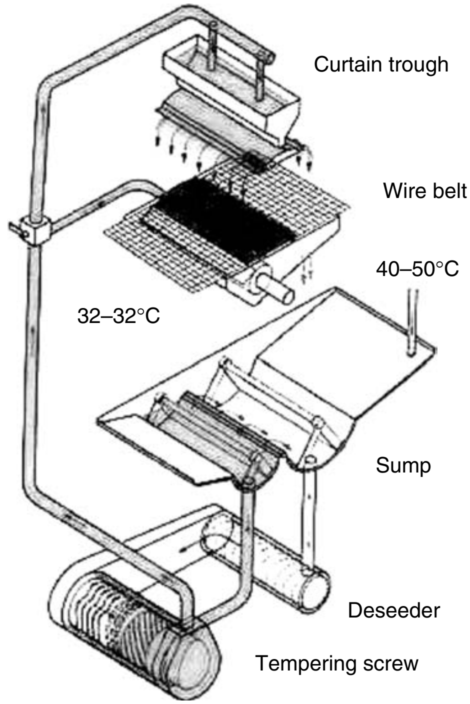

Figure 14.19 Enrober with inbuilt temperer.

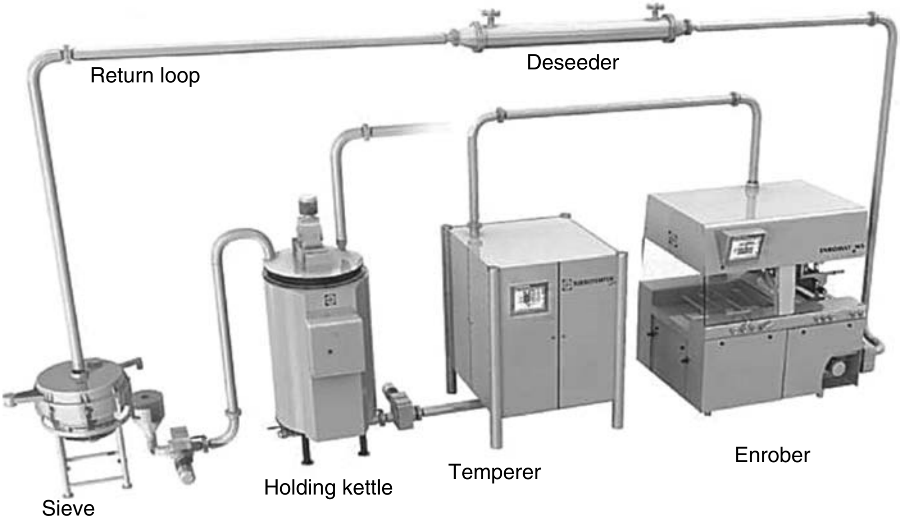

Figure 14.20 Pipe circuit for an enrober with an external temperer.

To control the temper in the sump, a proportion of the masse is returned via a deseeder to the temperer feed tank. A sieve should be included in the circuit so that any broken pieces of the product centre can be eliminated. Such small pieces can otherwise build up inside the enrober, leading to a discontinuous curtain and to poor visual quality of the coating.

14.3.5 Chocolate recirculation

An amount of 1 kg/h (2.2 lb/h) of chocolate is needed per 1 mm belt width for one curtain, 1.5 kg (3.3 lb/h) for double curtains. The contents of the enrober should be exchanged every 6–10 min to avoid build-up, to keep a constant temper, to avoid air bubbles in the curtain and to reduce changes in colour and density due to air incorporation. Since a 1000 mm (40 in.) wide enrober has an internal capacity of about 150 kg (330 lb), changing the contents every 10 min will necessitate a feed of 1000 kg/h (2,200 lb/h).

The recirculation pump is a pawl type (Chapter 11), chosen for gentle handling and minimal temperature increase. It also has good suction characteristics and will handle nuts etc. without much breakage.

For modern Sollich enrobers running on milk chocolate, the recommended water temperature for the sump is ~0.5°C (1°F) lower than the required masse circulation temperature, as some heat is added by the recirculation pump. Recommended water temperature for the table is 3.0°C (5.5°F) above the water temperature of the sump. The ambient temperature inside the enrober hood should be 24–30°C (75–86°F); lower temperatures will only cause a build of chocolate on the internal surfaces. The temperature of the item to be coated should be in the range 22°F–24°C (72–75°F); a higher initial temperature needs a longer cooling time.

14.3.6 Temper

Temper has been discussed in Chapters 12 and 13, but it is possible that a degree of temper is required for the optimum coating performance, which does not conform to the 'good' temper value.

- A slight over-temper can be used if there is a limited cooling tunnel length and quicker solidification of the chocolate is needed. The disadvantage of this is a less fluid masse and so a thicker coating.
- A slight under-temper gives a more fluid chocolate, which can result in a more uniform coat.

Both the gloss and the shelf life of the finished product should be checked when making these changes. If problems occur with the product exiting the coolers still being soft, the following should be checked:

- Poorly tempered product masse, not enough seed.
- Reheat stage too warm.

- Too much soft fat in the product masse. (Nut oil, soft CBE or milk-fat (Chapter 19).)
- Cooling time too short or temperatures not set correctly.

Coating chocolate has a grey sheen:

- Very untempered or overtempered chocolate.
- Enrober hood or blower air at too high a temperature, which de-tempers the chocolate.
- Cooling in tunnel too intensive, setting it in one of the unstable crystalline forms.

14.3.7 Enrober components

Whether fitted with a temperer inboard or externally, enrobers have the same basic components.

14.3.7.1 The curtain

There are two main methods of controlling the feed rate to get a continuous curtain.

- A trough with an adjustable slot in the bottom.
- A trough with a rotating roller(s) to control feed rate.

In either case, there should be a feed pipe into the trough about every 250 mm (10 in.) across the unit, to equalize the holding time of the chocolate across the curtain. Tempered chocolate changes very quickly when not stirred and if there is only one feed, it takes longer to reach the outside edges of the trough, where it will contain larger crystals and less liquid fat, and so be more viscous.

The metal discharge plate on the underside of the curtain trough can usually be tilted at various angles. If it is in an approximately horizontal position, there will be two curtains and if it is angled one curtain is produced.

The position of the curtain trough can be adjusted horizontally and vertically, with the first curtain normally being about 20 mm (0.8 in.) before the start of the bottoming trough. If the curtain is more than 20 mm (0.8 in.) above the article, it can be wavy and may cause air to be included. The adjusting plate(s) at the sides of the curtain trough must be set by hand to give a constant level in the curtain.

A roller produces a more even and more easily controlled curtain, but is more expensive. Most older enrobers, as well as many new ones, use the simpler adjustable slot to form the curtain, generally with perfectly satisfactory results. The necessary criteria include a uniform, thick curtain across the complete machine width, even with relatively viscous chocolate.

Using a thin chocolate layer (approx. 1 mm (0.05 in.)), most of the air bubbles present in the chocolate can burst. A still smaller trough slit (0.5 mm (0.02 in.)) will show even better results; however, it may be necessary to sieve the chocolate to prevent blocking such a narrow aperture.

14.3.7.2 The bottomer

Chocolate from the curtain flows into the bottoming tank; this may be a simple plate, or it may be fitted with a bottoming roller, which transports the masse upwards. This roller rotates in the opposite direction to the belt. The sides of the bottoming tank each have an opening which acts as an overflow into the sump. The depth of the bath is controlled by the speed of the bottoming roller and is normally 6–10 mm (0.25–0.4 in.). If it is set too high, the chocolate can roll or overflow over the front of the scraper (see Figure 14.21), light product centres then do not run freely into the bottoming bath and create a blockage. If the chocolate level in the bottoming bath is too high, the rotary valve on the chocolate feed pipe can be opened: it serves as bypass and directs part of the chocolate back into the sump. Controlling the chocolate level in the bottoming bath by means of partially opening and closing the discharge flap is not recommended, as the chocolate then runs through the wire belt and air bubbles can be incorporated.

To form a bottom without the curtain, the chocolate valve lever must be moved to the 'bottom coating' position. All of the chocolate supplied by the pawl pump is then directed to the bottoming tank.

A 'pre-bottomer' is sometimes used to ensure that the base of the item is correctly coated, this being a stand-alone unit that as the name implies, adds only a bottom. It is effectively an enrober without a curtain, and is followed by a cooling table allowing 2–3 min to set the base so that it transfers to the wire belt of the enrober. If it is shorter, it will need to run so cold that condensation can be a serious problem. A hold down device (see Figure 14.22) will

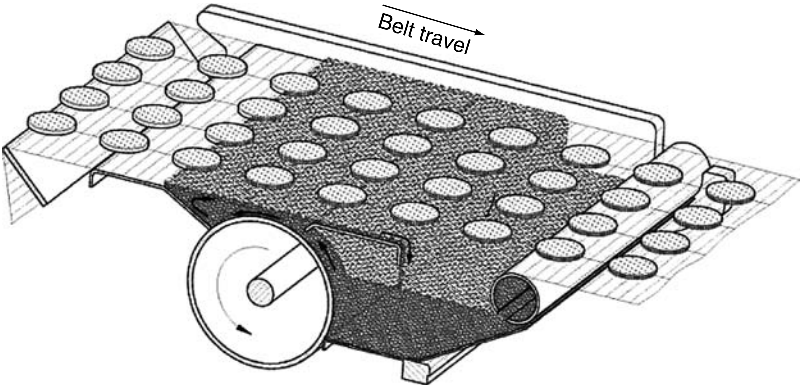

Figure 14.21 Schematic diagram of a chocolate bottomer.

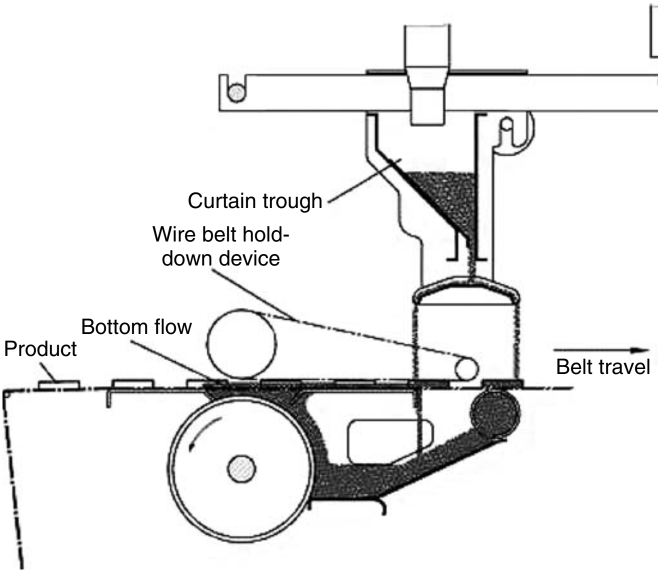

Figure 14.22 Schematic diagram of enrober hold-down device.

be needed to control lightweight items. They are not often included in a line, but can help to put a good base on a difficult product.

14.3.7.3 The blower

Blowing reduces the coating thickness mainly on the upper face of the article; it can also leave a distinctive fine wavy appearance that improves the visual character of the product. The blowing effect is regulated mainly by adjusting the amount of air, though the height of the blower mouth can be adjusted, with a gap of 15–20 mm (0.6–0.8 in.) between articles and the blower mouth piece being usual. The blower discharge lip can also be moved. A lip air temperature of 30–33°C (86–92°F) with a tilt of about 10° against the belt direction is generally best.

As the blower air circulates within the cabinet it may become too warm and a slide on the upper part of the coater can be opened to suck in air: For a constant and accurate blower output, the discharge lip must be cleaned once a week and the turbine once a year. Blowers are calibrated during manufacture to give an even flow all the way across the belt; with the calibration record usually being kept by the manufacturer.

14.3.7.4 The wire belt

The rod network wire belt is at the heart of an enrobing system and was perhaps the principal invention that led to the success of the first enrobers. Both its construction and installation require care and accuracy, if it is to have a good service life. The belt tension should be set so that it is carried perfectly in the drive sprockets, with the teeth in true alignment. Any oscillations or unevenness that might cause excessive belt wear should be avoided or at least minimized.

14.3.7.5 The sump

The wire belt draws chocolate falling into the sump down to the bottom, where it can mix with freshly tempered masse.

14.3.7.6 Detailing

The detailing rod removes excess chocolate that would otherwise cause a tail to appear at the end of articles. It is a rod about 3 mm (0.1 in.) in diameter supported by clips, and needs to be absolutely straight! The clips and the scraper can wear, and both need to be in good condition.
The best effect is achieved with the following settings:

(1) Minimum spacing between the detailing shaft and the cooling tunnel transportation conveyor.
(2) A gap between article bottom and detailing shaft of about 2 mm (0.1 in.).
(3) The detailing shaft should normally run in the opposite direction to the product, except for small items when it turns in the same direction as the belt: Failure to do this may result in pieces being retarded by the detailer, leading to a lot of rework.

Very small items or those with arched bottoms can turn over when transferring from the wire belt to the cooling tunnel belt. The detailing device can be lowered and the nose bar of the cooling tunnel belt set lower and closer to the wire belt.

14.3.7.7 Rollers

A licking roll is fitted under the wire belt both to remove excess chocolate from the underside of the product returning it to the coater tank and to help clean and support the belt.

An additional bottom scraping device can be fitted to remove more chocolate from the underside of the article. Three or four rollers are normally installed and the sweets pass over them just after leaving the curtain. The rollers rotate at varying circumferential speeds and are all fitted with a scraper. They are normally about 20 mm (0.8 in.) in diameter and their number may vary according to the size of the items being enrobed. This device is most frequently used to remove excess chocolate when coating biscuits.

Removal and installation of the bottom scraping device can be carried out in a few minutes.

14.3.7.8 Hold-down devices

A holding down grid enables half or shoulder coating, also called dipping or masking, to be carried out. It can also be used to completely dip articles

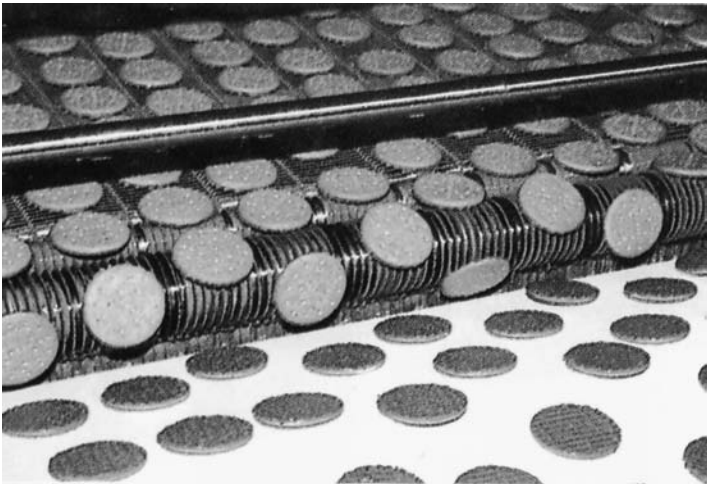

Figure 14.23 Picture of biscuit turn over device.

into the bottoming bath chocolate without interfering with the curtain. By adjusting the bottomer, an upwards flow of chocolate between the wire belt and the holding down device can be achieved, so that articles with a very uneven and porous surface and overhanging pieces are completely covered with the chocolate. This process leads to a more complete coating for difficult articles than would be possible with only the curtain and bottoming bath system. The holding down grid is installed between the bottoming tank and the curtain trough, though it can be extended forwards to prevent small articles moving around on the belt.

Biscuits may be coated top and bottom or only underneath. There are feed systems available to turn them over at the exit from the enrober (Figure 14.23), as well as the hold-down devices to control them whilst being coated.

14.3.8 Changeovers

Enrobers designed for rapid changeover are also available, some components of which are on wheels, and push in and out of the line as required with rotary joints on all feed lines. Changeover time is around 10 min.

An alternative is two enrobers in-line, one after the other, with an extendable belt that allows the product to be run through one of the enrobers and so avoiding contamination of either product or enrober.

Enrobers are manufactured that are suitable for wet cleaning, which can be useful when changing between incompatible masses or those containing difficult to remove flavours.

14.3.9 Avoidance of air bubbles

Generally bubbles are not a major problem on enrobed items, as the coating is fluid enough for them to be displaced or burst by the blower. However with thicker masses or some more difficult products, bubbles can be a problem and action may be needed to minimize them. Certain basic precautions should be taken anyway, even if bubbles are not an obvious problem.

Each feed pipe to the curtain trough should have its outlet under the chocolate surface to avoid incorporating air. The correct rate of replacement of masse in the enrober by freshly tempered masse will also help prevent the build-up of bubbles due to recirculation. Holding tanks should be filled under the product surface, or using an angled pipe end which directs the flow down the wall of the tank. The tempered feed to the enrober should either have an extended feed pipe terminating under the surface or have a ‘cup’ under the pipe-end to eliminate air incorporation. Opportunities for the chocolate to fall any distance inside the enrober should also be eliminated.

14.3.10 Avoidance of chocolate build-up inside an enrober

One of the major reasons for having to stop and clean or reheat an enrober is a build-up of chocolate on the internal surfaces that can increase the temper and hence viscosity of the masse, and can also endanger the belt.
Some simple precautions will help:

- Always keep the cabinet windows closed.
- Cooling water must be >10°C (50°F), use a higher volume if necessary.

Side heating can be retrofitted using the 45°C (113°F) water circuit to supply it. These coolers bolt on outside the trough. 3-shift heating packages are also available, consisting of wire heaters for the nose rollers at infeed and discharge, as well as cross members and the bottoming pan. The square structural beams can also be trace-heated by buying exchange units with a suitable groove. An agitator in the feed trough can also help prevent build-up.

14.3.11 Down stream processes

14.3.11.1 Engrossment

It may be necessary to add a layer of particulates onto the centre either after enrobing, or between two coatings. Cereals, nuts, kibbled high boiled candies and ‘hundreds and thousands’ are typical of the kind of addition that is made.

The article to be engrossed is conveyed with its coating still soft onto a layer of the engrossing material. More is dropped onto the bars via a curtain to ensure an overall covering. The bars pass on to a wire mesh belt that allows excess pieces to fall through and be recycled. Finally they will usually

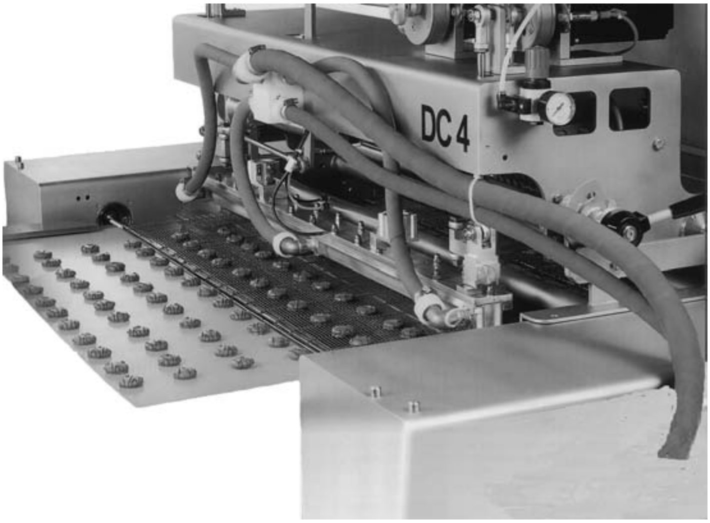

Figure 14.24 Decorating machine. See Plate 14 for the colour image.

go through a second enrober to receive a protective second coating before passing into the cooler.

14.3.11.2 Decorating

A wide variety of patterns can be applied, using the same or different colour chocolates; then by using a comb, these patterns can be dragged and modified. A decorator (Figure 14.24) may be placed immediately after the enrober, or alternatively, further down the line to let the wet coating masse partially set and so be less messy. A combination of applied decorations and combs can be used to produce distinctive patterns even with the same colour chocolate.

The most common units are made either by Sollich (Decormatic) or by Woody Stringer in the USA. The original Stringer, first produced in 1956, was capable of making zigzag decorations in thick or thin patterns on candies and baked goods. Over the years, various features were added beginning with a single-loop attachment for producing circles, ovals and slanted zigzags. Later, the double-loop attachment was developed, allowing the decorator to produce more complex designs such as the figure of eight (8), tree bark and cross-hatching. Heaters were added to ensure an even temperature across all the nozzles. The Stringer can be custom designed to produce zigzag, single-loop, double-loop, and cross-hatching designs. Likewise, the Decormatic is a very versatile unit capable of applying many designs.

Both units will require a small local temperer, if the decoration uses a different chocolate masse to the coating.

14.3.12 Cooling

The cooler normally occupies around two thirds of the linear space of the enrober installation.

As with coolers used for moulded products, both latent heat and heat of crystallization need to be removed. Without the plastic mould to insulate part of the product, cooling times tend to be shorter for enrobers, especially if the cooler belt runs on a cold table.

A higher temperature and longer cooling time are more favourable than a lower temperature and shorter cooling time. Milk chocolate requires a longer cooling time than dark chocolate due to higher milk fat contents and consequent lower solidification temperatures.

14.3.12.1 Suggested cooling times (Sollich)

Depending on coating thickness: the presence of soft fats such as nut oils or milkfat can add up to 4 min.

Dark chocolate:	4–6 min
Milk chocolate:	6–9 min

A lower air cooling temperature can be used for compound coatings (<10°C (40°F)).

Lauric coating:	2–3 min
Non-lauric coating:	4–6 min

Conclusions

The machines described in this chapter enable good quality chocolate goods to be made, often at high speed, and generally using very few operators. They are however equally capable of making large amounts of waste and rework. The difference lies in the skill and knowledge of this small workforce responsible for its installation, maintenance and operation.

Acknowledgements

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Further reading

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Chapter 15

COLD FORMING TECHNOLOGIES

J.H. Walker and S.T. Beckett

15.1 Introduction

Traditional chocolate making relies on chocolate being cooled relatively slowly so that the cocoa butter sets in the correct crystalline form. Too low a temperature in a cooling tunnel will indeed result in the product having a very short shelf-life due to fat bloom. When untempered chocolate is used to coat ice-cream it has a relatively soft texture due to it crystallizing into unstable forms. This does not bloom however because it is maintained at a very low temperature where the fat is unable to migrate or change its crystalline form. Very low temperatures can also be used in certain circumstances and a Mars Incorporated (1998) patent claims that cooling tunnels can be operated at high speeds and sub-zero temperatures (preferably below –5°C (23°F)) and yet produce glossy products, with increased bloom resistance.

The technology described in this chapter has mainly been developed to produce filled chocolate products without the need of the time and space required to produce a chocolate shell, i.e. fill, partially set, invert, shake and turn over again (Chapter 14). It can also be fitted into a traditional tablet line (Figure 21.2), but unlike 'single-shot' depositors (Chapter 17) it requires a second chocolate depositing point to back-off the product.

15.2 Background

This technology is in fact based on an old idea, which has only now becoming widely used throughout the confectionery industry. Boyd and Yates (1923) issued a patent, which showed a cooled metal plunger being pushed into a mould, which was partly filled with chocolate. The idea being that the chocolate would form a partly set shell, which would retain its shape, once the plunger was withdrawn. This system, probably because it operated at temperatures not much lower than that of the chocolate, suffered from the problem that it was indeed difficult to remove the plunger from the chocolate

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in the relatively short time allowed by a production plant. Consequently, a lot of the patent was concerned with release agents, such as alcohol or water, which produced a quick separation of the plunger. It also tended to spoil the surface of the chocolate, if not the chocolate itself, so the system was never sold by commercial confectionery machine manufacturers. By changing the operating temperatures and conditions however, a commercial product plant was operated, without any release agent in 1987. The Aasted company applied for a patent (Aasted, 1993) and have subsequently sold machinery based on this technique. Other companies such as Bindler and Knobel also supply equipment using the principle of chilled plunger technology to produce chocolate shells.

Unlike 'single-shot' manufacture, the shell is made independently of filling, so the matching of viscosities is no longer a problem. Also the proportion of centre to chocolate can be as high, or even higher than traditional shell moulding. As with the latter, it is necessary to use a backing-off system to complete the shell.

15.3 Principle of operation of the cold forming technologies

The process starts by pouring sufficient tempered chocolate into the mould to make the shell and to allow for a small excess. This amounts to about half the chocolate that is deposited in a traditional shell moulding plant. The excess is required to ensure that the chocolate reaches the top of the mould all the way around (it may preferentially be pushed up through part of a non-symmetric mould) and also there will be small differences in sizes between different moulds.

A frozen plunger, with the shape of the inside of the sweet, is then inserted into the chocolate. The liquid chocolate is thereby squeezed up around the plunger and forms the shell (see Figure 15.1). It is necessary for the air to escape and not form bubbles or surface marks (Kniel, 1997) and so the rate of entry of the plunger into the chocolate can be important. Aasted have developed a system in which the final millimetre of the insertion is relatively slow.

The length of time the plunger stays in the chocolate depends upon its temperature. The Aasted system operates at –15°C to –21°C (+5°F) (Aasted, 1997) and it only takes about 2 s or less for the chocolate shell to be hard enough for the plunger to be removed. In the Bindler system, the stamp is only at –5°C (23°F), which means that it must be kept in the chocolate for 4 or 5 s.

Once the plunger has been removed a scraper removes the excess chocolate from the mould and the centre is deposited in the shell. Finally the products are backed-off with liquid chocolate, as for traditional shell moulding, and the mould and product cooled, before de-moulding and wrapping.

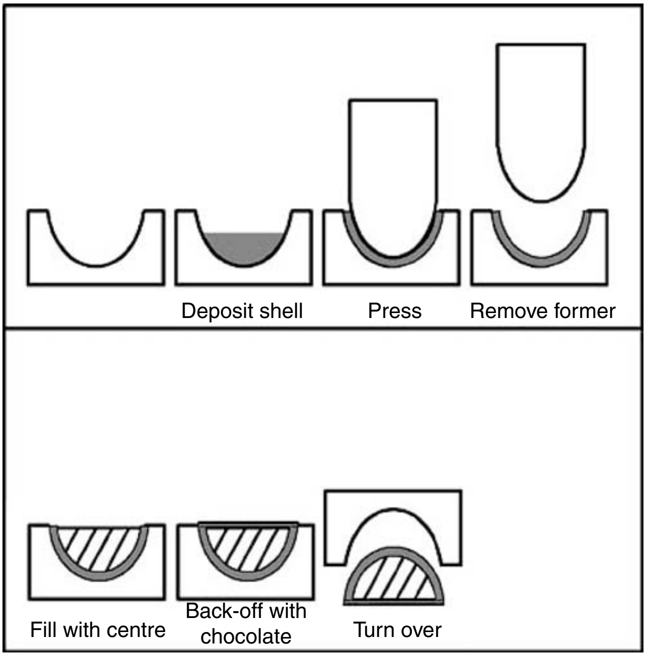

Figure 15.1 Schematic diagram of cold forming process.

One of the major problems of having the low temperatures is that under normal ambient conditions, ice will rapidly form on the plunger. In order to overcome this, the cone or plunger units are kept in a humidity-controlled environment. Because of the higher temperatures involved, this is a less serious problem with the Bindler system. This company also suggests that the cold plunger releases even better from the chocolate if it is coated by a very thin layer of ice crystals. This may be because when the warm chocolate comes into contact with the ice, a film of water is formed on the chocolate shell.

Where the chilled cone or cold plunger fails to separate satisfactorily, it is possible to spray it with an alcohol/glycerol mixture. This lowers the freezing point and appears to give satisfactory results with moulds, such as ball-shape, which had previously caused problems.

In order to change from one mould shape to another it is only necessary to change the plunger plates together with the moulds. A wide range of products can therefore be made on what is essentially a simple moulding line.

As was noted earlier, it would be expected that the very cold temperature of the plunger would cause the fat to set in its unstable crystalline form and so rapidly form bloom. This has been shown not to be the case, with even the inside of the products remaining glossy after long periods. Part of the explanation may lie in the fact, that because of the short time of contact, only the surface can really reach the very low temperatures. The bulk of the fat present remains liquid, and has to lose its latent and some specific heat in order to set. This heat must pass through the surface made by the plunger, as the mould, if plastic, is largely an insulator. In passing through this surface the temperature will rise and convert the unstable crystals into a stable form.

Dr Ziegleder, of the Fraunhofer Institute in Freising in Germany, has carried out studies to compare the crystallization of the chocolate fat phase following different types of processing. The short temperature shock during cold forming did not have a detrimental effect and the same crystal forms of cocoa butter, as for the traditionally moulded product were found after solidification. It had been shown that the inner surface of the shell may reach temperatures lower than about 11°C for a few seconds (Boehme *et al.*, 2003), but this treatment is too short for starting any crystallization within the chocolate masse. (Chocolate crystallization has its maximum rate at about 15°C (59°F) and would need at least about 7 min to set (Ziegleder, 1995).) During storage trials, traditionally produced and cold-formed shells showed more or less similar stability against migration and bloom. This is not surprising as the chocolate in both cases was crystallized within the cooling tunnel and could produce the same density and solid fat content, respectively. In some trials, however, traditionally moulded pralines were found to develop fat bloom earlier than cold-formed ones, probably, because the migrating filling oil penetrates faster through the thin areas of the shell (Boehme *et al.*, 2003; Ziegleder, 2004). (A traditionally moulded chocolate shell has thick and thin areas, which are created during the turning-over of the mould, because the surface tension forces unevenly affect the chocolate that pours out. Cold-formed chocolate shells have an even wall thickness, which results from the controlled gap between cone and form.) In other trials, cold-formed pralines were found to be less stable, perhaps due to their accelerated production speed (Hinterberger *et al.*, 2007). The bloom stability of pralines is strongly dependent on the production speed and cooling time. If the time in the cooling tunnel before filling is too short, shells from all types of moulding technique have a reduced resistance to fat migration and bloom.

15.4 Advantages of the cold forming technologies

(1) *Controlled shell thickness.* Provided that the plunger is centrally located, the shell will have a well-controlled thickness. This gives good weight control and reduced rework, in that the shells are stronger. It is possible, for example, to design the mould and plunger in such a way as to have extra chocolate where the article is most likely to break for example the neck of a Santa Claus figure.

(2) *Less chocolate is required than for a shell moulding plant.* Very little chocolate is scraped off the moulds in cold forming system, compared with the 50% or even more, which comes out of the mould upon inversion,

during traditional processing. This surplus chocolate needs reheating and re-tempering. Consequently the new method requires smaller tempering machines, smaller tanks and has less chocolate being processed at any one time, for the same final through-put.

(3) *Very low fat chocolates can be processed.* When producing small articles, the process is largely independent of the chocolate viscosity. This has enabled 'chocolates' with fat contents as low as 22% fat to be made into shells (Aasted, 1997).

(4) *Inclusions of other ingredients can be added to the shell.* Shells can be made to any pre-designed thickness. With the thicker ones it is possible to add other ingredients such as chopped nuts and rice etc.

(5) *Special shapes can be produced.* Shapes that would be difficult to produce by traditional shell moulding for example deep cone shapes with a variable thickness, can be made using cold forming. Normal or book moulds (Chapter 14) can be used. It is also possible to bring two moulds together to produce hollow figures etc. The accurately formed shell rim, when reheated around the circumference of the product, will form a good seal when the two mould halves are closed.

(6) *Easy change of chocolate type.* There is little waste and cleaning when changing the type of chocolate being processed.

(7) *Smaller space requirement.* This type of plant only requires a similar space to a normal moulding line, which is much less than a shell moulding one. Some articles require very much less cooling, because of the heat already removed by the cone. Shorter tunnels can therefore be used or higher throughputs achieved.

(8) *Cleaner moulds.* For the Aasted system (with rim plate) the surface of the mould does not require scraping and therefore the mould will remain cleaner for a longer period.

15.5 Disadvantages of the cold forming method

(1) *The need for air conditioning in the processing zone.* As was noted earlier the cone or plunger must be used under relatively low humidity conditions.

(2) *The requirement for very precise mould manufacture and positioning.* If the cone is not in the centre of the mould, then one side of the product will be thin and the opposite one thicker. This means that both the mould itself and the positioning mechanism must be very accurate. Kniel (1997) showed that at Chocolate Frey, the maximum tolerance for a 1000 mm (3.3 ft) wide production line was only +0.3 mm (0.01 in.). Depending on the shape of the product to be made, and the size and format of the mould, the minimum

shell thickness may be in the range of 1.5–2 mm (0.05–0.07 in.). To achieve this accurate alignment of the plunger tool to the moulds, care must be taken to adjust the plunger tool. This operation can take some time.

(3) *The cost of new plungers and moulds*. Because of the precision required, new moulds and plungers cannot be produced cheaply.

(4) *The need for additional cooling for the cone/plunger*. This is not of course needed for traditional moulding plants. To eliminate the risk of contamination of the product from leaking cooling fluid pipes, care must be taken with the design and installation of the cone tool.

(5) *Possible difficulties with some larger products*. Kniel (1997) indicates that Chocolat Frey had had difficulty in producing equal thickness edges when producing 100 g (3.5 oz) filled tablets.

(6) *Possible difficulties with some smaller products*. For some systems the number of mould impressions is limited by the pitch of the tooling. Therefore it may not be economical to produce small products using this technology.

15.6 Further developments

15.6.1 'Mouldless' system

With this technology the chocolate is deposited directly onto an existing steel or plastic belt line or onto other components such as biscuits, nuts or raisons etc. A cold-shaped pressing tool then descends upon the chocolate and moulds and sets it into the required shape (Figure 15.2). The tool can be made with a wide variety of shapes and designs and is able to put a high definition image onto the chocolate. All pistons are mounted individually and can be exchanged, so that different shaped articles can be made in one pressing operation.

The Aasted Company in Denmark make this system under the name FrozenConeMouldless™. Because there is no chocolate return system it is relatively easy to instal the plant by just pushing it from the side onto a pre-existing belt system. In addition there is little cleaning and waste.The production speed can be high and the factory at the Danish manufacturer Carletti has two pressing devices, each with 75 closely arranged plungers. This produces 63 750 moulded 4 g (0.14 oz) articles per hour. The pressing time in each stroke is below 1 s. The chocolate is reported (Aasted, 2007) to be in the Form 5 and so gives good bloom resistance.

15.6.2 Multiple product with direct packing

With cold forming technology it is possible to change individual plungers and moulds, therefore making it possible to make a selection of sweets at

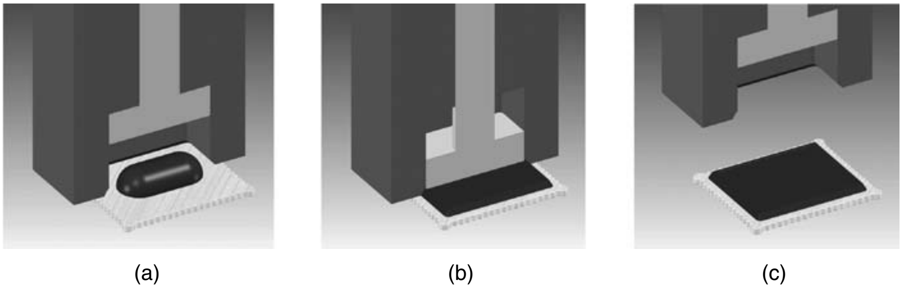

Figure 15.2 Schematic diagram of the operation of mouldless plant (Aasted-Mikroverk, Denmark). (a) Deposit of chocolate on biscuit; (b) cold pressing and (c) removal of cold press.

Figure 15.3 Chocolates with different shapes and colours made with single deposit (Aasted-Mikroverk, Denmark). See Plate 15 for the colour image.

the same deposit. It is also possible to modify the depositor so that different chocolate types are fed to individual moulds. In this way a selection of different coloured sweets is produced (Figure 15.3). Aasted-Mikroverk has developed the concept (ChocoAssort™) for moulding all the differently coloured and shaped articles in the same pressing operation and subsequently transferring them in the same order directly from the moulds to the boxes. This greatly reduces handling and simplifies the robotics required (see Figure 15.4).

15.6.3 Solidification on plunger

In this system the chilled former is dipped for a controlled time and depth into liquid chocolate. The former is removed from the chocolate bath and the

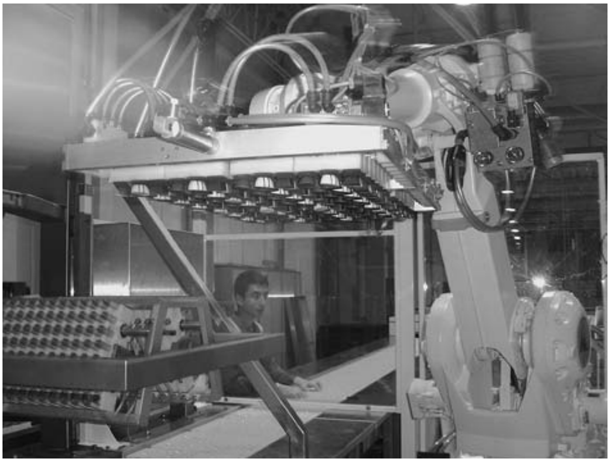

Figure 15.4 Robot loading complete boxes using the ChocoAssort™ system (Aasted-Mikroverk, Denmark). See Plate 16 for the colour image.

chocolate is allowed to solidify. The chocolate shell is then ejected from the former and positioned onto an indexing conveyor belt. The shell can then be filled with a liquid or semi-liquid filling. This equipment is manufactured by Chocotech Gmbh.

Conclusions

Cold forming is one of the few new technologies that has been developing within the chocolate industry within recent years. Its ability to produce a wide range of articles with good weight control, with less dependence upon chocolate viscosity and with minimum supervision, perhaps explains its increasing popularity.

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Chapter 16

CHOCOLATE PANNING

M. Aebi

16.1 Introduction

16.1.1 History

Historical records on the subject of panning show that it was first used for pharmaceutical products. A gentleman named Razes over 1100 years ago, used materials such as slime substances from *Plantago psylium* seeds, and coated pills or tablets. Over time, honey, gold, silver and finally sugar was used to cover the bitter taste of these pharmaceutical ingredients. The first confectionery coated mouth-sized pieces are believed to be made in Nîmes France around the year 1200. Over the years, new ingredients and centres were mixed and dried in pots and pans with a final separation by hand. (These techniques can still be used today for the quick production of prototypes.) Descriptions exist of larger parabolic dishes hanging from the ceiling on two ropes or chains and these being moved over an open fire. This required both stamina and strength to produce the goods. Around 1840, a confectioner in France invented a pan mounted on a shaft, which could be turned manually. The principals of this process and the techniques that were used then are still valid today, even with the development of ever bigger and more sophisticated equipment. All still involve a rotating container containing the centre pieces. The coating material, whether it be chocolate for example for coating nuts, raisins etc. or sugar for coating chocolate (SMARTIES^{TM} and M&M^{TM} etc.), is then added in a form in which it can coat the outside of the centres, as they tumble over one another in this container.

16.1.2 Definitions

Coated goods were first termed 'dragee' in Europe and was probably derived from the Greek word *tragein* meaning nibbling. The definition of pan coating may best be described with the following words:

> Pan coating is the build up of a centre (kernel or corpus) with a liquid or liquid and powder substances with multiple layers or continuous phases, which are set,

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> hardened or dried to smooth or pearled surface and often finished with a sealant and or a polishing agent, utilising rotating pans or drums creating a fluid bed.

The machinery used is often compared visually with a cement mixer. The drums or pans are horizontal or have their front slightly elevated and are fitted with internal ridges, which are used to aid mixing. As the product mixes, thin layers of liquid are added to coat the centre material. It is during the drying or setting of this coating, that the tumbling action causes the surfaces to rub against each other to form a smooth finish.

Care has to be taken before marketing the products made by panning, because some countries have standards, covering pan-coated goods and it is always advisable to check local laws and regulations. Frequently panned goods are named by their centres and/or the shell applied to the dragee: Almond centre with a chocolate shell would be called Chocolate Almonds.

16.2 Panning methods

As this book is concerned with chocolate, it is worth mentioning all the different types of panning, because more than one technique can be used to make some varieties of panned sweets. The different methods are listed in order of relevance to the chocolate industry.

16.2.1 Chocolate panning

Chocolate panning is a temperature-dependent method in which the coating solutions are melted under the influence of heat and hardened again by the removal of this heat. Several layers of warm melted coating are applied to the centres and solidified again by cooling. Chocolate panning is probably no longer the correct name for this process. Although chocolate is still the predominant coating medium today, compound and yoghurt coatings are fast gaining popularity.

16.2.2 Soft coatings

Soft coatings are produced with the absorption and desorption of moisture. A liquid is applied and allowed to flow over the centre before it is dried out using absorbing solids. The liquid should have adequate bonding properties to hold all the solid particles (usually a sugar) in place. Frequently, multiple layers of powder will be required to completely dry out the whole wet layer as far as the centre material is concerned. Relatively thick layers can be applied to the centres and so the product rapidly gains weight, which makes this technique particularly useful in the confectionery industry.

Depending upon the amount and type of the powder used, soft coatings harden over time to almost the same hardness levels as hard coatings. Sugar eggs and jellybeans are just two of the more well-known products made utilizing this method.

16.2.3 Hard coating

Hard coating is a method, where the solids are dissolved in their respective solvent. In confectionery, water is predominantly used for this task. Any type of sugar can be dissolved in water to a concentration close to its saturation point at the usage temperature. The higher the solids content in the liquid, normally the shorter will be the drying time. Care should be taken not to over-dry and cause cracking, or to dry too quickly because of encapsulating moisture that will later migrate through the sweet and damage the finish of the product. Hard coating is also known as warm coating or French coating. The name French coating goes back to a time when this type of process was mostly carried out in France. Warm coating is a process where the pan was heated with steam coils or by an open gas-flame placed under the pan. Today most hard coatings are carried out at lower temperatures to prevent the centres from deforming (e.g. in caramels and chewing gum) or melting (e.g. the chocolate in M&M™s and SMARTIES™).

16.2.4 Film and suspension coating

This technique is most often used in the pharmaceutical industry and involves ingredients not generally approved by National Food Legislation. The solvents used here include alcohol and ether, which perform a similar function to the water in hard coating. Great care has to be taken due to their explosive nature and to avoid air pollution. Some of the more modern equipment available incorporates side-vented pans in which some of these volatile chemicals can be captured and reused.

Surprisingly, suspensions are not widely used in the confectionery industry as an alternative to the absorption process for making soft coatings. Suspensions can easily be produced by mixing, followed by further homogenizing in a colloid mill. The suspension can then be sprayed onto the product, thereby avoiding a lot of the dust normally generated when the powder is applied onto the wet product in the pan.

Polymers, both in solution and in suspensions, can be continuously sprayed in order to form a film on the product. By the continuous application and the simultaneous drying, an exact balance can be reached, whereby the viscosity of the solution on the product surface slowly increases and eventually produces a hardened coating. Film coatings have the advantage of being relatively quick to apply and they will form an even coating around the centres, thus preserving the shape of the sweet centre.

16.3 The process of chocolate panning

The range of equipment available is very large, ranging from a few kilos to 3 tonnes, and includes conventional pans (round or tulip shaped), semi-automatic belt coaters and fully automated self-contained units. However, over the years, the principals of chocolate, compound and yoghurt coating have not changed and by and large the following steps have to be taken into consideration in order to obtain a good panned product:

- centre selection;
- centre preparation;
- coating selection (largely dictated by the marketing requirements);
- engrossing, which involves
  - building the base with chocolate or compound etc.
  - engrossing – giving rapid weight gain
  - smoothing;
- polishing;
- sealing;
- packaging.

16.3.1 Centre selection

A wide range of centres can be used for chocolate coating. Natural centres are particularly popular, especially if the pan-coating plant is not part of a sweet manufacturing facility. Many manufactured centres have to be treated immediately after their production to preserve the quality or to be panable before oxidation or other deterioration sets in. Centres should be of a slight convex shape, with no sharp edges, in order to avoid irregular build up and uncoated spots. Almonds, peanuts and cashews are some of the more difficult samples to coat. Almonds generally have sharp edges, which often give rise to uncoated areas. Roasted peanuts have a tendency to split causing 'doubles' due to their concave split area, whereas cashews tend to have a blank underside because of their natural curve.

It is also important to minimize the size variations of the centres, as every type and shape of pan will act as a classifier and separate smaller pieces from the larger ones. This means that certain sizes become localized within the pan and this segregation tends to become magnified by the end of the process.

The hardness and brittleness of the centres also has a large impact on the batch size distribution and the throughput of the final product. Soft centres such as raisins can easily deform, which results in the coating flaking off later in the process.

The temperature of the centre pieces also affects production in several different ways. Cool centres will aid the setting of the coating, but centres that are too cold can provoke irregular finishes or cracking of the shell, causing the coating to flake off. With light and porous centres, the temperature should not deviate too much from that of the future storage conditions of the final product. This is to avoid subsequent expansion or shrinkage, which once again would result in cracking of the coating.

The following centres are very commonly used:

- nuts which are the most popular natural centres, for example almonds, peanuts, hazelnuts and cashews;
- fruit which either in dried form or as an infused product, for example raisins, orange peel, apricot, prunes etc.;
- soft and hard caramels and hard-boiled sugars in honeycombed form;
- liquid-filled shells, which are initially solid, but are converted into liquids after coating;
- fondants creams, jellies, etc.

It is important that the coating manufacturer communicates with the centre supplier in order to obtain the correct centres within a relative narrow specification.

16.3.2 Centre preparation

Preparing the centres is one of the most important tasks in pan-coating. There are many reasons for this for example irregular centres cause deformed product, oil/fat migration will spoil the surface, whilst oily and smooth surfaces will not allow the chocolate coating to grip, frail centres will break etc.

The preparation step is known in the industry as sub-coating, gumming, isolating and stabilizing. Each name is probably based on the purpose for which the process was intended. However, carefully selected centres like dry roasted nuts, centres with little or no oil migration, free-flowing raisins with water content of no more than 13% and kernels providing good grip (chocolate adhesion), do not require any of these sub-coating procedures.

16.3.2.1 Gumming

In gumming the wetting mass, in the soft pan method, contains colloids together with some kind of drying powder. Currently, starch- or dextrin-based wetting masses are preferred because of the limited availability of gum Arabic (*Acacia senegal*) and the fact that gelatine is not liked in some markets as it may not be kosher or hallal. Gum Arabic and gelatine are, however, ideal for this task.

In the gumming process irregularities and ridges caused by the processing of the centres are rounded off. Many natural products also have a tendency of being pan unfriendly and need this process. The syrup should be around 40–50% solids with a high content of glucose to insure proper sticking and prevent the crystallization of the sugar.

The pans are filled with a predetermined amount of the centres. Using a ladle or other form of a container, the liquid is poured over the centres as they roll over one another, so that they quickly become wetted. It is very important to determine the right amount of liquid to use. If not enough is added the centres will emerge with uncoated spots and have a generally uneven appearance. If too much liquid is added the centres will start lumping and very wet areas will attract excessive amounts of dusting powder. In addition to this, with the sticky high glucose masse the formation of double and multiple centred panned goods will occur. As soon the centres are evenly wet, dusting with a powder can begin. The powder must be added as quickly as possible in order to make sure that the product pieces separate easily. With a slow powder application, the water in the wetting solution can dissolve part of the sugar, creating a paste in the pans. This increases the viscosity of the tumbling masse resulting in the formation of large balls. In addition, as more sugars is dissolved by the wetting masse, the sucrose/glucose ratio will change and it will start to crystallize. This results in a more brittle and harder masse (hard coating effect). Fine crystalline sugars are preferred to powdered sugar because this coats the surface of the centre much more evenly and the ridges and cracks are filled in much better. Once again lumping must be expected when powdered sugars are used, especially when the amount of liquid used is incorrect. The exact amount is difficult to determine due to the variations in the surface to weight ratio of the natural products. Once the pan load is wetted and dried again with dusting material, the process is repeated again for up to five times. If free powder is detected in the back of the pan, the product should be removed and the pan cleaned before the next layer is applied, otherwise free powder will adhere on the centres in an uneven manner during the subsequent wetting process, creating lumpy and irregular product.

It is not possible to suggest exact quantities to use in this process and only trial and error will give you the right formula for the product being coated.

Once the required number of coating layers have been applied, the centres should be removed from the pan and layered onto shallow trays for overnight drying. It is important for air to circulate between the trays, when they are stacked.

16.3.2.2 Isolating

Isolating is a term used where there is an actual physical separation required between the centre and the chocolate coating. Many of the centres used in chocolate panning contain oils or fats. Most of this oil/fat is not compatible with the cocoa butter in the chocolate and so the centre must be isolated from the chocolate, in order to prevent migration of the oils with the consequent blooming and softening of the chocolate (see Chapter 19). In addition, many product centres have a fatty surface which will not allow the chocolate coatings to stick properly during the early stages of the coating process. To make matters worse, should the chocolate coating subsequently crack, a full or partial de-shelling will occur. However, as was mentioned earlier, some of these issues can be reduced or prevented with the careful selection of centres.

Gelatine forms a good continuous film on many centre products, and is more elastic and less prone to cracking than an isolating film of gum Arabic. The process used for isolating is identical to that for gumming.

16.3.2.3 Stabilizing

Stabilizing is a step used in the panning procedure to prevent fragile centres from breaking under the tumbling action during the early stages of panning, before the coating itself makes the product strong enough to withstand the collisions between the pieces. Some typical fragile centres and the processes used to stabilize them are described below:

(1) *Soft raisins* are very difficult to pan. The centre is flexible and the chocolate coating is unable to build up on it without cracking, and this will result in deshelling of the product. To counteract this problem, one of the two techniques can be used.
    (a) The raisins are firstly wetted with a high glucose starch syrup, with care being taken to make certain that the liquid penetrates into the wrinkles of the dried fruits. Fine crystalline sugar is then sprinkled onto the wet centres. This solidifies in the cracks and keeps them rigid during further processing. As with gumming it is desirable to let the product dry in shallow layers overnight.
    (b) A low-viscosity, high-fat chocolate is used to wet the raisins. This is then dried with powdered sugar before the fat sets. The sugar can be coloured with cocoa powder to avoid the formation of a contrasting white layer between the raisin and the chocolate.

(2) *Sugar crust coatings on liquid centres* (e.g. liqueurs) will break very easily in a coating pan, releasing the liquid, which in turn causes significant damage to the product bed. In this case a small and slow turning pan (10 rpm) should be used. Be careful not to break these centres as they are loaded into the pan and commence wetting the product with a gelatine masse before starting the pan. Rotation is then started and the wetting completed. As soon as the centres are wet, powdered sugar is added. The pan is stopped immediately after the powder is distributed over the surfaces. The key to success is not to rotate the pan excessively and thereby avoid cracking the shells. The treated centres are carefully removed and dried overnight in shallow layers. This process may have to be repeated again the following day.

(3) *Flaky centres* (layered, honeycombed etc.) disintegrate as soon they come in contact with a sticky or heavy mass. The product can be sprayed with melted flavoured fat, which impregnates the surface. Once the centre is cooled the fat layers set, strengthening the pieces. This product must then be isolated before applying the chocolate coating.

These examples illustrate ways in which several challenging problems can in fact be solved.

16.3.3 Selection of chocolate and compound coatings

Panning is often called an art, and in reality panning operators do have to be very flexible and adjust process according to variations in the ingredients and in the environment. Very often insufficient attention is paid to the selection of the chocolate or coatings used in panning.

Firstly, if your product is to be sold with the word chocolate on its packaging, then it is necessary to make sure that the recipe being used conforms to local standards (see Chapter 25). The colour and flavour must also take into account the centre being used. In general, stronger and darker coatings are selected for sweet and strongly flavoured centres, whereas milkier chocolates are required with milder centres so that both flavours can be distinguished.

The coating particle size is based on the end use of the product, or the composition of its centre. If it is anticipated that the product will be savoured and slowly melted in the mouth, a coating with a small particle size has to be selected. On the other hand, if the piece is being chewed or the centre has a coarse texture, it is possible to select a grittier coating, which may be cheaper to produce (Chapters 7 and 20).

The plastic viscosity (Chapter 10) of the coating is generally not critical. The real issue is the yield value (value of stress used to sheer coating, tensile strength). Terms like heavy coating (high viscosity, high shear) and light coating are frequently used. Manufacturers of spray systems (used to spray chocolate onto the tumbling centres in the pan) usually recommend a viscosity range which is best for their equipment. Low yield values are recommended for light and low-density centres, to prevent clumping of the product. Higher yield values may be used if the centres are sufficiently heavy and fast moving to break away from each other. Very liquid coatings have no adhesive properties and tend to 'slip' on the product, resulting in bare patches, whilst very high yield value coatings tend to build up unevenly on the centres and also form deposits on the pan walls.

The setting properties of the coating greatly influence the final throughput of the product and this means that there are big differences between panning with chocolates and with compound coatings. Chocolate will be considered first of all. Experts continually argue as to whether chocolate is best used in a tempered or untempered state. There are however reasons why each might in fact be preferred. Untempered chocolate will process somewhat slower, but is easier to handle. Because of the shearing that is exerted on the chocolate during tumbling and the cooling of the centres by the air system, a self-tempering takes place in the pan. Low-fat and soft cocoa butter (Brazilian) will set somewhat more slowly and will appear gummier in character at the beginning of the process. Harder and higher fat chocolate will set more quickly and harder, which may increase the throughput, but make it more difficult to produce a very smooth surface. However, there are no real negatives with either type of chocolate. Cow's butter oil (milk fat) can have a greater impact on the setting of the chocolate than the selection of the type of cocoa butter.

Untempered chocolate has one characteristic, which makes it easier to pan than any of the compound coatings: the initial setting temperatures of cocoa fat is lower (approx. 25°C (77°F)) than the temperature at which the set fat will melt (approx. 30°C (86°F)). This temperature difference will give the operator a wide temperature range to work in, for smoothing and engrossing purposes.

Compound coatings are made with either fractionated or hydrogenated fats. Fractionated fats set very quickly, which results in a fast throughput rate. Hydrogenated fats have a wider range of fractions with different setting temperatures and may include some which are still liquid at room temperatures. Setting times can therefore be long, which may make the coating stay soft for a very long time and also make it difficult to coat the centre evenly. Products made with a soft coating shell should be stored for overnight before polishing is performed. Water-based polishing agents can easily interfere with the soft or oily fraction of hydrogenated fats, forming an emulsion, which prevents the surface from getting hard; a requirement for a good and highly glossy polish. With the correct information it is possible to produce a coating that is tailored to the centre and process. This makes the production procedure much more robust and is a step towards the removal of art in panning.

16.3.4 Chocolate and compound engrossing

This section explains the actual chocolate coating step. If all the preparation and the issues previously discussed have been carried out correctly, the actual chocolate engrossing will be relatively easy.

Since there are three major panning systems (manual pans, belt coaters and jumbo pans) in use within the confectionery industry, the engrossing process will be described in general terms for all systems and the differences indicated where appropriate. No matter how automated the system have become over the years, the principles of chocolate panning have remained the same.

The engrossing process with chocolate can be broken down into three segments for smooth-surface products and two segments for pearled-surface ones.

(1) Smooth surface:
  - Base coating (establish the foundation);
  - Rapid engrossing (weight gain);
  - Smoothing.

(2) Pearled surface:
   - Base coating (establish the foundation);
   - Pearling (weight gain).

The base coating is usually the most important part of the engrossing process. The aim of this part of the process is to build a solid layer of coating and cover natural ridges for example the edges and tips of almonds. Chocolate temperature for the engrossing process should be 31–35°C (88–95°F) for manual pans and 35–40°C (95–104°F) for automated pans with spray systems. Compound coatings should be kept 3–6°C (5–10°F) higher than for chocolate.

To start the process, a predetermined quantity of the previously pretreated centres is loaded into the pan. The centres should be free from dust and other debris. Should a variable speed drive be available, the pan should be adjusted to a lower speed setting to minimize the flaking of the precoating from the centres. Immediately after starting the pan, the application of the chocolate can begin. The cooling of the coating should start immediately the centres have a nice even covering layer. The centres are still relatively cold at this time, so the chocolate will set very quickly. Once the first coating layer has set, this procedure is repeated three to five times. In small manual pans it can be helpful to support the product bed with your hand in the direction of rotation, in order to assist the mixing and tumbling action. Large pans have built in baffles for this purpose. Care should be taken, to properly cool and set the product, but not to harden the fresh shell layer in a way so as to make it brittle and thereby cause deshelling.

Rapid engrossing is the step in the process, where most of the coating weight is applied. The pan can be speeded up to get a faster product flow. A 1.07 m (42 in.) pan can be run at approximate 22–25 rpm. The product crest will reach half way up the pan wall (Note: a wet bed will be higher than a dry one). The 2/3–2/3 rule should be used to determine the best place for the introduction of chocolate into a manual pan, using a drip feed or spray system. This means with an elevation 2/3 up the bed and 2/3 into the pan from the front, as this is the position where the product speed is at its greatest (see Figure 16.1). All other pan systems containing multiple nozzles that are aimed 2/3 up on the bed and are equally spaced across the length of the pan.

As has already been mentioned, the speed of the application can now be increased. Chocolate can be applied rapidly with the cool air blowing at the same time. The bed temperature will increase quickly due to the added warm masse, the latent heat created by the crystallization of the fat in the coating and from the friction existing in the wet bed. This will be a balancing act; if the air is too cold, very rough and bumpy surfaces will develop, which will slow down the process, and additional time will be required for smoothing. However, if the temperature in the product bed goes up too far for too long, then the outcome will be twofold pending the type of coating being used. A low-fat high-viscosity chocolate coating will become too soft and will start to deform. Deformation is recognized by the coating being pinched

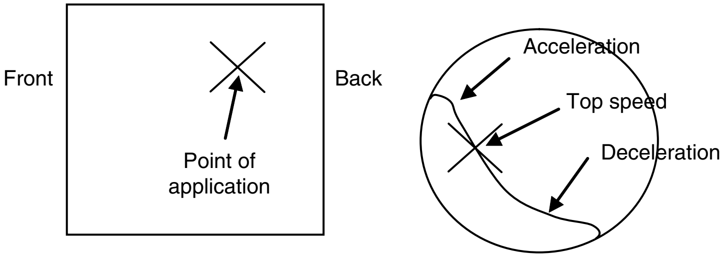

Figure 16.1 Point of addition of chocolate into a manual pan.

and squeezed towards the narrow end of the centrepieces, and even worse, the layers may peal off. With a high-fat coating, the opposite happens: thin layers of coating will start to melt off the tips and start to adhere on the flat side (where there is less friction and pressure) of the centres, causing the centre to be exposed at the tips. With drip feeding or ladle application, an additional defect can happen. Chocolate, which is to warm and applied in a thick stream, will melt the nearby coating layers where they are in contact with the fresh chocolate and bare spots will develop. This can be avoided by letting the product bed cool and solidify from time to time. Intermittent cooling is well worth carrying out as a better product and shorter engrossing times can be obtained, provided that not too much heat has to be removed through a thick layer of chocolate. The smoothing process can begin when about 80% of the total chocolate has been applied to the centre. Weight gain can easily be determined by weighing ten or twenty average sized sweets throughout the process. Large panning systems often have the advantage of load-cells fitted under the drum or under the chocolate feed tanks. Load-cells under the drum are not recommended, due to the difficulties reading an unstable signal caused by the rotating drum and the shifting of the product.

The smoothing process is critical in order to obtain a good polished product. The product should be checked for appearance shortly before the final layers of the coating are applied to the centres. The product should be cooled in order to avoid overheating of the inner layers once the smoothing process begins. The air is then turned off and the product allowed to continue to tumble for a while. Manual pans with lids should be covered to expedite the warming process. The ridges, if any, developed during the rapid engrossing will start to warm up and the coating will begin to move into any cracks. The remainder of the chocolate should then be added, to prevent the natural ridges on the centres becoming exposed (e.g. the tips of almonds). Care must be taken at all times not to overheat the product bed. The sweets will now develop an unruffled and even surface. As soon as the product appears smooth cool the bed one last time. The product can then be carefully removed from the pan and stored overnight. The chocolate will then have time to crystallize properly before the polishing begins. In large operations, the overnight storage is often omitted for scheduling reasons and the polishing step then has to begin immediately after the product has cooled and properly set.

Pearling is a type of product appearance now not often seen, but is nonetheless very attractive in assortments. The pearled sweet is covered with ridges and cracks. The polishing process will then only highlight the crests, giving the chocolate piece a very contrasting surface, even more so in the case of dark coatings. The pearling begins immediately after the formation of the base coat. Coating is continuously sprayed or dribbled onto the product bed. At the same time, cold air, possibly at a relative high pressure, is blown onto the product. This will not allow the coating to spread and start to build ridges and bumps. It is important to have coating continuously entering the pan so that the crests do not smooth out, but not at such a rate that the product bed starts to warm up. The chocolate viscosity can control the fineness and distribution of the ridges. A thin low-yield value coating will give a small grained appearance, whereas high-viscosity coatings produce relative large ridges. Once the product has reached its final weight, the polishing process can begin.

16.3.5 Polishing and sealing

Polishing and sealing makes a product look attractive. There is nothing more appealing to the customer than a highly polished, glossy chocolate sweet. Like all the previous panning stages, polishing is a two-step process. In theory, one or two coatings of shellac (shellac is the refined resinous secretions of the lac insect) would be sufficient to produce a good shine. However shellac, diluted in alcohol, will interact with the chocolate or the compound coating, so the final surface is poor. To avoid this interaction, a sub-coat is applied as a barrier. The polishing masse consists of colloids (gum Arabic, dextrin, starches, etc.) in sugar syrup, with glucose added as an adhesive and to prevent crystallization. To reduce the possibility of the product bed sticking together, it is advisable to add 3–5% of cocoa butter or hard fat as a separating agent. The polishing masse should then have a total solids content of 55–65%. Polishing solutions, which are available commercially, are in general a lot easier to use than home-made ones. This subcoat has a high polish of its own. Unfortunately, it is a water-based coating which loses its brilliance very quickly in a humid environment and so requires a sealant.

It is useful to understand what causes a high gloss. With the elimination of cracks, scratches and impurities and the like, a narrow spectrum of light is reflected from the surface instead of being absorbed, thus giving the glossy appearance. A good gum solution, or shellac, acts as a filler and also forms a continuous film over the surface, thereby providing all the requirements for a high gloss.

Polishing is usually carried out in pans dedicated to this task. The environment should be dust free, cool and dry. The pans are equipped with ribs or baffles to prevent the product bed from slipping, once the product has been polished. Where no ribbed pans are available, a smooth pan can be modified by coating the inside with a thin layer of dark chocolate. Before the chocolate hardens, scratch it in the direction of the pan axes. This will then create enough resistance to roll the product bed. The ideal drying air temperature is 13°C (55°F) with a relative humidity (RH) below 55%. A RH of less than 45% can cause the formation of a skin, trapping moisture and leading to subsequent flaking off of the polishing material.

The chocolate-coated sweets, free of dust and debris, which have been set overnight at room temperature or well cooled (for large-scale operations), are loaded in the polishing pan. The product can then be tumbled for a short period to further improve the surface (care must be taken not to heat up the product). Once the product has reached the desired smoothness, cold air is turned on to start hardening the surface, usually producing a product bed temperature of 15–17°C (59–63°F). The air is then switched off and sufficient polishing masse is applied with a ladle, or spray, to evenly coat all the sweets. Once the chocolate pieces have a wet appearance, the air is applied again and the product bed is dried. The drying time for the first coat takes around 5 min, and should not be shortened, otherwise the polishing layer will surface dry and flake off. Once the sweets are no longer clammy to the touch, the step can be repeated. The second layer will normally give the best results when the drying takes about 8–10 min. If the product still has only a very poor gloss, a third or even fourth layer may be required. The product is subsequently further dried and tumbled until a high gloss is achieved. When completely dry, the product is ready for the sealant. (Dust from flaking polishing materials can damage the surface if tumbling continues when the product is too dry.)

Sealing of the panned and polished product can now begin. Shellac, also known as confectionery glaze, is very commonly used for this process. In the United States three to four pound cut shellac (pound cut is a ratio term equalling three or four pounds of shellac to one gallon of alcohol (approximately 1 kilo in 2 litres)) with some added wax is readily available from suppliers. When using a spray system, the sealing masse is usually thinned down even further with alcohol (or other solvent), to counteract the evaporation of the solvent in the air before it reaches the product.

The centre must be thoroughly dried before sealing as any moisture still present will form a grey haze under the shellac.

As soon as the product is evenly covered with sealing solution, cold dry air is turned on to evaporate the solvent. Care should be taken that the correct amount of shellac is being applied. Insufficient sealant will give a blotchy surface, whilst excessive amounts of shellac will result in stretch marks. Often operators keep the pan stationary as the solvent evaporates, with only the occasional turn. Preferably, however, newer commercial sealants can be used, which contain waxes that enable the pans to run continuously. Once the solvent has evaporated, the pan can be rotated slowly for 5–10 min to produce a high gloss.

The processing is now finished, but in order to obtain the best results the product should be stored overnight, as it takes shellac almost 24 h to cure and become moisture resistant. Placing the cool product in relative humidities above 50% will however cause it to become sticky. This is reversible and will go away with time, or as soon as the product warms up. Should sticking occur the tray containing the product should be shaken with one blow. Trying to separate the product with the hand, will permanently mark the surfaces.

The solvents used for the sealants have to be treated careful, as there is a danger of explosion in the storage facilities, if they are not handled correctly. Air pollution from volatile organic compounds (VOCs) is another major concern. For these reasons the polishing area should be well ventilated. Some countries also restrict the use of VOCs and it is therefore necessary to ensure that the process is being carried out within the local legislation. Systems are available to contain and destroy the VOCs for example wet scrubbing, condensation, bio-filtration and thermal oxidation etc. High capital cost installations tend to have smaller operating costs and vice versa. The cheapest system with the highest operating cost would be a direct flame afterburner. This can be made more environmentally friendly by re-using the resulting heat.

Alternative sealing masses and techniques are being developed, but do not yet give satisfactory results. Suppliers of polishing solutions should be contacted to obtain up-to-date information regarding alternatives and current legislation. In temperate climates shellac may not be required at all, if the product is sold in high-quality packaging.

16.4 Packaging and storage

The type of packaging to be used is normally determined by the sales and marketing departments. It is however important to realize, however, that the packaging should not only be attractive at point of sales, but should also protect panned products. Problems such as moisture transfer, scratching, splitting and light induced rancidity must be prevented in order to preserve texture, flavour and appearance. Wrapping material suppliers can be of great assistance in this respect. A highly glossy surface is one of the biggest attributes of most panned confections. Once hazing, bloom and scratches have started to form on panned chocolate, the customer will think that the product is old and stale, no matter how fresh it might be. In all cases, a storage test should be carried out to determine the right packaging material.

For the customer to receive the best possible product, care must be taken during its packaging. It is very easy to damage the chocolate coat, and the risk should be minimized by keeping handling and transfer-points to a minimum. Long drops and large storage containers of unpackaged product should be avoided. Damaged and broken sweets as well as lose parts from the shells will detract from the appearance of the product. Relative humidity in the packaging department should ideally be 60%, if the product has previously stored in it and has reached a temperature equilibrium. If, however, this is not possible, the room air has to be treated in such a way that the humidity at the chocolate surface temperature is lower than 60%, in order to avoid a tacky slow flowing product.

16.5 The panning department

16.5.1 Room conditions

The environment conditions are critical to good panning and the room therefore should preferably not have an outside wall, especially in extreme climates. Shielding the room from the influence of the elements can be a great cost saver and will maintain good conditions throughout the year. The preferred temperature is no more than 15–18°C (60–65°F) at a relative humidity of less than or equal to 60%. Chocolate is set by cooling, not evaporation, but moisture can greatly influenced its setting properties, especially if spray systems are in use. The exception to this rule is large volume panning equipment, which is self-contained and has internal temperature and humidity control.

Polishing and sealing should be carried out in a dust-free environment. If possible, the polishing pans should be separated from the engrossing pans by a wall, or at least some distance should be kept between the pans doing these two processes. The temperature and humidity should be similar to that in the engrossing area. In most cases, alcohol is used as a solvent for the shellac application and this requires additional ventilation. Manufacturers of some large panning equipment claim that it is possible to polish and engross in the same pan. This is only possible if the panning equipment is free from dust accumulations and additional polishing agents are used to repolish the pan walls.

Because of the relatively cold environment, all the coating supply pipes must be water heated and/or well insulated to prevent freeze-ups, which could cause long stoppages in production.

A good process air supply is required to obtain high-quality products, but this is often undersized. A 1.05 m (42 in.) pan requires approximate 8.5 m^3/min (300 ft^3/min) of treated air at a maximum of 10°C (50°F) and it is best if the air can be cooled to remove moisture and then reheated. Once again, when obtaining large volume panning equipment, the manufacturer should be consulted as to the type of fan that is needed for the intended product. In all cases, a low-pressure high-volume system is the most satisfactory, the one exception being for pearled products, where a high-pressure high-volume system is needed to deliver intensely, cold air to the product.

16.5.2 Panning equipment

Considerable development of new panning equipment has taken place over the last 20 years. From the original round pans mounted on a tilted shaft, ever-larger pans have been built, often mounted horizontally. This type of equipment is normally called a drum rather than a pan. In addition, belt coaters (described further on) are available for the medium-sized production plant.

Great progress has been made in the area of control systems, turning panning from an art into a science. An endless discussion can be held on the relative merits of different types of panning machinery. For this reason, this section is restricted to a list of some of the major equipment categories.

Traditional pans are still the most common equipment in use. They are relatively cheap, but require a skilled operator. This type of pan was originally made of copper, but is now being replaced with stainless steel. On the one hand, copper was easy to fabricate into the bowls and has a high thermal conductivity giving excellent heat transfer. On the other it can act as a catalyst in promoting fat oxidation and will react with some of the more acidic coatings. Shapes range from almost disk like, with large diameter to depth ratio, which is ideal for sugar coating with its deep bed, to elongated tulip-shaped pans, which are preferred for the chocolate coating applications. Tulip pans, as they are called, have a relatively larger load capacity, in spite of having little mechanical friction against the back wall and a relative shallow bed depth. Engrossing pans should be smooth on the inside to avoid pockets, where product can easily stick and build up. If the product is expected to slide, as it should towards the end of the polishing cycle, then a ribbed pan must be used to assist the product to roll. The angle of the shaft is normally between 18° and 22° to the horizontal depending upon the relative amounts of mixing action and friction that are required. Pan turning speed is normally in the range from 20 to 28 rpm. The actual speed being dictated by the pan size and the desired peripheral speed. As a guideline, the product should be about three-quarters of the way up on the pan wall. Foot-operated start and stop switches are very beneficial, because they allow the operator easy manipulation of the product during start-up and unloading.

Belt coaters are based on an endless slate or wire belt. The pocket for the product is created with the help of two large disks on both sides (Figure 16.2). This type of coater is very easy to use, and can be equipped with computer controls. Their open design makes them very easy to load and unload. Unloading is performed by simply reversing the belt and the product is discharged into any means of transportation available. Large dropping doors isolate the process from the room environment. The product pieces tumble well, although there is very little lateral mixing. These systems are relatively inexpensive, have a short process time and are ideal for the medium-sized production plant. Several pan manufacturers have recently also marketed belt coaters.

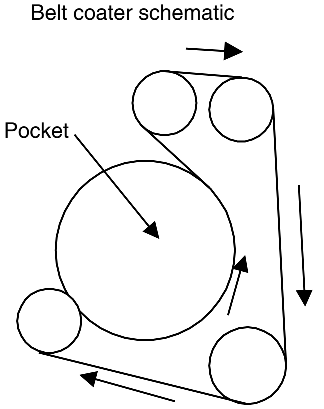

Figure 16.2 Schematic diagram of Belt coater.

Automatic panning systems, with large machines have been built for large capacity production facilities. These machines can contain up to 3 tonnes (6600 lb) per charge and several configurations are available. The pan manufacturer should be fully informed about the intended product to be produced on the machines, in order to obtain a well-tailored piece of equipment.

The drum diameter can range from 1.5 to 2 m (5 to 6.5 ft), with the load capacity being controlled by changing the drum depth. (Wider diameters relatively reduce the product's exposure to spray and to the air.) Baffles are used to move the product backwards and forwards to get an even mix and counteract the regional variances resulting from localized spray systems, powder applicators and air supplies. As the drums grow in length, however, it becomes a major engineering challenge to build manifolds supplying >40 spray nozzles, and ensure that each supplies the same amount of fluid.

Two pan types are available: solid pans with all the auxiliaries entering from the back (opposite to the operator) and the perforated drums (side vented), where the air enters from the pan sides and is pushed through the product bed. Perforated drums work well with a process where evaporation takes place for example sugar coating. Loading, unloading and the coating process can be controlled by a programmable logic controller (PLC), and minimal supervision is required. All pan manufacturers offer automated cleaning systems (clean-in-place). Being self-contained, automatic panning systems are virtually independent of the panning room's atmospheric conditions. Such fully automated systems remain, however, very expensive.

The names and addresses of some of the manufacturers who are able to supply panning equipment and advice on its operation are given at the end of the chapter.

Summary

Even today, many people still regard chocolate panning as an art and it may well be. However, if great care is taken during the processing and all steps are followed carefully, high-quality products can be produced. It is necessary to follow the complete process summary, as short-cuts seldom work.

References

The following book is recommended for further reading:

Silesia Confiserie Manual No. 4 – Silesia Gerhard Hanke KG, Apt. Fachbücherei, Postfach 210554, D-41431 Neuss.

Manufacturers

Bosch Packaging www.boschpackaging.com.
Carle & Montenari S.p.A., Via Trebbia 22, I-20089 Quinto de Stampi - Rozzano (Mi) Italy.
Driam Metallprodukt Gmbh & Co. KG, Aspenweg 19–21, D-88097 Eriskirch, Germany.
DT&G Limited – Finn Coater, Park Works, Old Bidstone Road, Birkenhead, Merseyside CH41 8BP, UK.
Ets Dumoulin et Cie, 5, Rue Auguste Perdonnet, ZI Le Closeau, 77220 Tournan-En-Brie, France.
Martin Lloveras S.A. Ctra de Rubi, 294, Box 71, 08220 Terassa, Barcelona, Spain.
MacIntyre Chocolate Systems/Ladco, Sir William Smith Road, Kirkton Industrial Estate, Arbroath, Angus DD11 3RD, UK.
Nicomac Inc., Via Curiel 12, I-20060 Liscate – (Mi), Italy.
Thomas Engineering Inc. 575 W. Central Road, Hoffman Estates, IL 60195, USA.
Vector Corp. 675 44th Street, Marion, IA 52302, USA.

Chapter 17

NON-CONVENTIONAL MACHINES AND PROCESSES

S.T. Beckett

17.1 Introduction

It is very hard to define what is conventional and what isn't. Every chocolate factory tends to be different and some manufacturers modify standard equipment to meet their individual needs.

Most chocolate making factories are based on a mix, grind and conche/liquefy principle, with special equipment being used to adjust the flavour or decrease the processing time. Chocolate can, however, only have a good texture and glossy surface if it is correctly tempered. A lot of research has taken place into the different polymorphic forms of cocoa butter (see Chapter 12) and into designing new tempering machines (see Chapter 13). Most of the latter are based on the general principles of scraped surface heat exchangers. Three novel approaches have however been developed, which may in the longer term come into wider scale commercial use. The first to be described (ultrasonics) has also been used to aid conching.

It is the chocolate using departments, however, that perhaps show the greatest degree of diversity and innovation. For this reason the major part of this chapter is devoted to three chocolate usage processes, which are becoming more widely used and are considerably different from the traditional moulding and enrobing, described in Chapter 14. These are:

(a) extrusion
(b) 'single shot' depositing
(c) aerated chocolate.

As extruders are also used for chocolate making, both applications are reviewed in this chapter.

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17.2 Ultrasound

Nordenskjold and Holmquist proposed the use of ultrasound to conche chocolate or cocoa mass as early as the 1940s. The high-frequency accelerating and retarding forces were used to impart energy into the product and this was said to have the following effects:

(1) Acceleration of some chemical reactions without changing the form of the reaction for example the extraction of tannins from cocoa mass.
(2) Freeing of gases from the mass.
(3) Formation of electrostatically charged oxygen and ozone, thus causing some oxidation.
(4) Homogenization of the ingredients.

It is now known that ultrasound at high intensities creates free radicals, which promote oxidation and other reactions – these may be beneficial to some types of chocolate, but detrimental to others. For example, it is said that whereas oxidation may assist flavour development in plain chocolates, it may give rise to an unpleasant taste in milk ones. Initially, in fact, treatment with ultrasound was more successful with plain or bitter chocolate, where it was generally found to reduce conching time from about 72 to 36 h. Mosimann (1963) in particular developed it for use with all types of chocolate, so that it could be used as part of a manufacturing process which required no conching at all (Figure 17.1). He concluded that many people were using too long a treatment time (up to 120 s) and limited his processing period to a fraction of a second. Mosimann found that ultrasonics accentuated flavours, including some bad ones, so it was necessary to ensure that the latter were not present in the feed material. In addition some de-aeration was needed for milk chocolate. For these the exposure time was extremely critical, with longer times giving a deterioration of flavour and an increase in astringency. The ability of ultrasound to generate free radicals decreases with increasing frequency and therefore the frequency used is crucial. It was found that 800 kHz was required to heat the chocolate and give inferior results and although the most suitable frequency was found to vary with the chocolate recipe, it was normally in the region of 20 kHz.

Ultrasound has also been shown to improve the texture of the final product and make it less sticky in the mouth. This may be related to the fact that it aids the tempering of chocolate. Roberts at the Leatherhead Food RA in the UK used ultrasound in the 1980s to promote the formation of specific polymorphic forms, whose type depended upon the temperature used. He also found that tempering, particularly of plain chocolate was improved. Milk recipes were less effected, probably because of the influence of the milk fat.

This has been subsequently developed by Kraft, Jacobs, Succhard, R&D, Inc. (1997), who describe work in which ultrasound is applied in order

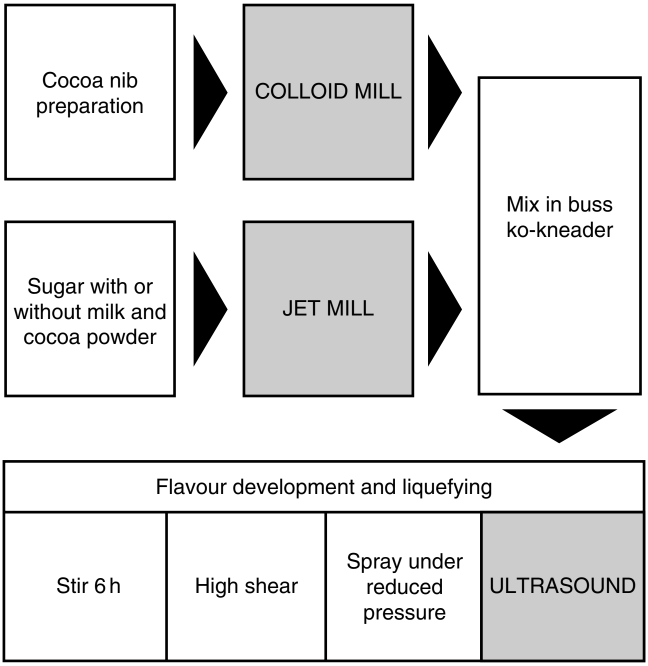

Figure 17.1 The Mosimann process for chocolate making.

to retard fat bloom in fat-based confectionery masses. The chocolate is cooled to a temperature of at least 3°C below the melting point of the required crystalline state. Pulses of ultrasound are then applied. The pulse lengths and intervals can vary over a wide range, but preferred values are said to be from 0.5 s to 4 s or 5 s. Similarly although a wide range of ultrasound frequencies can be used, the range 20–100 kHz appears to be the most effective. The use of the ultrasound is said to make the tempering process more robust and to give products with optimal contraction, gloss and snap.

Ultrasound can also be used to determine the amount of crystalline fat within chocolate at different temperatures, i.e. the solid fat index. Povey (1997) has shown that this can be done by cooling the fat or chocolate to 0°C (32°F), before grinding it into a powder, which is smaller than the wavelength of sound. The powder is then dispersed in a mineral oil at a fraction of 20% w/w, and the temperature raised to the range needed for the measurements. The amount of solid fat present can be calculated from the velocity of the ultrasound through this mixture. This technique has shown the presence of solid fat in the range 33–80°C (91–176°F) and this has been attributed to phospholipids, mainly from the added lecithin in the case of chocolate.

The use of ultrasound to measure chocolate temper on-line was unsuccessful however, as the signal from air bubbles within the chocolate was much greater than that from the crystallizing fat (Anon., 2002).

17.3 High shear/low-temperature crystallizer

In Chapter 13 it was noted that high shear was considered to be of critical importance in rapidly tempering chocolate and that Ziegleder (1985) had demonstrated that cocoa butter could be tempered in 30 s at very high shear rates. It was also said that this could not be achieved with standard tempers. One of the main reasons for this is the difficulty in keeping the cocoa butter crystals at a low enough temperature to stop them melting, when the high shear is dissipating heat into the fat.

This is illustrated in Figure 17.2 (Windhab, 1995), which plots the crystal volume fraction of dark chocolate against the rotational speed of a crystallizer. This machine operates by shearing the fat as it is being cooled. Initially, as the speed is increased, more seed nuclei are able to spread throughout the sample. This eventually tempers it, which enables it to set quickly – the actual crystal content required to temper chocolate varies considerably from author to author, but is probably in the range of 1–3%. Eventually, the speed becomes so high that the energy generated by the crystallizer melts some of the crystals. Subsequent increases in speed further decrease the temper.

Windhab *et al.* (1994) overcame the melting problem by maintaining the walls of his crystallizer (Figure 17.3) at a very low temperature (4°C (35°F)) and keeping the outlet temperature between 28°C and 30°C (82°F and 86°F) to prevent the machine from blocking. This was possible because the cocoa butter or chocolate was being pumped through the concentric cylinder shear gap in a way in which there was no possibility that there were any 'dead spots' and because some heating was being provided due to the shearing. The actual shear energy was controlled by varying the speed of the inner

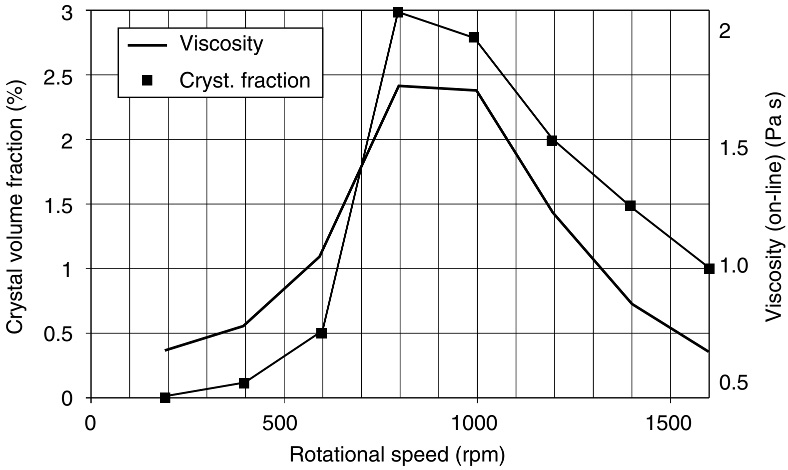

Figure 17.2 Pre-crystallization of dark chocolate in a pilot plant crystallizer under constant cooling conditions (15°C, 59°F).

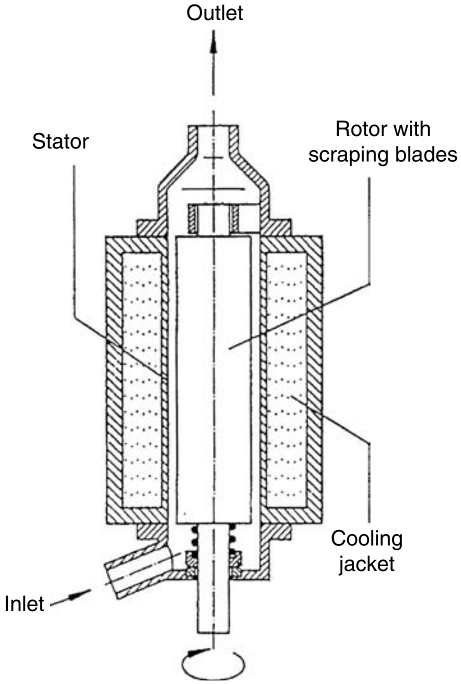

Figure 17.3 Principle of the continuous shear crystallizer (Windhab, 1994).

cylinder within the range 600–1200 r.p.m. It was possible to obtain a stable temper by using in-line temper/viscosity readings on the outlet from the crystallizer to control its speed of rotation.

It would have been expected that, because of the low temperatures, the unstable crystalline forms of cocoa butter would be produced. Windhab showed, however, that in his crystallizer the crystal type was related to the power input per unit volume of material. He was also able to show that the crystals produced contained a higher proportion of Form V crystals than a conventional temperer. He was therefore able to produce a very good temper with a residence time of about 10–15 s.

This principle has been incorporated into a new tempering machine that is sold by the Bühler company of Switzerland and described in Chapter 13.

17.4 High-pressure temperer

A Bauermeister pressure tempering system has existed for many years operating at pressures of between 175 and 1000 kPa (25–150 psi) in combination with shearing and cooling. Trials in Japan, however, have shown that it is possible to temper pre-cooled chocolate by pressure alone

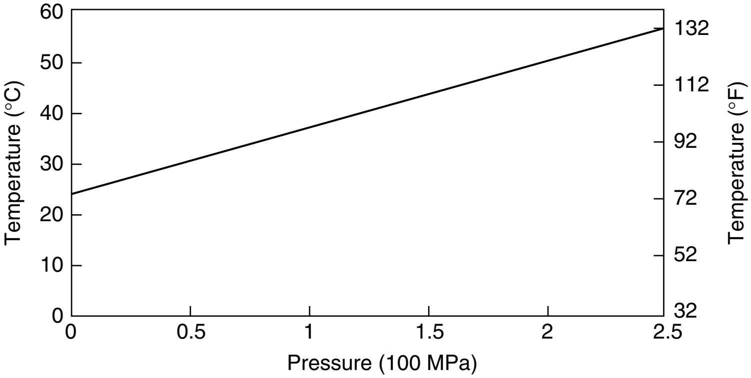

Figure 17.4 The effect of pressure on the melting point of cocoa butter (Yasuda and Mochizuki, 1992).

(Yasuda and Mochizuki, 1992), but at much higher levels (about 150 MPa or 20 000 psi).

Very high-pressure systems have been developed for the food industry in order to kill vegetative bacteria without the need for heat. Fruit colour and flavours are therefore better preserved and commercial machines are used to manufacture jams and preserves. This type of machine has been shown to be also able to act as a temperer.

The principle behind this process lies in the fact that the melting point of cocoa butter rises linearly with pressure (Figure 17.4, Yasuda and Mochizuki, 1992) according to the equation:

$$T = 0.14P + 26.6 \tag{17.1}$$

where T is the solidifying temperature (°C) and P the pressure (MPa). From this it can be calculated that applying a pressure of 150 MPa has an equivalent effect to lowering the temperature of the cocoa butter by 20°C (36°F). This means that, if this pressure is applied to liquid cocoa butter at 30°C (86°F), all the main different crystal types are formed. When the pressure is released however, those unstable forms with lower melting points disappear leaving tempered chocolate. Experimentation showed that at least two pressure pulses are required with holding times of up to 5 min.

This is obviously not suitable for industrial applications. Further trials indicated, however, that by returning 10% of the tempered chocolate to the feed system as seed crystals, a holding time was no longer required. A prototype continuous pressure temperer was therefore developed (Figure 17.5).

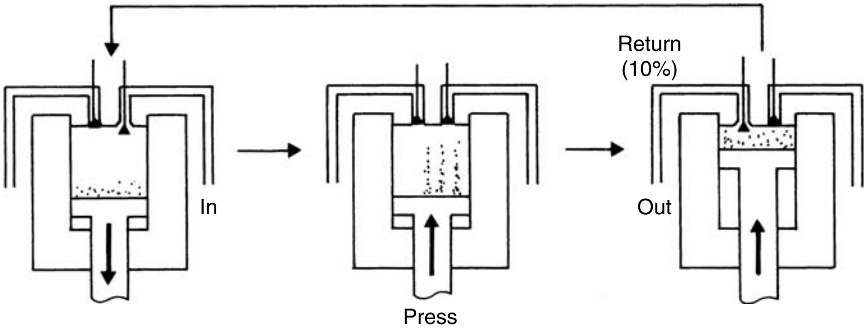

Figure 17.5 Diagram of prototype system for tempering chocolate using very high pressures (Yasuda and Mochizuki, 1992).

17.5 Extrusion

17.5.1 Types of extruders

Extruders are widely used in the food industry for applying high shear, fast heating or cooling and for 'flashing off' volatiles to remove moisture or flavour compounds. If the processing required is just one of mixing, kneading or compacting, a single-screw design can be used. In the confectionery industry, however, the twin-screw extruder is more common, being employed in the making of licorice, toffee and jellybean-type articles. In the chocolate industry it has been used to treat cocoa mass, for flavour improvement (Section 17.5.2), as a liquefier to partially or fully replace the conche (Section 17.5.3), or to shape tempered chocolate to produce novel products (Section 17.5.4).

Two distinct types of twin screw extruder exist, namely co-rotating and counter-rotating systems. Their major characteristics are outlined in Table 17.1. Typical designs of the elements attached to the two rotating shafts are illustrated in Figure 17.6 for the two types of machine.

An extruder can be adapted by rearranging the elements within it, so as to give a series of shearing and degassing stages as required. Because of the very large internal surface area of the extruder relative to the amount of chocolate present, it is possible to control the temperature very accurately, as may be required for flavour development or when processing tempered chocolate. Additions of fat, emulsifiers or flavouring ingredients can be made at different positions down the extruder barrel, which adds to its versatility.

17.5.2 The extruder as a flavour modifier

The ability of an extruder to heat and de-gas liquids has led to its use in pasteurizing or flavour modifying cocoa mass or nibs. Traditionally this has

Table 17.1 Comparative characteristics of co- and counter-rotating extruders.

Co-rotating screws	Counter-rotating screws
Mass transport by positive conveyance and drag	Positive conveyance acts like a 'screw pump'
Longitudinally open flights leaves open path from feed to discharge	Radially and longitudinally closed flights. The screw flights form sealed chambers. Limits mixing but quickly generates pressure. Good transport of low viscosity material
Pressure generation depends upon the number and pitch of the reverse pitch elements and very much upon the die exit. The through 'path' limits the upper pressure obtained	Pressure generation by the reduction of pitch length
Good mixer but less control over temperature and shear	Poorer mixer, but each small 'pocket' of material can have a more precisely controlled temperature regime. Within limits, temperature and shear can be controlled independently

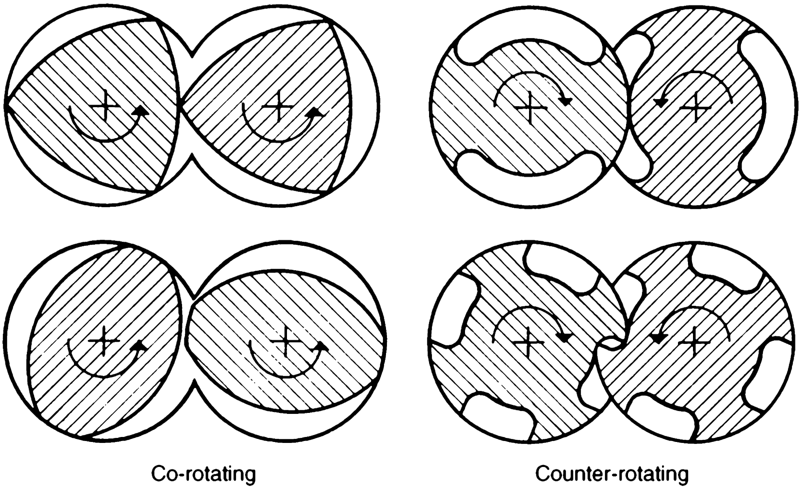

Figure 17.6 Examples of cross-sections of co-rotating and counter-rotating extruder elements.

been carried out by thin film or spray devices (Chapter 9). One system using an extruder, developed by Werner and Pfleiderer (1989), adds water or steam into the extruder, where the cocoa nibs are thoroughly wetted and slightly crushed. Pasteurization is carried out by applying a high temperature over a short time. The steam de-gasses at the machine outlet, taking with it many other compounds, including some acidic ones, which are detrimental to chocolate flavour. The high humidity during the process also raises the water

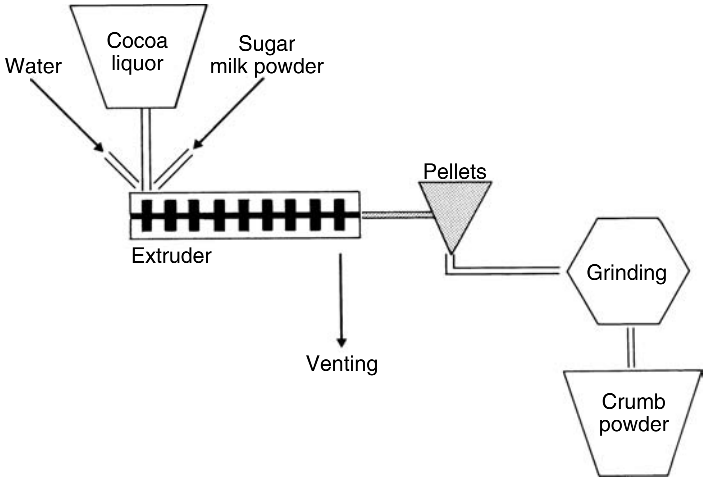

Figure 17.7 Chocolate crumb-making process using an extruder (Anon., 1996).

activity (equilibrium relative humidity) of the material, thereby increasing the probability of destroying *Salmonella* and other bacteria (Chapter 23).

In addition to treating cocoa mass to remove flavours and thereby shorten conching times, an extruder can also be used to treat the chocolate ingredients to produce a crumb type of flavour. As was described in Chapter 5, chocolate crumb was produced historically to give the milk needed for chocolate making a longer shelf-life. Although this may now no longer be necessary, the cooked caramel flavour is preferred in some markets, for example the United Kingdom. The manufacture of crumb usually involves a vacuum drier, and is relatively slow and expensive.

In the Continua crumb process (Anon., 1996 and Figure 17.7) the crumb flavour can be produced in about 60 s. Sweetened condensed milk and/or milk powder, water and sugar are fed into a twin screw extruder together with cocoa mass. Here they are thoroughly mixed and heated to a temperature of 95–130°C (203–266°F) depending upon the desired final flavour. Towards the end of the process the mixture is reduced under temperature by applying a vacuum. At this stage the residual moisture is 1–3% and the mixture has a consistency which enables it to be pelletized. This granulate is then milled to a powder, which can be used as the main ingredient in a traditional chocolate making process. The milling will also reduce the moisture by up to a further 0.5%.

17.5.3 The extruder as a chocolate conche

In Chapter 9, the importance of a high shearing system in reducing the viscosity of chocolate was emphasized. In addition good temperature

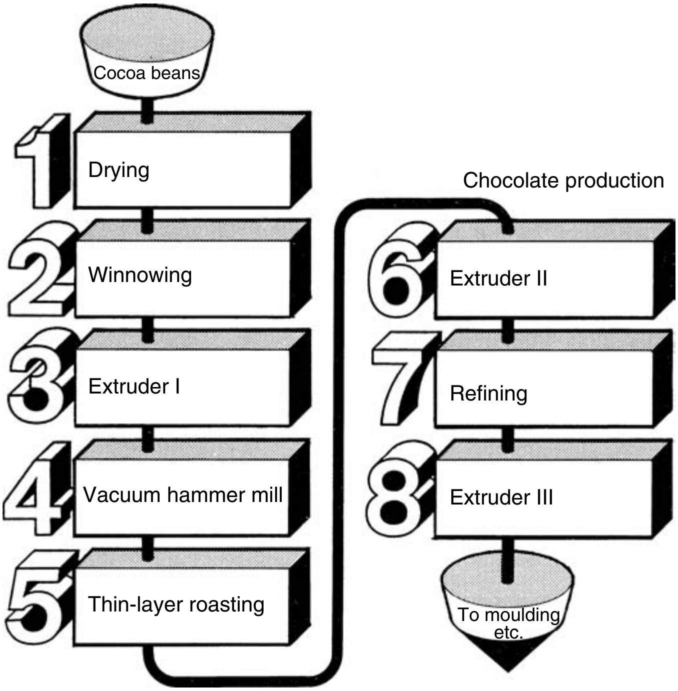

Figure 17.8 Werner & Pfleiderer system for chocolate manufacture.

control was said to be necessary to ensure that the correct flavour was developed. The extruder has these properties and has therefore been applied to chocolate conching.

One of the first descriptions of it being used for this purpose was as part of a novel chocolate process developed by Werner and Pfleiderer (1970). The total process in fact used three extruders (Figure 17.8). The beans were dried and winnowed before being slightly crushed under high moisture conditions in the first extruder, as was described above. The cocoa mass was then produced by grinding followed by thin-layer roasting. The second extruder was then used to mix in the other ingredients, apart from the surface-active agent and some of the cocoa butter. It also completed the flavour development, by heating and venting. A roll refiner then reduced the solid particles to the required size, before the chocolate was fed into the third extruder for the final additions and liquefying. The total process was reported to take 30 min and to be able to operate between 300 and 3000 kg/h (660–6600 lb/h) and to produce a wide range of flavours.

Although described as a twin-screw, co-rotating, high-shear continuous mixer, the Teledyne Readco continuous processor has many of the features of an extruder. The close clearances between the paddles and between the paddles and barrel walls provide the high shear for all the material

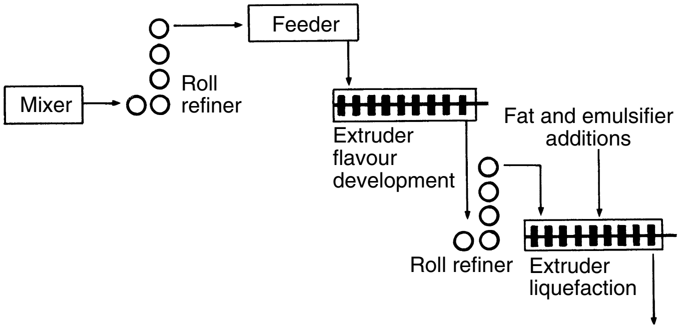

Figure 17.9 Continuous conching system using Teledyne Readco Processor (Aguilar *et al.*, 1995).

present and thus very efficient liquefying. The movement of the shafts is essentially self-wiping, so very little cleaning time is required. Units have been designed with hollow paddles and/or jacketed barrels to give a precise temperature control.

This type of machine has been used as an alternative to the conche, in order to produce a relatively thin chocolate with a very short processing time. Ziegler and Aguilar (1995) and Aguilar *et al.* (1995) describe experiments in which two 5 cm (2 in.) shaft processors were used in series to conche a milk powder-based milk chocolate. The first processor acted as a flavour developer, with the second being used as a liquefier, the final lecithin/cocoa butter additions being metered in half way along the barrel (see Figure 17.9). In some experiments, an additional roll refiner was used between the two processors, or following conching. The latter was said by Niediek (1991) to be a method of producing some of the best quality chocolate.

The residence time in a Teledyne Readco continuous processor is determined by the screw configuration, masse feed rate, discharge opening size and screw speed. Using the high shear system, only the feed rate was found to have a significant effect. For rates between 30 and 10 lb/h (14–4.5 kg/h) the mean residence times were between 2 and 8 min. Even with these short times the chocolate appeared to be fully liquefied. The temperature of the first processor was critical both for the flavour of the chocolate and its viscosity. The Casson yield value and the plastic viscosity (see Chapter 10) were much lower for a temperature of 70°C (158°F) than for 40°C (104°F). When even higher temperature were used, however, the chocolate became gritty and post-processor refining was required.

The flavour of the chocolates produced were compared with that produced from the same roll refiner material, but which had been processed in a traditional batch conche for 24 h at 60°C (140°F). The samples were found to be significantly different, but there was no significant preference for either. The chocolates were evaluated in terms of sweetness, caramel, milk and chocolate flavour. Of these, only caramel was found to be effected by the processing time and temperature. The chocolate processed at 90°C (194°F) was found to be most like the batch conched control chocolate. This chocolate was however gritty. This may have been due to the crystallization of amorphous lactose. Many milk powders contain a high proportion of lactose in the amorphous state. Crystallization is both time and temperature related and Arvanitoyannis and Blanshard (1994) demonstrated that in anhydrous mixtures with sucrose (i.e. as in chocolate) this transition would take place within minutes at temperatures of 90°C (194°F). This crystallization, which would be expected to change the flavour and improve the flow properties, would also take place in the batch conche, but over a much longer period of time.

The Teledyne Readco continuous processor was therefore able to match many of the properties of a traditional conche. Its advantages were said to be:

(1) Reduced conching time.
(2) Faster product changeover and greater flexibility.
(3) Increased production rates.
(4) Reduced energy requirements.
(5) Smaller floor space needed.
(6) Less material in process.
(7) Enclosed operation and improved cleanliness.

17.5.4 The extrusion of tubular shapes, ropes and nets

When chocolate is tempered part of the liquid fat solidifies thus making it thicker. It is however still flowable, as it can be used to enrobe sweet centres, or be poured into moulds. As the chocolate is further cooled, more of the fat solidifies and it becomes paste-like. In other words it will deform under pressure, but will retain that shape once any force is removed. In this state it is possible to extrude the chocolate onto a mould or belt, where it is subsequently cooled in the traditional manner. The extrusion must be done quickly whilst there is sufficient liquid fat present to enable it to deform in the extruder nozzle, but before it has become solid.

Cadbury Schweppes Ltd & Mercer (1981) applied this principle to produce net shaped or tubular products. The tempered chocolate is rapidly cooled, whilst continuously being stirred, until it reaches a temperature where the chocolate becomes sufficiently viscous to extrude. Instead of extruding the chocolate through a hole, cooled net-forming dies can be used. The inner and/or outer parts of the die can be rotated or oscillated to give different patterns (see Figure 17.10). This net can be passed over a cooled mandrel to form it into a tube. If this mandrel is hollow, a filling material such as mallow, fondant, fudge or spread can be fed directly into the tube. The tube can be cut as it leaves the mandrel and is passed on to the take away belt.

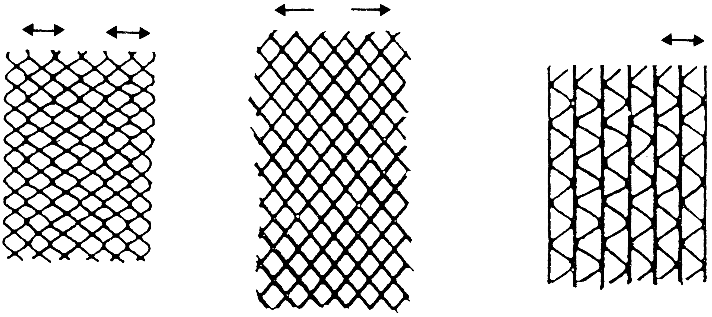

Figure 17.10 Selection of net designs produced by Cadbury Schweppes Ltd & Mercer (1981) extrusion technique.

The major problem with this type of technology is that the processing conditions, in particular the temperature and the chocolate viscosity must be very tightly controlled. If the extruded tube is too liquid, due to a high temperature or low viscosity, the tube will collapse and become mis-shapen. Too thick a chocolate will not extrude properly and may have a rough surface or crack upon bending.

Sollich GmbH & Co. has also developed a machine to extrude chocolate paste into a stick or rope (Hilker, 1996). The chocolate flow properties are influenced by the fineness of the chocolate and the recipe, but above all by the temperature which must be carefully controlled. Tempered chocolate is cooled between the pump and the extrusion nozzle, so that the chocolate rope, being discharged onto a transport belt, has a surface temperature of about 22°C (72°F). It is therefore sufficiently viscous to hold its shape, but is too soft to cut immediately. This can be carried out after a short cooling period. This extruder can produce chocolate products containing solid ingredients with a diameter of up to 1 mm (0.04 in.) and which have a smooth surface or have a twisted shape.

The Sollich stick-extruder has been further developed to produce a chocolate mesh. In this machine several extruding heads are located one after the other above a moving belt. The heads are moved backwards and forwards across the width of the belt. When the distance covered by one oscillation of the heads is the same as that of the movement of the transport belt itself, a diagonal pattern of thin chocolate strands is produced. This can then be repeated by a series of subsequent heads to produce a product with a woven-like appearance. The number of strands, together with their diameter, determines the height of the product. Increased visual impact can be made by extruding different coloured chocolate for the different levels. In addition textural contrast can be achieved by putting wafers, nuts or crispies between the chocolate layers.

As with the Cadbury process, the temperature and chocolate viscosity are critical. Here it is important that each strand be present and be of the same diameter. In order to do this every pipeline from the pump to the extruding head is the same length and temperature. One feed pump is connected to three nozzles, each of which produces five strings.

The chocolate mesh is still too pasty to cut cleanly when it is deposited upon the belt, but would be very brittle if it were left to solidify fully. An intermediate stage is provided by passing the product for about 4 min through a conditioning tunnel. After this the chocolate mash is cut using a slitter and guillotine. Final separation and wrapping is carried out after a second cooling tunnel. This process gives very good weight control with individual pieces being within +2% of each other. Production lines are available which can make the product at a rate of 500 kg/h (1100 lb/h).

The above processes depend upon accurate temperature control and use a chocolate that is in a semi-liquid state. An alternative approach, based on processing in the plastics and ceramic industry, was described in Beckett *et al.* (1994). Trials, where the chocolate remained essentially solid throughout the process, were carried out on a laboratory scale. Solid chocolate buttons about 10 mm (0.4 in.) in diameter and 3 mm (0.1 in.) in thickness were fed into a Florin ram extruder (see Figure 17.11). The extruder and chocolate were at an ambient temperature of 23°C (73°F). The extruder initially compacted the chocolate before extruding it in the form of a rod or tube. The extruded chocolate had no detectable temperature rise, so the processing was essentially iso-thermal and was called cold extrusion. It was found that a continuous uniform extrudate could be obtained at temperatures above 18°C (64°F) up to just below the melting range of the chocolate (about 30°C, 86°F), and so accurate temperature control was no longer required.

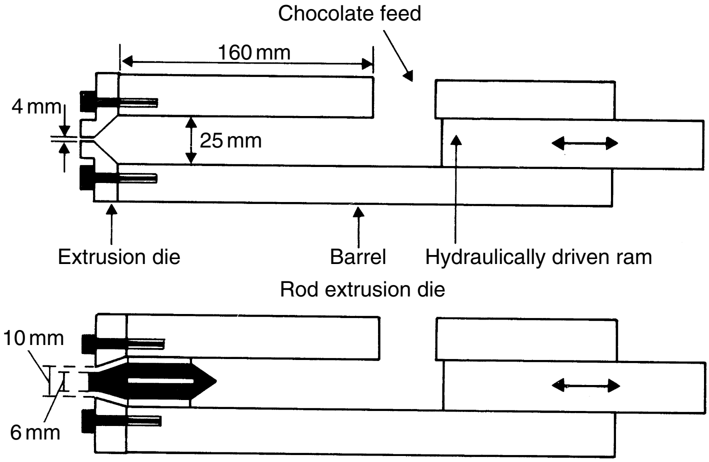

Figure 17.11 Schematic diagram of the 'Florin' ram extruder when used to produce rods and tubes (Beckett *et al.*, 1994).

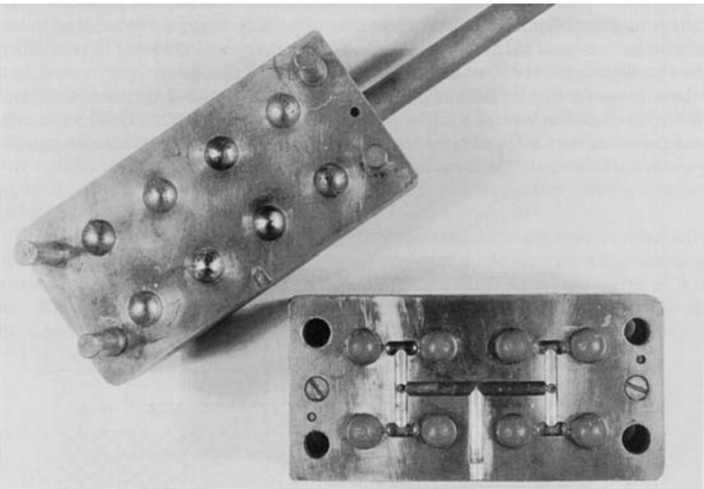

Figure 17.12 Photograph of injection mould used to make small balls (Beckett *et al.*, 1994).

The surprising property of the extruded chocolate was that it remained in a plastic condition for a significant amount of time, enabling it to be twisted or even tied into knots. The actual length of this plastic state was found to depend upon the type of chocolate, the extrusion conditions and the post-extrusion storage temperature. In general it took from 30 min to several hours for the chocolate to return to its previous brittle form.

Many plastic products are formed by injection moulding. Because of the plastic nature of the cold-extruded chocolate, this type of process was investigated. A mould capable of producing eight 12 mm (0.5 in.) diameter balls (Figure 17.12) was attached to the Florin ram extruder. Once again the trials were carried out at room temperature. Eight balls were consistently produced, but their surface quality was variable, ranging from matt to glossy. The entrance gate to the ball was only 200 μm (0.008 in.), showing that chocolate can be extruded through a very narrow opening.

This process (Mackley, 1993) can be carried out using single and twin screw extruders in addition to the original ram-type machine. With skillful process control, therefore, it is possible for liquid chocolate to be tempered, solidified and extruded in a single extrusion-processing step.

17.6 'Single shot' depositors

17.6.1 Background

A substantial proportion of the chocolate confectionery market consists of moulded filled sweets, i.e. a chocolate shell containing a contrasting centre which can be praline, sugar fondant, peanut butter etc. The advantages of moulded products over enrobed ones (Chapter 14) are that they can be made in a much wider variety of shapes and that they have a higher gloss finish. The main disadvantage is the number of procedures required to produce a traditional shell moulded product, i.e.:

(1) mould warming;
(2) tempering of the chocolate;
(3) depositing the chocolate to fill the mould;
(4) shaking to remove air bubbles;
(5) cooling and inverting to remove the centre chocolate;
(6) vibrating to control shell thickness before inverting again;
(7) shell cooling;
(8) scraping to remove excess chocolate from mould;
(9) deposit the centre;
(10) vibrate and cool centre;
(11) re-heat the back of shell and the centre;
(12) deposit tempered chocolate to produce back (bottom) of sweet;
(13) scrape off excess chocolate;
(14) vibrate and cool;
(15) demould.

Although obviously complex, shell moulding works well and can be used with a wide variety of centres including whole nuts and cherries and the filling can be as much as 66% of the sweet.

Single-shot depositing is more limited in the types of centre that can be used, in that this must be of a pumpable form. In addition the centre is normally less than 50% of the sweet. It does however enable a very wide range of products to be made by a much shorter process. Cadbury Ltd. in the United Kingdom has used the process for over 60 years, but has only been available to the confectionery industry at large as ready manufactured plant since the 1970s (Jeffery, 1990).

17.6.2 Basic principles of 'single-shot' depositing

The basic principle behind this technique is illustrated in Figure 17.13. As can be seen, it relies upon carefully timed depositing through concentric cylindrical feeds and through a central nozzle. Tempered chocolate is fed through the outer ring and the centre is deposited down the inner tube.

The sequence starts with the chocolate being deposited through the complete nozzle hole. After a predetermined time the centre starts to flow, so that a ring of chocolate surrounding a rod of centre is being forced through the nozzle. Subsequently, the centre stops and a plug of chocolate once again flows through the nozzle, to complete the sweet. Thus a chocolate 'balloon' is formed containing the centre confectionery. This may be deposited on a

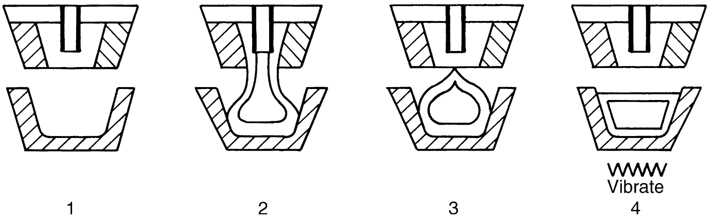

Figure 17.13 Schematic diagram of the principles of 'single-shot' depositors.

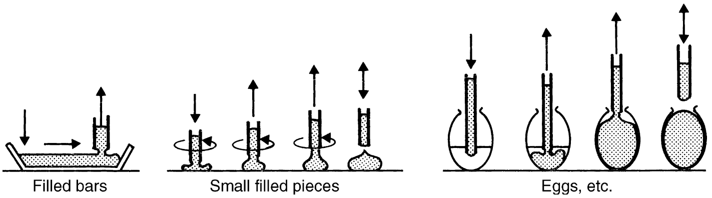

Figure 17.14 Illustration of some of the moulds used with 'single-shot' depositors.

belt to form a chocolate 'kiss' (see Figure 17.14) or more usually falls into a mould, where it is vibrated to make the chocolate and centre conform to the required shape, which includes bars and egg shapes. The product is then cooled and demoulded ready for wrapping. Egg-shaped products can be made by depositing into a book mould, i.e. one which consists of two moulds which are hinged at one edge (Chapter 14). The hinges open to release the product once the chocolate has set.

This process is obviously much quicker than the traditional process, with the whole product being formed in one depositing action, hence the name 'single-shot'. Its big advantage is that it can greatly extend the range of products, which can be produced on a standard moulding line, at a low cost compared with a shell plant.

This principle was taken even further by Cadbury Ltd., who developed a triple-nozzle version. This produced a double centre sweet for example jam (jelly) inside fondant, surrounded by chocolate. The German company Winkler and Dünnebier has since produced a triple-shot machine for putting two centres into praline shells (Anon., 2005). The Awema company have taken this one stage further to produce a 4-(Quadro) shot depositor. By using a mechanical nozzle plate and the specially designed hopper dividers, it is possible to produce products with two fillings in two-component shells as is shown in Figure 17.15. The viscosity of the two fillings can be different.

17.6.3 Limitations of 'single-shot' depositing

(1) *Temperature of depositing.* The process needs the temperature of the centre to be no higher than that of the enclosing tempered chocolate. If it is, the

Figure 17.15 Chocolate products with two components in the centre and shell. Reproduced with permission of Awema A.G., Switzerland. See Plate 17 for the colour image.

chocolate will detemper resulting in slow setting and poor contraction during manufacture and a poor textured easily blooming product. The actual temperature will depend upon the type of chocolate used, in particular its fat phase. In practice this is higher for dark chocolate at about 33 –36°C (91–97°F) than for milk chocolate, which will be in the range 28–31°C (82–88°F). It is possible to have a temperature towards the top of this range by using a harder cocoa butter, i.e. one from Malaysia rather than one from Brazil. In milk chocolate the lower the proportion of cow's butter, the higher will be the tempered chocolate temperature, which then allows for a warmer centre material. Where it is possible to use vegetable fat in chocolate or for coatings, a high melting point cocoa butter equivalent fat (see Chapter 19) (sometimes known as a cocoa butter improver) can be used to raise the operating temperature by a few degrees. Even this, however, is not enough for the process to be used to make hard toffee centres, as the toffee would require much higher temperatures still, to be flowable at the correct rate through the central depositor. These sweets require a shell moulding or enrobing plant.

(2) *Matching viscosities of the chocolate and the centre.* The process operates best when the centre viscosity matches as close as possible that of the tempered chocolate, which surrounds it. The latter can be increased by lowering the temperature and/or increasing the temper. Typical Casson plastic viscosities lie in the range 10–80 Pa s (100–800 Poise). Mechanically operated cam systems required very good viscosity matching, but programmable electronically controlled machines can tolerate bigger differences between the two (Watson, 1997).

(3) *Size of inclusions.* The centre has to be forced through the inner depositing channel. Although it is normally possible to include small pieces, such as bits of nuts, it cannot be used with whole nuts, cherries or raisins etc. Even small pieces can cause the central channel to be blocked or break the outer chocolate 'skin'.

(4) *The ratio of centre to chocolate.* Early 'single-shot' depositors had a centre that was about 40% of the product. This has been increased to 55% or

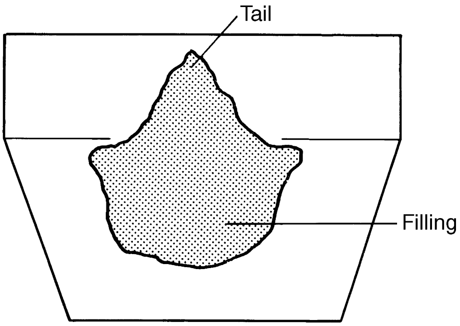

Figure 17.16 Diagram of 'tailing' in a moulded product.

more by the use of electronically controlled machines and one manufacturer claims that products with 80% have been produced (Awema, 2007) The shape is also important with more spherical egg-shaped products having higher centre proportions than moulded tablet shapes (Figure 17.14).

(5) *'Tailing'*. This is of course also a problem with shell-moulded products. This occurs when the centre, instead of stopping the flow completely, when the depositor closes, forms long 'tails' or 'strings' due to its elastic or gummy nature. These form a passage through the chocolate (Figure 17.16), which often results in the centre leaking out of the sweets. This is a major cause of rework with soft caramels, syrups and jellies.

17.6.4 Key control parameters

Jeffery (1990) gave the following parameters as being key to obtaining satisfactory results from a 'single-shot' system:

(1) Accurate *timing* of both chocolate and centre deposits, which must be independent of each other.
(2) Accurate control of depositor piston or pump *speeds*, independent of depositing rate, to control the velocity of the fluid through the nozzle.
(3) Accurate *valves* to stop the depositors and obtain the material from the feed hoppers (often rotary valves are used).
(4) A controlled 'suck-back' to minimize 'tailing'.
(5) *Temperature* control of centre and chocolate to within +0.1°C (+0.4°F).
(6) Accurate *weight* control of both components.
(7) Accurate *location* of the deposit in the mould. Otherwise the chocolate 'skin' may distort leading to weak spots.
(8) Good *design* of nozzle assembly.
(9) Correct *temper viscosity*. Both temper and viscosity need to be consistently well controlled. (Use of accurate viscometers and tempermeters is strongly recommended.)

(10) *Shakers* should have a length, amplitude and frequency which is independent of the product throughput, so that the plant conditions can be optimized.

(11) A *cooling time* of at least 40 min is normally required to avoid cracking of the chocolate.

(12) The *mould shape* is particularly important with blocks or tablets, where cooling stresses on the product must be minimized to prevent cracking. An 'egg' shape is almost ideal for this technique.

17.7 Aeration of chocolate

17.7.1 Types of aeration

Aerated chocolate has a lower density than normal chocolate, as some of the solid material and fat is replaced by a gas. This gives the consumer what appears to be a larger product at the same weight and usually a softer texture and melting sensation. It does not reduce the calorific value, as this is measured in calories per gram and is therefore the same whether or not there is air inside it.

There are four very different types of products that have been produced over the years (Jeffery, 1989). The most common is where the individual bubbles within the chocolate are clearly visible and have a mean diameter within the range of about 0.05–3 mm (0.002–0.1 in.). The normal density of chocolate is 1.3 g/cm^3, but due to the presence of the bubbles aerated chocolate tablets are produced with densities of 0.4–0.8 g/cm^3. This can be produced under vacuum (Section 17.7.2) or by beating in gas under high pressure (Section 17.7.3). The first product on the market was Rowntree's Aero® in 1935, which is currently still manufactured by Nestlé. Most of these products are produced by first making a shell either by traditional shell moulding (Chapter 14) or by cold forming (Chapter 15). The aerated centre is then deposited and allowed to set, before further liquid chocolate is poured into the mould to give a smooth back.

It is possible to produce very fine bubbles, so that they are not clearly visible to the naked eye. This is sometimes known as micro-aeration and can produce densities as low as 0.7 g/cm^3. At these densities it produces a quicker melt and creamier texture. The main application is for moulded chocolate biscuits, where it is able to reduce the percentage by weight of chocolate on the final product.

Another type of aeration is where continuous tubes of air run within the chocolate. These can be produced by extruding semi-set or solid chocolate as described in Section 17.5.4. An example of this type of product was marketed by Cadbury under the name of Spira®.

In normal chocolate the fat is the continuous phase which binds it all together (see Chapter 10, Figure 10.13), but certain aerated products are held together by the solid particles, in particular the sugar, forming a continuous skeleton. This also makes it possible to make very low fat products. The air bubbles are irregular and this type of product does not melt with heat like normal chocolate. It can however have a very low density for example 0.2 g/cm^3 and it dissolves rapidly in the mouth, releasing a chocolate flavour. It tends to have a whitish appearance and two methods of manufacture have been described, both of which are based on evaporating water from chocolate ingredients (Section 17.7.4).

17.7.2 Vacuum aeration

When liquid chocolate is placed in a vacuum, it will rise into a foam. If this is then cooled and the fat allowed to set, it will retain its structure. Sometimes additional gas, usually carbon dioxide, is mixed into the chocolate before the vacuum is applied. The size and shape of the bubbles can be very variable (see Figure 17.17) as they are affected by many factors including the chocolate viscosity, the vacuum intensity, emulsifier type and the rate of set of the chocolate (Haedelt *et al.*, 2005). It is very easy to incorporate other large ingredients such as nuts and nougat within the aerated product. Vacuum systems however tend to be difficult to maintain in a hygienic condition and often need a relatively high labour rate to operate, so high-pressure aeration systems tend to be more widely used.

17.7.3 High-pressure aeration systems

These systems incorporate gas into tempered liquid chocolate under high pressure. Some of the gas dissolves and any remaining gas is dispersed

Figure 17.17 Different sizes of bubbles in aerated chocolate. See Plate 18 for the colour image.

as fine bubbles using a high-speed beater. The latter is important to the system as if it generates too much heat it will destroy the chocolate temper. The pressure will also affect the product bubble size, as it is the release of this pressurized chocolate into normal atmospheric pressure that causes it to froth and form the bubble structure. Special depositors are needed to feed the chocolate into moulded shells or to extrude it as a continuous sheet. There are several patents for these depositors, but as with single-shot systems, it is very difficult for large pieces of other ingredients to be added.

The type of gas that is used is very important. For visible bubbles carbon dioxide is often used although nitrous oxide is said by some workers to give a more intense cocoa flavour and a different texture (Murphy, 2005). If nitrogen is used however only very fine bubbles are formed and micro-aerated products are produced. This difference is said to be due to the different solubilities of the individual gases in chocolate.

17.7.4 Water evaporation methods

The earliest description of a process to make this type of product was in a Cadbury Patent (1975) and resembles one of the crumb-making processes described in Chapter 5. Sugar is dissolved in water before being emulsified with cocoa liquor and milk solids. The mixture is then concentrated to approximately 10–12% in a scraped vacuum evaporator. The resulting paste is dried to less than 2% water in a continuous vacuum band drier. This type of aerated 'chocolate' was able to be made with a low fat content, which did not meet the regulations to allow it to be called chocolate. It has a very low density (0.1–0.3 g/cm^3) and is able to be cut into pieces or granulated for use as inclusions in other products such as ice-cream or cakes.

An alternative way of producing this type of product is described in Nestlé (1999) patent with a higher fat version in a Meiji patent (Meiji Selk Kaisha Ltd, 2001) and was said to be used to produce a product called Poff®, which was sold on the Japanese market (Figure 17.18). The process involved emulsifying water with liquid chocolate before solidifying it into sheets or the shape of the product. This was then freeze dried to remove the water. The space previously occupied by the water is filled by air forming a low-density aerated chocolate. This too can be cut or granulated if required.

Conclusions

Many new machines are being developed for both chocolate making and use. For chocolate making the main aim of most of these appears to be to shorten the processing time, whilst retaining the same taste characteristics of the final product and also matching or improving upon its viscosity parameters.

There have been many developments in the chocolate usage area; several based on old ideas that have become more practical due to modern

Figure 17.18 Light aerated chocolate from Japan.

engineering and control developments. Those described in the chapter have shown how chocolate can be produced in new shapes, such as meshes, or how to aerate it to make a low-density product.

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Chapter 18

CHOCOLATE REWORK

E. Minson

18.1 Introduction

Rework is a fact of life for manufacturers of all food products and this includes those handling chocolate and confectionery (compound) coatings.

Almost equally universal is the policy that 'we should create no rework'. This lofty goal is admirable, but certainly not practical in everyday operations. Indeed, the very nature of chocolate processing and handling inevitably results in the generation of rework. As machinery making fat-based coatings should definitely not be cleaned out with water containing solutions (see Chapter 23), product changeovers and 'cleaning' are often accompanied by the generation of significant quantities of rework.

18.2 Rework

Rework can be minimized by techniques including:

- proper order of processing,
- appropriate equipment layout and installation,
- evaluation of and training in proper processing procedures,
- selection of suitable quality raw ingredients.

Rework generation can often be minimized by processing products in the right order. It is relatively easy to go from a white coating base to a darker chocolate, but difficult to go in the other direction without the generation of significant rework quantities in the cleaning stage.

Proper equipment layout can often assist in minimizing rework when multiple products are being processed. The investment in extra piping or efficient pigging systems (see Chapter 11), for example, can help maintain the separation of different coatings and fats. This means that less clean-out material may be produced minimizing this additional source of rework. In addition, finished products contain less cross contamination and are therefore of a higher quality.

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A thorough determination of proper process procedures, followed by the training of employees to ensure their implementation, is vital in assuring that finished products are up to the standard and not destined for the rework bins. The consistent use of suitable raw materials, with predetermined quality levels, is also an important factor here.

Once rework is generated, however, it is very necessary to understand where the rework can be best utilized. Well thought out procedures, on how to reclaim and use the rework, should be determined for all sectors of the production facility. Adequate pre-planning may not be possible, however. Rework is not always predictable and one cannot invariably make good advance decisions on its possible use.

There is one thing that it is essential for all manufacturers to take into account, i.e. the maximum permitted usage levels of rework MUST be carefully determined. These maximum levels must then be monitored and strictly enforced.

18.3 Constraints

Many constraints limit the possible utilization of rework. These include:

- legal,
- functional,
- flavour,
- hygiene,
- quality control (including lot tracking), and
- allergens.

Legal and regulatory issues largely involve the labelling of the finished product into which the rework is incorporated. First, one must be sure that the rework ingredients can be legally used according to the laws of the country where the final product (now containing the rework) is sold (see Chapter 25).

A major issue is assuring that the final product's ingredient statement or declaration includes all the constituents of the rework. This is vital, as greater emphasis is now being placed on full label disclosure of all ingredients, including those used at trace levels. Nowhere is the issue more acute as with allergenic constituents. Many individuals are sensitive to a wide variety of proteins. Their responses to extremely low levels of these proteins can be life threatening. Their only defence is one of avoidance. It is therefore vital that all rework ingredients appear on the final, finished product label declaration for example this product may contain nuts.

Legislation has been enacted in many countries requiring special identification of allergens. If any allergens can be carried in with rework, it is mandatory that the allergen be highlighted in accordance with the specific national regulation. However, while a manufacturer needs to label if there is any possibility of introducing an allergen via rework, they must also be careful not to label if the allergen will not be present. Otherwise, there will be little available for the person with allergies to eat. Manufacturers should consider moving their allergen containing products (and rework) to separate, specialized facilities, ensuring their other products are not exposed to allergens.

Mandatory nutrition labelling has also become the norm in many countries. Although some deviation from stated values is permitted, to allow for differences in analytical methods as well as raw material variations, improper usage of rework could result in values which breach the regulatory standard.

Many companies have a 'like into like' procedure for rework. Although this will help control the inadvertent introduction of improper ingredients, it is by no means enough to entirely avoid the addition of undeclared components. A thorough review of each lot of rework must be undertaken to ensure the ingredient label of the finished product is not compromised.

Additionally, many countries have standards of identity for finished goods. These rules commonly dictate mandatory ingredient levels, as well as prohibiting the presence of certain components. Decision on the use of rework batches must take into account any compositional requirements for the finished product.

The maintenance of functionality in the finished product is of utmost importance and it is vital that any rework ingredients do not interfere with its processing or textural characteristics. Perhaps the biggest number of problems arise when rework alters the functional properties of the fat base. Incompatible fats in rework could render a chocolate or coating susceptible to poor texture, fat bloom, and inconsistent processing temperatures (see Chapter 19).

Flavour is always critical for the manufacturer of any food item. Variability in flavour often occurs due to the natural deviations within the basic raw materials. The use of rework can exacerbate the already complicated difficulty of maintaining a consistent flavour profile. The ability of the general public to detect changes to a product's flavour should never be underestimated.

Hygiene is also a very important issue (see Chapter 23), and the use of rework can greatly increase the risk from microbiological and other contamination. First of all, rework is subjected to extra handling, which in itself increases the opportunity for contamination. Rework can often be left in storage for extended periods of time (while it awaits the right 'home' or until enough has been produced to be worthwhile reprocessing). The longer the period the bigger the risk of infestation from insects.

The age of the chocolate rework needs to be carefully monitored. If the material is held too long and deterioration has occurred, this will have a negative impact on the flavour and shelf-life of the recipient product. This is especially true when the rework's fat has degraded (a problem particularly with many compound coatings which may go soapy/rancid).

As chocolate products are very sensitive to microbiological contamination (De Luka, 1996), extra care is vital. In addition, during storage, rework (as with any ingredient) can be subjected to insect and rodent infestation. It must therefore be stored in proper sealed containers. Rework must be treated with the extra care afforded to an ingredient and not like a scrap/waste material.

18.4 Economics

Chocolate and related ingredients are often among the most expensive of the ingredients in a confectionery or bakery item. Accordingly, rework containing chocolate must be wisely used. Economically, the best solution is one where chocolate or coating rework goes back into itself.

Whenever possible, it is desirable to separate the chocolate components from any other ingredients that have already been combined with them. This may be as simple as remelting the product and physically sieving out the other components. Caution needs to be exercised, when using chocolate rework, that any fat containing inclusions have not already released excess quantities of the 'foreign' fat into the chocolate. The consequence could be bloom, tempering problems, poor mould release, and fat bloom (Rittenberg, 1996).

In addition, the effective separation of the chocolate from other components is often difficult. For these processes to be economically viable, a large pool of rework is necessary (Beckett, 1990). This author described several machines which could be useful in recovering chocolate from finished confections and baked goods. Many food manufactures have invented their own devices to carry out this separation into one of the three channels illustrated in Figure 18.1.

For a hard centred good (such as a cookie or cracker), it is firstly important to eliminate any loose debris. This is followed by a mild heating process and then a blower to force the now liquefied coating from the surface of the reworked product. Temperatures must be moderated to inhibit heat damage to the coating (recommended temperatures are under 50°C (122°F)).

Beckett further noted a process for recovery of chocolate from soft centred confections. This involves dissolving of the centre with water, followed by drying of the chocolate. In this process, cool temperatures are maintained to keep the fat of the chocolate in a solid form. Water is then used to dissolve any non-coating constituents. It should be noted that the process of moisture elimination from chocolate can be quite difficult.

Alternately, the chocolate and other ingredient combinations may be recycled together into an appropriate portion of the processed product. Careful selection of the best use for this type of rework requires extensive knowledge of the finished goods' processes and where the rework can be used most advantageously (with the maximum economic value as well as the least change in product quality).

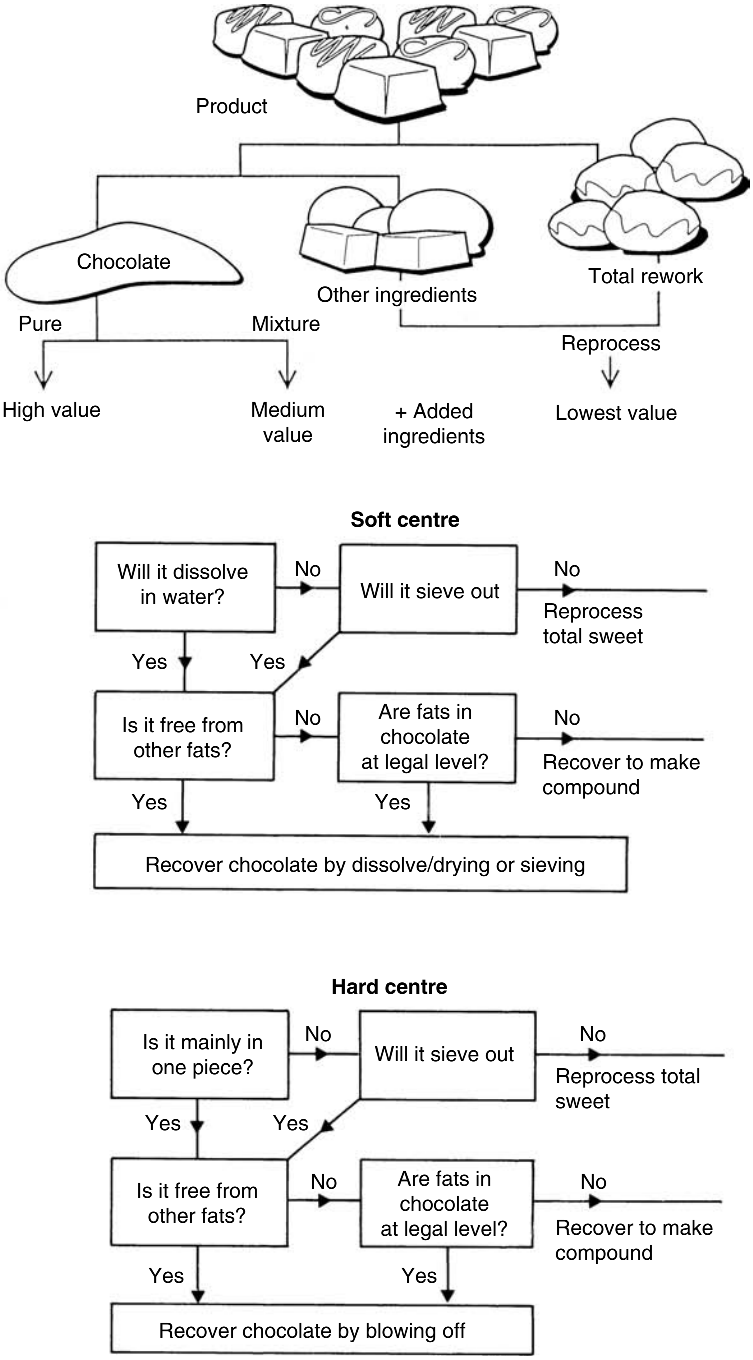

Figure 18.1 Schematic diagram showing the different approaches to processing rework (Beckett, 1990).

Conclusions

A final word of warning is appropriate. When in doubt, stop! If you have not already considered all the pitfalls associated with the use of rework and planned around them, stop! Nothing can be worse than ruining a good batch of product due to the injudicious addition of rework. Don't let a little rework leave you with a lot of rework.

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Chapter 19

VEGETABLE FATS

G. Talbot

19.1 Types of vegetable fat

Apart from cocoa butter, which is itself a vegetable fat, other vegetable fats also have a widespread use in chocolate and coatings. In this chapter we will examine three groups of vegetable fats:

(1) Cocoa butter equivalents.
(2) Lauric cocoa butter substitutes (fats containing lauric acid, e.g. from palm kernel or coconut).
(3) Non-lauric cocoa butter replacers.

Nomenclature in this area is often confusing with the terms 'equivalents', 'alternatives', 'substitutes' and 'replacers' being used almost interchangeably. The following convention for nomenclature will be used in this chapter:

- *Cocoa butter alternatives* (CBAs) cover all those vegetable fats which can be used to replace cocoa butter in chocolate and coatings (sometimes called 'couvertures' or compound coatings, see Chapter 25). They can be sub-divided into:
  - *Cocoa butter equivalents* (CBEs) which are vegetable fats with similar chemical and physical characteristics to cocoa butter and can hence be used interchangeably with cocoa butter in any recipe.
  - *Cocoa butter replacers* (CBRs) which are vegetable fats of a non-lauric origin with similar physical, but not chemical characteristics to cocoa butter and which can be used to replace most of the cocoa butter in coating applications, and
  - *Cocoa butter substitutes* (CBSs) which are vegetable fats of a lauric origin with similar physical, but not chemical characteristics to cocoa butter and which can be used to replace almost all of the cocoa butter in coating applications.

In some texts CBRs are referred to as non-lauric CBRs and CBSs are referred to as lauric CBRs.

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19.2 Fat properties

The properties of a fat can be described in terms of its chemical composition, its physical nature and its organoleptic qualities. All edible fats are comprised of triglycerides as illustrated in Figure 19.1, where the chemical structure of the triglyceride POSt, a major constituent of cocoa butter, is diagrammatically represented.

The triglyceride consists of a backbone of glycerol esterified with three fatty acids. In the diagram, the fatty acids are palmitic (P) at the 1-position, oleic (O) at the 2-position and stearic (St) at the 3-position.

The type of acid and its position in the triglyceride molecule is important and both are designated in this shorthand form of triglyceride nomenclature, POSt being different to PStO, although constituent acids in both of these triglycerides would be one-third palmitic, one-third oleic and one-third stearic. The triglyceride POSt belongs to the group of triglycerides that are called symmetrical mono-unsaturated and are often referred to as the SOS triglycerides (where S refers to all saturated acids). These contribute around 80% of the triglycerides in cocoa butter (see also Chapter 12).

All fats comprise mixtures of triglycerides and the fatty acid composition of a fat is therefore the sum total of the fatty acids contained in each of the constituent triglycerides. The composition is conveniently determined by gas liquid chromatography (GLC, Chapter 22) of the fatty acid methyl esters (FAME). The triglyceride groups (e.g. SOS) produced by the positional distribution of fatty acids on the glycerol backbone can be measured by high-performance liquid chromatography (HPLC) of the triglycerides.

The melting behaviour of a fat is critical to its behaviour in chocolate formulations. This characteristic is best measured by determination of the content of solid fat at a particular temperature. Nowadays, this is determined by nuclear magnetic resonance (NMR), which is a direct measure of the level of solid fat in a sample (Chapter 22). The value obtained is called the N_t-value, representing the amount of solid fat (N) at temperature t °C. Figure 19.2 illustrates the N_t curve of cocoa butter and the interpretation of N_t curves is also described in this figure.

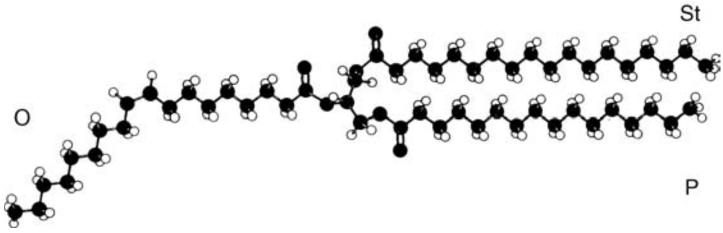

Figure 19.1 Structure of triglycerides. Nominally it is the POSt molecule in the β-form with all carbon zigzags similarly oriented and lying approximately in the plane of the molecule. Reprinted with the permission of Loders Croklaan.

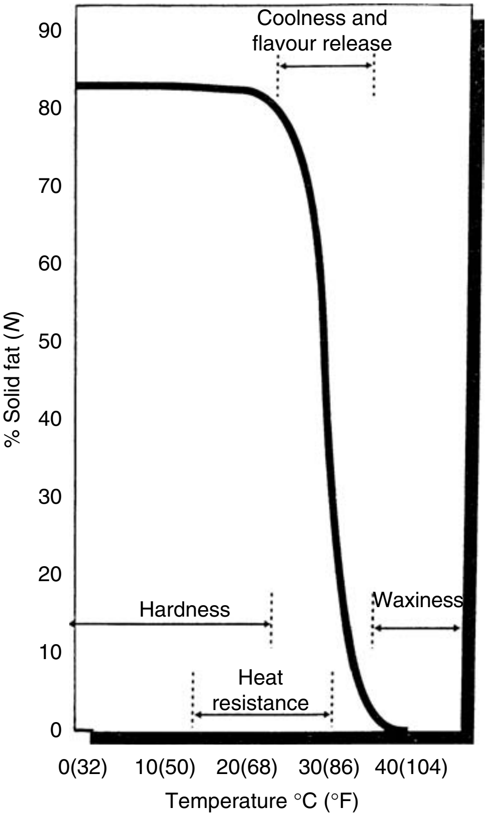

Figure 19.2 Solid fat content of cocoa butter by NMR. Reprinted with the permission of Loders Croklaan. Interpretation of an N_t curve: A graph of *N* values can be plotted against temperature (*t*) showing the amount of solids on the vertical axis and the temperature at which these solids exist on the horizontal axis. The curve formed by joining the N_t points accurately details the physical properties of a given fat:

- A high *N* value up to 25°C (77°F) means that the fat is hard and brittle at room temperature.
- Heat resistance is related to the percentage of solid fat still present at temperatures of 25–30°C (77–86°F).
- A steep curve means that the hard fat becomes liquid after a comparatively small rise in temperature. If this happens some degrees below body temperature the quick melt-down of the fat results in a cooling sensation.
- Fats with significant solid contents above body temperature 37°C (98.4°F) have a waxy mouthfeel.

N_t-values, or solid fat content data, can also be used to illustrate the formation of eutectics. In fats this occurs when two incompatible fats are mixed together. The result is a blend in which the melting point is lower than that of either of the components, resulting in a softer, usually unsatisfactory product.

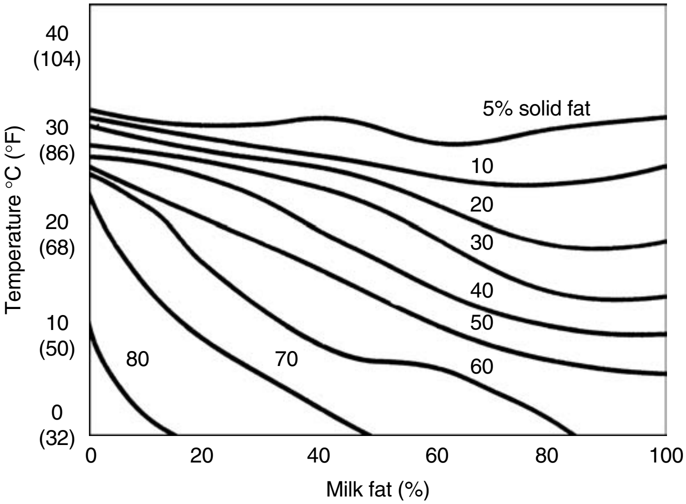

Figure 19.3 Melting profiles of fat blends of cocoa butter and milk fat. Reprinted with the permission of Loders Croklaan.

This is illustrated in Figure 19.3 which shows the melting profiles of mixtures of cocoa butter and milk fat. Although milk fat is a common component of chocolate its triglycerides are dissimilar to those in cocoa butter and the two fats are essentially incompatible. The softening caused by the resulting eutectic composition has, however, long been tolerated and indeed considered acceptable because of the organoleptic properties which milk fat imparts to chocolate.

The melting properties of a fat may also be influenced by the phenomenon of polymorphism. This is particularly the case with cocoa butter and related fats. Substances are polymorphic when they have more than one crystal form, the different forms of crystal melting at different temperatures. Chocolate must be tempered to develop the correct crystal form. The correct polymorphic form must also be established by tempering before NMR measurements are taken. Polymorphism is considered in more detail in Chapter 12.

19.3 Cocoa butter

Before considering both the organic and physical chemistry of CBAs, it is necessary to understand the organic and physical chemistry of cocoa butter itself.

In terms of its fatty acid composition (Table 19.1), cocoa butter is a relatively simple fat. Three fatty acids, palmitic, stearic and oleic, generally account for over 95% of the fatty acids in cocoa butter. Of the remaining acids, linoleic acid is present at the highest level.

Table 19.1 Typical fatty acid composition of West African cocoa butter. Adapted from Gunstone *et al.* (1986).

Myristic acid	C14:0	0.1%
Palmitic acid	C16:0	26.0%
Palmitoleic acid	C16:1	0.3%
Stearic acid	C18:0	34.4%
Oleic acid	C18:1	34.8%
Linoleic acid	C18:2	3.0%
Linolenic acid	C18:3	0.2%
Arachidic acid	C20:0	1.0%
Behenic acid	C22:0	0.2%

Table 19.2 Triglyceride composition of cocoa butters. Reprinted with the permission of Loders Croklaan.

	Brazil	Ghana	Malaysia
SSS	1.0	1.4	2.3
SOS	63.7	76.8	84.0
SSO	0.5	0.4	0.5
SLiS	8.9	6.9	6.8
SOO	17.9	8.4	5.1
OOO	8.0	6.1	1.3

S = saturated fatty acids (mainly palmitic and stearic); O = oleic acid; Li = linoleic acid.

Not only does this ‘simple’ fatty acid composition translate into an equally ‘simple’ triglyceride composition, it also translates into a very specific triglyceride composition (Table 19.2). The major group of triglycerides is the SOS group, composed predominantly of POP, POSt and StOSt (P = palmitic O = oleic, St = stearic acids). Since each of these triglycerides is obviously an individual chemical entity with a particular melting point, the combination of such chemically similar triglycerides in cocoa butter imparts the sharp melting profile for which cocoa butter is prized.

There are, however, differences between cocoa butter of different origins (as can be seen in Table 19.2), especially in the SOS/SOO ratio. In very broad terms, SOS is a group of triglycerides which are solid at room temperature, whereas SOO is a group of triglycerides which are more liquid at room temperature. Thus Brazilian cocoa butter with a high level of SOO is less solid than Ghanaian cocoa butter, which in turn is less solid than Malaysian cocoa butter. These qualitative comments can be seen in a more quantitative fashion in Table 19.3 which shows the solid fat contents of these three cocoa butters as measured by pulse NMR.

Table 19.3 Solid fat contents[a] (by pNMR) of cocoa butters. Reprinted with the permission of Loders Croklaan.

Temperature				
°C	°F	Brazil	Ghana	Malaysia
20	(68)	66.3	76.2	81.2
25	(77)	60.1	70.4	76.2
30	(86)	36.9	45.1	54.8
32.5	(90)	6.6	13.3	19.7
35	(95)	2.0	0.0	0.0

[a] Tempered at 26°C (79°F) for 40 h prior to solid fat content measurement.

19.4 Cocoa butter equivalents (CBEs)

19.4.1 Properties and production

Research into the chemical properties of cocoa butter in the 1950s led to the conclusion that its triglycerides had a unique structure, and the realization that, for the formulation of chocolate, any fat intended for use in blends with cocoa butter would need to have triglycerides of a similar structure.

Unlike all animal fats, some vegetable oils contained triglycerides of the appropriate structure. This made possible the production of specific fat fractions, which, when blended, had properties almost identical to those of cocoa butter itself.

A Unilever patent on the invention was filed in 1956, and CBEs were launched in the British market (Best *et al.*, 1956). They were immediately successful, and a partnership developed between the UK chocolate industry and Loders and Nucoline, the Unilever subsidiary specializing in the production and marketing of these new confectionery fats. At that time, and in fact until 1977, there was no official composition for chocolate in the United Kingdom, but the major manufacturers agreed to use a maximum of 5% cocoa butter equivalent (CBE) on the total weight of the chocolate.

Because of the successful use of CBEs in British chocolate their incorporation at a 5% level extended into other EU countries, first into Denmark and Ireland and then to Sweden, Austria, Finland and Portugal. Their use was permitted under national regulations but it took until August 2003 for there to be an EU-defined set of chocolate regulations (see Chapter 25).

Purely from a functional point of view a cocoa butter equivalent must meet certain requirements in order to perform satisfactorily in chocolate:

(1) It must have a melting range which reflects that of cocoa butter.
(2) The fat should have a fatty acid and triglyceride composition close to that of cocoa butter.
(3) The fat must be compatible with cocoa butter.

(4) The fat should allow processing of chocolate products in an identical manner to that of cocoa butter-based products.
(5) The fat should crystallize in the same polymorphic form as cocoa butter, that is in the beta modification.
(6) The appearance and bloom free shelf-life of chocolate products containing CBEs should be at least identical to products based on cocoa butter alone.
(7) The fat should have good flavour stability.

To these the 2003 EU regulations (EU Directive 2000/36/EC, 2000) added some further requirements. Prior to 2003 any vegetable oil could be used provided it met the above functional requirements. However, the EU regulations specifically defined six oils which could be used in the vegetable fat part of the chocolate. Any oils not on this list could not be used in EU chocolate. The list comprised the following six oils:

Illipe, Borneo tallow or Tengkawang	*Shorea* spp.
Palm oil	*Elaeis guineensis* *Elaeis olifera*
Sal	*Shorea robusta*
Shea	*Butyrospermum parkii*
Kokum gurgi	*Garcinia indica*
Mango kernel	*Mangifera indica*

There was also permission given for the use of coconut oil in chocolate to be used as a coating on ice cream.

Further restrictions were placed on the oil in terms of the type of processing which the vegetable fat was allowed to undergo, limiting this to fractionation and refining. Fractionation is a process of crystallization and separation in which the SOS triglycerides in these oils can be concentrated to a level similar to that found in cocoa butter. This restriction meant that enzymic rearrangement, which could be used to produce CBEs from oils grown in temperate climates, was specifically excluded. Although only enzymic rearrangement is specifically excluded, other processes, such as hydrogenation, are also excluded because they are not on the permitted list.

Finally, the vegetable fats must be miscible in any proportion with cocoa butter and be compatible with its physical properties (melting point and crystallization temperatures, melting rate, need for tempering etc.). Essentially these physico-chemical requirements are much the same as many of those in the list of requirements for a CBE given earlier.

It should be stressed that these requirements only apply to chocolate sold within the European Union. Countries outside the EU have their own national regulations. Some countries, such as the United States (U.S., 2006) do not permit the use of added vegetable fat in chocolate but do allow its use in 'chocolate and vegetable fat coatings'. Some other countries allow the use of vegetable fats in chocolate without many of the restrictions which the EU place on both its composition and level of use. Insofar as there is any internationally accepted standard for the use of vegetable fats in chocolate the Codex Alimentarius standard STAN 87–1981 was revised in 2003 (Codex Standard for Chocolate and Chocolate Products, 2003) to permit the use of vegetable fats in chocolate up to a level of 5% of the finished product (after deduction of the total weight of any other added edible foodstuffs e.g. nuts and raisins). However, as legislation can change, it is advisable to check the legislation within any specific country before including vegetable fats in a chocolate composition.

Although individually none of the vegetable fats permitted within the EU have the same triglycerides in precisely the same proportions as in cocoa butter, they do contain some of the component glycerides. For example palm oil contains POP, and this can be separated from the other glycerides in palm oil by fractionation. Shea and sal oils contain StOSt, which can also be isolated by fractionation. Moreover illipe butter contains mainly POSt with some StOSt. Careful fractionation and processing of appropriate oils, and skilled blending of the glyceride mixtures produced in this way, make it possible to manufacture CBE fats with properties very close to those of cocoa butter. This is illustrated in Figure 19.4 where the plantation crop palm oil is used to produce a fat rich in the triglyceride POP, while non-cultivated seed oils such as shea, illipe and sal are used to produce fats rich in the triglycerides POSt and StOSt.

Table 19.4 lists the natural fats that can be used in CBE manufacture, together with the geographical origin of the respective crops, their triglyceride composition as well as some comments regarding their use.

The most commonly used oils are, however, palm, illipe and shea. Their suitability for use as CBEs in terms of containing high levels of POP, POSt

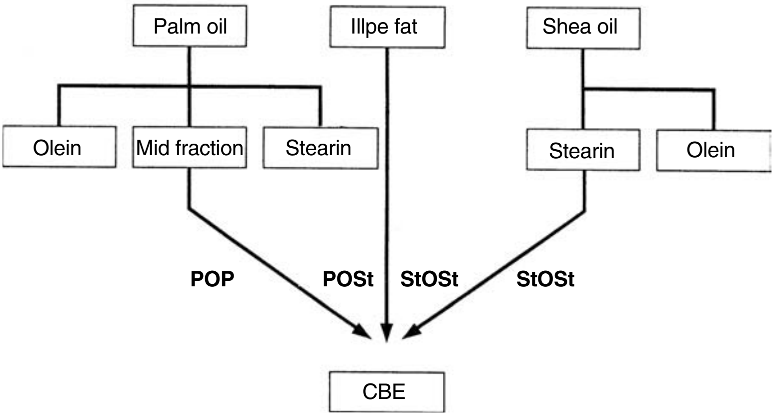

Figure 19.4 Process scheme for production of a CBE blend. Reprinted with the permission of Loders Croklaan.

Table 19.4 Natural fats used in CBE manufacture. Reprinted with the permission of Loders Croklaan.

		Triglyceride composition			
Fat	**Area of origin**	**POP**	**POSt**	**StOSt**	**Comments**
Palm (*Elaeis guineensis*)	Malaysia	H	M	L	Readily available
Illipe (*Shorea stenoptera*)	Borneo	L	H	H	Intermittent availability
Shea (*Butyrospermum parkii*)	W. Africa	L	M	H	Variable availability
Sal (*Shorea robusta*)	India	L	M	H	Variable quality
Mango kernel (*Mangifera indica*)	Tropics	L	L	H	Limited use, low yields
Kokum (*Garcinia indica*)	India	L	L	H	Low availability, variable quality

Table 19.5 Triglycerides of palmitic–stearic–oleic–rich fats. Adapted from Jurriens (1968).

Triglycerides	Cocoa butter	Palm oil	Illipe fat	Shea butter
No double bonds	2.2	8.5	3.1	3.7
One double bond				
MOP	0.9	1.2	–	–
MOSt	1.3	–	–	–
POP	12.0	24.1	6.6	0.5
POSt	34.8	7.0	34.3	6.4
StOSt	25.2	0.5	44.5	29.6
Total SOS	78.2	32.8	85.4	36.5
Total SSO	4.1	5.3	0.4	3.1
Two double bonds	16.0	35.0	9.0	38.7
Three double bonds	3.5	19.8	2.1	18.2
>Three double bonds	–	0.5	–	–

and StOSt can be seen from the detailed analysis carried out by Jurriens (1968) (Table 19.5).

Because the triglycerides used in CBEs are of the same type as those present in cocoa butter, blending the two fats together produces no adverse interactions either in terms of melting properties or in terms of polymorphism. This excellent compatibility between cocoa butter and CBEs can be shown in the form of an iso-solids diagram (Figure 19.5). This shows that cocoa butter and Coberine (a well-known CBE) are fully compatible over the complete range of compositions. No lowering of solid fat content at any

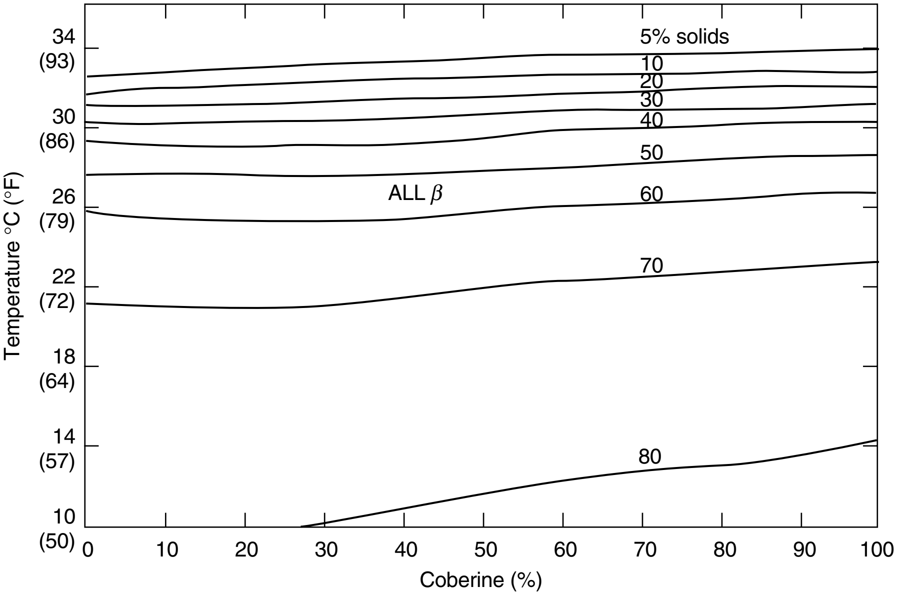

Figure 19.5 Iso-solids phase diagram for cocoa butter/Coberine (CBE) (from Gordon *et al.*, 1979). Reprinted with the permission of Loders Croklaan.

temperature is detected as one fat is added to the other. In addition, there is no indication of separate phases unique to one or other component. This complete compatibility allows, in theory, any amount of cocoa butter to be replaced by a CBE. Whilst this is true, in practice two types of product exist using CBEs. In some countries, as we have seen, up to 5% vegetable fat can be included in chocolate under the standards of identity of chocolate, that is where it is still permissible to call the product 'chocolate' (see Chapter 25). In addition, most countries will also permit much higher levels of inclusion of CBEs in place of cocoa butter, but in this case the product cannot be labelled 'chocolate'. These products have been given the name (within the oils and fats and confectionery industries) of supercoatings. Both uses will be considered in turn.

19.4.2 Chocolate containing 5% CBE

Typical chocolate recipes containing 5% CBE are shown in Table 19.6. Generally speaking, the production and processing of chocolate containing 5% CBE is the same as that required for CBE-free chocolate.

The main adjustments required in tempering chocolate as a result of formulation changes are those needed as a consequence of the inclusion of milk fat. Tempering temperatures should be decreased by about 2°C (3.5°F) when 20% milk fat is included (in the fat phase of chocolate).

Table 19.6 Typical recipes for chocolate containing CBE. Reprinted with the permission of Loders Croklaan.

	Milk	Dark
Cocoa mass	10	40
Cocoa butter	17	7
CBE	5	5
Full cream milk powder	24	–
Sugar	44	48
Fat composition		
Cocoa butter	22.3	28.2
CBE	5.0	5.0
Milk fat	6.5	–
Total	33.8	33.2
Expressed as % of fat phase		
Cocoa butter	66.0	85.0
CBE	14.8	15.0
Milk fat	19.2	–
Total	100.0	100.0

CBEs like Coberine will tolerate the inclusion of this level of milk fat without any need to significantly alter processing conditions. They will also tolerate somewhat higher levels of milk fat, but the tempering temperature would then need to be decreased (as indeed it would if higher levels of milk fat were used with cocoa butter alone).

By varying the relative levels of the palm, shea and illipe contents of a CBE, different properties can be conferred on the CBE in terms of melting profile, milk fat tolerance and tolerance to softer forms of cocoa butter. It is also possible to produce a harder CBE which would not only be equivalent in its compatibility, but would also improve the hardness of some of the softer qualities of cocoa butter. Such CBEs are known as CBIs (or cocoa butter improvers). It is also possible to modify the type of CBE used in chocolate or supercoating to give improvements in tempering response, or to the viscosity of the chocolate after temper.

19.4.3 Supercoating

Supercoatings are coatings which are prepared using real chocolate recipes, where all the added cocoa butter is replaced by a CBE. It was shown earlier that CBEs are compatible with cocoa butter across the whole formulation range and thus supercoatings are equivalent to chocolate in most respects, but must not be labelled as such. For example, CBEs like Coberine can be used to replace cocoa butter in all types of formulation, including plain and milk recipes. If desired, the cocoa mass can be replaced by cocoa powder

Table 19.7 Typical supercoating recipes. Reprinted with the permission of Loders Croklaan.

	High milk	Low milk	Dark
Cocoa mass	10	10	40
CBE	22	24	12
Sugar	46	46	48
Full cream milk powder	22	10	–
Skimmed milk powder	–	10	–
Fat composition			
Cocoa butter	5.3	5.3	21.2
CBE	22 0	24.0	12.0
Milk fat	5.9	2.7	–
Total	33.2	32.0	33.2
As % of fat phase			
Cocoa butter	16.0	16.6	63.9
CBE	66.3	75.0	36.1
Milk fat	17.7	8.4	–
Total	100.0	100.0	100.0

and CBE. CBEs such as Coberine have an excellent tolerance to quite high levels of milk fat in the chocolate without undue softening occurring. Other CBEs with a lower tolerance to milk fat have been developed to replace cocoa butter in chocolate and supercoatings where the milk fat content is less than 10% of the fat phase. Typical recipes for supercoatings are shown in Table 19.7.

As a guide to tempering conditions, a coating based on Coberine may have to be tempered at temperatures about 0.5°C (1°F) lower than for the corresponding cocoa butter chocolate. However, these figures also depend considerably on the actual recipe used and the tempering equipment, as well as the quality of the cocoa butter. Because of the close chemical similarity of CBEs to cocoa butter, supercoatings also require the same cooling regime. In addition, the equipment used requires no special cleaning when changing from supercoating to cocoa butter chocolate.

19.5 Lauric cocoa butter substitutes

Lauric cocoa butter substitutes CBSs are fully refined fats produced from palm kernel and/or coconut oil by means of fractionation and hydrogenation. In this way fats can be produced which have characteristics in terms of hardness, mouthfeel and flavour release similar to those of cocoa butter.

These fats, however, contain a high level of lauric fatty acids and have a completely different triglyceride composition to cocoa butter. This means

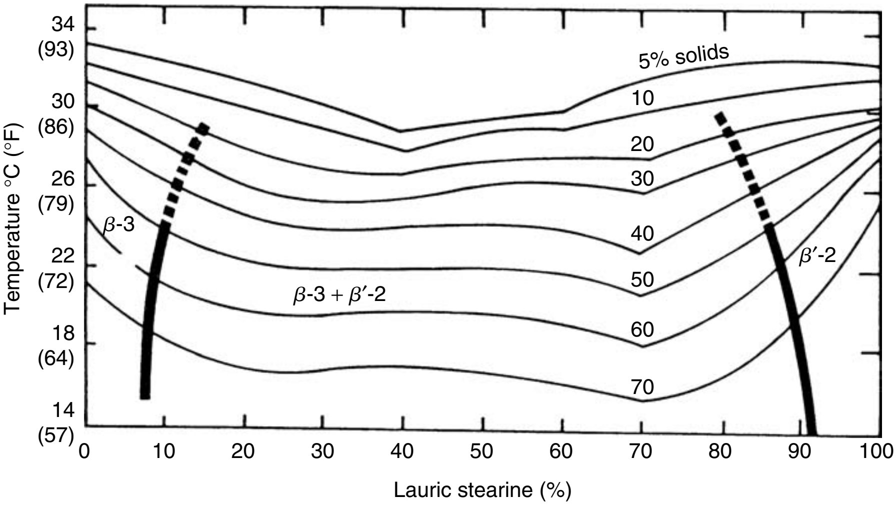

Figure 19.6 Iso-solids phase diagram for cocoa butter/lauric CBS (from Gordon *et al.*, 1979). Reprinted with the permission of Loders Croklaan.

that there is a considerable degree of incompatibility between lauric CBSs and cocoa butter. An iso-solids phase diagram of mixtures of cocoa butter and a lauric CBS is shown in Figure 19.6. This confirms the occurrence of mixed crystals over a wide range and indicates a strong depression of melting behaviour in comparison to the mixing of CBEs and cocoa butter. A narrow band of 'permissible' compositions is seen at each end of the diagram. Cocoa butter will retain its *β*-3 crystal form until about 5% lauric CBS is present. Equally a lauric CBS will retain its *β*′-2 crystal form until about 5% cocoa butter is present. Beyond these tight limits mixed *β*-3 and *β*′-2 crystals are formed which will result in processing problems, softer products and a substantial risk of fat bloom. (Crystal forms such as *β*-3 and *β*′-2 are described in more detail in Chapter 12.) Thus, about 5% cocoa butter is the safe maximum level of addition to lauric CBSs. In practice this limits the cocoa inclusion in recipes based on lauric CBSs to low-fat cocoa powder or fat-free cocoa powder rather than cocoa mass. Thus typical formulations are shown in Table 19.8.

Tempering or any form of pre-crystallization is unnecessary for enrobing or moulding thin bars. Following deposition, or enrobing, a glossy surface and fine crystal structure is obtained with lauric CBS-based coatings by cooling them rapidly, preferably at 8–12°C (46–54°F) and applying a high windspeed (up to 7 m/s), but taking care to avoid water condensation at the exit of the tunnel (Chapter 14).

An important feature with coatings based on lauric CBSs is to control the water content and to avoid microbiological contamination of the product. Occasionally chocolate confections, which contain lauric fats, develop a

Table 19.8 Examples of some typical recipes using lauric CBSs. Reprinted with the permission of Loders Croklaan.

		Milk		
Ingredients (%)	**Dark**	**A**	**B**	**White**
Cocoa powder 10/12	14	5	5	–
Full cream milk powder	–	10	–	–
Skimmed milk powder	7	10	17.5	20
Lauric CBS	31	29	31.5	32
Sugar	48	46	46	48
Total fat content	32.5	32	32	32
Total cocoa solids	14	5	5	–
Fat-free cocoa solids	12.5	4.5	4.5	–

In all the recipes 0.4% of lecithin is added to the formulation. These recipes can be adjusted according to the application and raw material requirements.

soapy taste and as a result the product becomes unpalatable. In most cases the fat has been split by a lipase enzyme, following microbiological contamination. This soapy taste in compound chocolate based on a lauric CBS can only develop in the presence of lipase and sufficient water. Hence control of the water content and microbiological, particularly lipase, content of the product is of major importance.

19.5.1 Quality control

19.5.1.1 Control of the water content

Normal good quality raw materials, processed according to good manufacturing practice, yield compound chocolate with a water content that is too low to allow microbiological deterioration. Special attention should be paid to the cooling conditions during processing of the coating to avoid condensation of water on the product. Because chocolate is hygroscopic, finished products should be packed in airtight wrapping and stored below 60% relative humidity. (See Chapter 14 concerning cooling tunnels.)

19.5.1.2 Control of microbiological contamination

Generally speaking, most processed raw materials for the confectionery industry are safe to use and are delivered with good microbiological specifications and an absence of active lipase. Post contamination during production and storage can be avoided by following hygienic working practices (Chapter 23).

19.5.1.3 Shelf-life

Products can be produced from coconut and palm kernel oil by hydrogenation alone. A range of products can be produced which have increasing melting points and hardness. Melting profiles similar to cocoa butter can be achieved, but the harder grades of these types of product have a pronounced tail in the melting profile and the mouthfeel is correspondingly waxy. The fractionation process removes the triglycerides responsible for this tail and the fractionated lauric CBSs have significantly improved mouthfeel. The use of hardened lauric oils is identical to that of the fractionated lauric CBSs. They cannot be mixed with cocoa butter to any appreciable extent and the maximum 5% cocoa butter rule applies. Products made with fats that have not been fractionated have one further major drawback – that is the shelf-life of the coatings is only a few weeks compared with a few months for the corresponding fractionated lauric CBS formulation. This is because the products quickly lose their gloss, become dull and bloom due to crystal modifications which spoil the appearance of the products.

Trans fatty acids are being increasingly seen as undesirable components in food and these are produced by partial hydrogenation of vegetable fats. In the case of hydrogenated lauric CBSs the amount of trans fatty acid present is usually quite low. One reason for this is that the lauric fat is completely hydrogenated resulting in a fat which is >99% saturated and <1% trans. This mainly applies to lauric stearines. On those occasions where the oil is only partially hydrogenated the amount of unsaturation naturally present in coconut or palm kernel oil is such that the trans content will be less than 10%. The problem of trans fatty acids is more acute with non-lauric CBRs.

19.6 Non-lauric cocoa butter replacers

Non-lauric cocoa butter replacers CBRs are produced from non-lauric oils such as palm oil and soyabean oil by hydrogenation and fractionation. Although these CBRs contain palmitic, stearic and oleic acid, their arrangement within the triglycerides is more random and the structure differs considerably from cocoa butter. In addition, a high content of trans acid (elaidic acid) is present. Consequently, non-lauric CBRs have a limited compatibility with cocoa butter.

Figure 19.7 demonstrates the effect on melting properties of mixing non-lauric CBRs with cocoa butter. This diagram illustrates not only the formation of eutectics (extra softening due to incompatibility) but also the occurrence of mixed crystals in the critical central area which will provoke loss of gloss and fat bloom formation to the confectionery product. Only the outer areas on the left and right-hand side of the diagram give fat mixtures which are stable. We may add up to 7% of the hardened fat to cocoa butter, or we may allow up to approximately 25% cocoa butter in the fat phase of non-lauric fat-based coatings.

As with lauric CBSs the central, unstable region gives mixed crystals, softer products and a likelihood of fat bloom formation. However, the region of stability at the CBR-rich end of the diagram is much broader than with lauric CBSs indicating that non-lauric CBRs have a greater tolerance

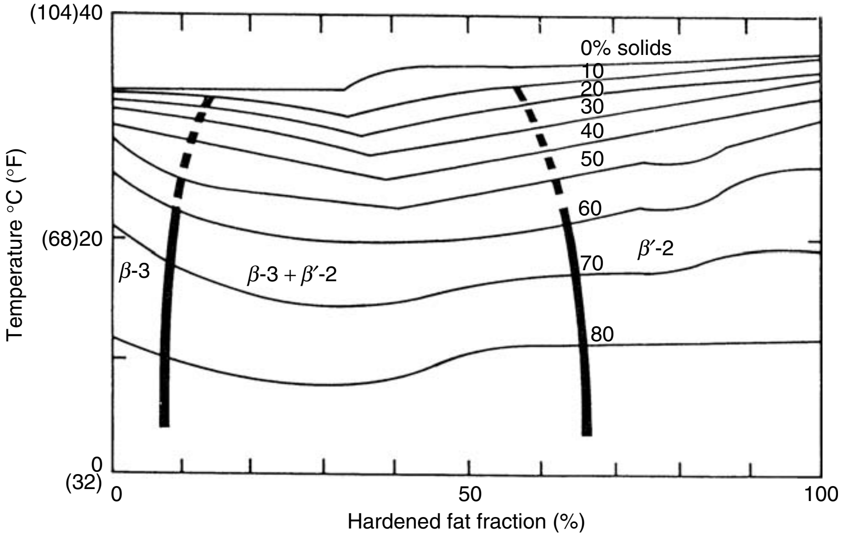

Figure 19.7 Iso-solids phase diagram for cocoa butter/non-lauric CBRs (from Gordon *et al.*, 1979). Reprinted with the permission of Loders Croklaan.

to cocoa butter. In practical terms, this means that cocoa mass can be used with non-lauric CBRs resulting in a much more 'rounded' cocoa flavour than can be achieved using lauric CBSs, where only low-fat cocoa powder is permissible. This allows typical recipes to be used such as those shown in Table 19.9.

The production of these non-lauric CBR-based coatings is similar to normal chocolate production, for example mixing, roll refining and conching. A Macintyre conche or a ball mill can also be used (Chapter 9). Following production of the coating the product is ready to be used immediately. No tempering is required and application temperatures for moulding, panning or enrobing may vary from 40°C to 48°C (104–118°F). This non-temper process allows for lower viscosity at the enrobing or depositing stations, which has advantages in certain applications. Non-lauric CBR-based coatings should be cooled under moderate to strong conditions, similar to those commonly applied for cocoa butter-based chocolate.

The problem of trans fatty acids has already been briefly referred to. The issue revolves around the effects which trans fatty acids have on blood cholesterol levels. Blood cholesterol is composed mainly of two types – HDL-cholesterol which is considered to be 'good' cholesterol and LDL-cholesterol which is considered to be 'bad' cholesterol. Trans fatty acids lower the 'good' HDL-cholesterol and raise the 'bad' LDL cholesterol. It is therefore now considered that consumption of trans fatty acids may be seen as a risk factor in cardiovascular disease. For this reason manufacturers are moving towards replacement of partially hydrogenated fats in their

Table 19.9 Examples of some typical recipes using non-lauric CBRs. Reprinted with the permission of Loders Croklaan.

	Dark		Milk		White	
Ingredients (%)	**A**	**B**	**A**	**B**	**A**	**B**
Cocoa mass	10	–	10	–	–	–
Cocoa powder 10/12	15	20	–	5	–	–
Full cream milk powder	–	–	6	–	20	–
Skimmed milk powder	–	–	12	17	5	20
Non-lauric CBR	28	33	28	34	30	35
Sugar	47	47	44	44	45	45
Total fat content	35	35	35	34.5	35	35
Total cocoa solids	25	20	10	5	–	–
Fat free cocoa solids	18	18	4.5	4.5	–	–

In all the recipes 0.4% of lecithin is added to the formulation. These recipes can be adjusted according to application and raw material requirements.
The non-lauric-CBR based coatings are given with a total fat content of 35%. This high percentage is normal for enrobing purposes, the process for which these products are mainly used.
The recipes containing cocoa mass and/or full cream milk powder are more suitable for countries with a moderate climate.

products. This does not necessarily mean that chocolate will be completely trans-free because there is a small amount (typically, 3–8%) of naturally occurring trans fatty acid in milk fat which will, of course, then be present in milk chocolate.

To address the whole issue of trans fatty acids in non-lauric CBRs oils and fats manufacturers have produced low-trans and, in at least one case, no-trans alternatives to their original high-trans CBRs.

19.7 New fats for chocolate and coatings

19.7.1 Fats to prevent chocolate bloom

Cocoa butter can exist in a number of different polymorphic forms (see Table 12.1, Chapter 12). When chocolate is properly tempered the cocoa butter will crystallize in form β_V. However, depending on the product's construction and the conditions under which it is stored, this cocoa butter can transform from form β_V to form β_{VI}. This polymorphic transformation is usually accompanied by the formation of fat bloom. The change from form β_V to form β_{VI} occurs more quickly at higher temperatures and is also accelerated by migration of soft oils (e.g. nut oils) from a filling into the chocolate.

Various vegetable fats were developed to inhibit this bloom formation. Initially they were intended for use as a vegetable fat at an inclusion level of 5% in chocolate. However, in most cases, the 2003 EU chocolate regulations prevented such use because they contained vegetable oils which were not one of the permitted six oils. The concept has, however, been further developed to take positive advantage of migration of fats from a filling into the chocolate coating. Such migration often results in bloom formation on the chocolate, but if one of these anti-bloom fats is incorporated as part of the filling, it will also migrate on storage with the softer filling fats (Talbot, 2006). As it migrates into the chocolate it gives the protection necessary to prevent bloom formation. Using the fat in this way also means that it is not restricted by local chocolate legislation, because it is not added directly into the chocolate.

19.7.2 Lower calorie fats

With the increasing development of lower calorie triglycerides systems, some chocolate manufacturers have used them to manufacture low-calorie confectionery. The two main products in this category are Caprenin™ and Salatrim (now marketed under the name Benefat™). Caprenin™ is a triglyceride produced by Proctor and Gamble, which contains caprylic (C8), capric (C10) and behenic (C22) fatty acids (Jones, 1992). It is claimed to have 5 calories per gram compared with 9 calories per gram for normal fats. The chain length of behenic acid is such that it is poorly absorbed by the body and thus has a lower calorific value than fatty acids such as palmitic and oleic acids; the shorter chain acids, caprylic and capric acids, are metabolized via a different metabolic pathway in the body, which means that they are closer to carbohydrates in this respect.

Salatrim or Benefat™ (Anon., 1996), marketed by Danisco, contains short and long fatty acid triglycerides and is also claimed to have a calorific content of about 5 calories per gram. The short-chain fatty acids are basically metabolized as though they were carbohydrates and therefore with a much lower calorific value than normal triglyceride systems. As with Caprenin™, the long-chain fatty acids from Benefat™ are less well-absorbed. Benefat™ has been used in some bakery coating systems, chocolate chips etc.

Summary

The scope for producing vegetable fats for use in chocolate and coatings with different melting profiles, crystallization characteristics, processing benefits etc., is essentially limitless. Vegetable fats can now be tailored for use both as CBEs (at the 5% level in chocolate) or as coating fats at higher levels of use which give improved viscosity characteristics, improved crystallization rates, enhanced fat bloom resistance, cool-eating sensations and a host of other processing and consumer benefits. Great strides forward have been made in confectionery fat technology, both in methods of production, and in the understanding of how the triglyceride composition of the vegetable fat relates to the processing characteristics and consumer perception of chocolates and coatings. Undoubtedly further developments will continue to be made in the future ensuring that the vegetable fat which, in many cases, controls the functionality of chocolates and coatings, keeps pace with the demands of both the chocolate manufacturer and consumer.

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Chapter 20

RECIPES

E.G. Wohlmuth

20.1 Chocolate tastes in different countries

20.1.1 History

If this chapter had been written 30 years ago, it would have been about 10 milk chocolate types, 5 dark versions and 10 vegetable fat coatings for the cake and ice cream industries. Today, the company the author worked for produces over 400 different recipes for the four different sectors of the confectionery industry:

(1) Chocolate confectionery
(2) Sugar confectionery
(3) Ice cream industry
(4) Bakery and baked or chilled goods.

Often there is a different flavour profile depending upon the sector of the industry and also a different flavour and viscosity profile, according to its use and global location. It is not only a question of cocoa solids and taste, but also of the claims that will be put on the final product. There are recipes for organic chocolate, Fair Trade, Kosher, chocolate and fillings without added sugar and many more. In addition there are those produced for special processing for example chocolate suitable for freezing, chocolate for panning and shell moulding, or for 'one shot' systems, etc.

20.1.2 Taste in different countries

20.1.2.1 UK

In the UK, the traditional milk caramelized 'chocolate crumb' flavour (Chapter 5) still predominates for milk chocolate tablets and cake coatings, but the Belgian mild and creamy taste is also liked and used in the chocolate confectionery industry. Dark chocolate has now a much higher total cocoa solids content than 10–15 years ago. White chocolate, traditionally

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a children's product, is now an acceptable product for adults, and most assortment boxes now have at least 25% white chocolates.

20.1.2.2 Belgium

Belgian chocolate is famous for its mild, full-milk flavour. This type of chocolate has now found favour all over the world and in many countries you will see products 'Made with Belgian Chocolate'. It is a sign of quality and consistency. White chocolate produced in Belgium is also liked.

20.1.2.3 France

France is the home of dark chocolate. It has many recipes and flavour profiles, many specialized chocolate recipe with the cocoa bean coming from a specific region and small cocoa bean growers. The industry has even started using the word of 'Grand Cru' for its very special products (a term borrowed from the champagne industry).

20.1.2.4 Switzerland

Switzerland is the home of some of the finest milk chocolate. The quality and the flavour of the Swiss milk powder was always very good. This is largely due to the fact that the maximum particle size of the refined chocolate is almost always below 20 μm, making a very smooth chocolate, together with the care taken with the conching process. This gives Switzerland a very good name for milk chocolate bars and confectionery.

20.1.2.5 Germany

A large proportion of chocolate making machinery is manufactured in Germany, but the chocolate products themselves tend to be designed mainly for the local market.

20.1.2.6 Italy

Italy is famous for producing of 'single items' chocolate confectionery, rather than tablets. Products like Ferrero Rocher are exported throughout the world.

20.1.2.7 English speaking countries (other than USA)

These generally follow the UK type of flavours, due to the fact that the major UK Companies have factories here.

20.1.2.8 USA

The top selling brand has a milk flavour that is quite strong and robust. European chocolate types and flavours are making some inroads into the confectionery market.

20.1.2.9 Other countries

Many major multinational companies have factories in these countries, which have followed the 'European route'. There are also many imports from

Europe. Local brands and flavours co-exist for example in Russia some milk chocolate has a very strong cocoa taste.

20.2 The basic ingredients

The ingredients and processing of chocolate are described in detail in other parts of this book. It is, however, useful to review their most important aspects, before examining different possible chocolate recipes.

20.2.1 Sugar

This can be refined cane or sugar beet, white or slightly grey in colour. Granulated sugar with a low percentage of sugar dust is preferable for roller refining.

20.2.2 Milk

Milk chocolate is still the most popular chocolate in the world, even places like China, where very little milk is used, the milk chocolate is highly regarded.

The milk powder used in the production of milk chocolate are normally spray or roller dried. Both can be purchased in full cream or skimmed versions. Milk crumb (Chapter 5) is manufactured by co-drying sugar and milk together with cocoa liquor. It is then often milled to the size of bread crumbs, which gave it the name of 'chocolate crumb'. This process adds cooked notes to the final taste.

The flavour profile and hardness of a milk chocolate is in fact determined by the choice of the ingredients being used. Spray-dried, full cream milk will produce a 'harder milk chocolate' suitable for tablets and chocolate confectionery. Using skim milk powder and butter oil (anhydrous) or roller-dried milk powder, results in a softer chocolate, suitable for the bakery and the ice cream sectors.

The quality of the milk powder is determined by the age, the time of the year it is produced, by the type of feed for the cows and the location of the pastures etc.

It is interesting that there are many different milk chocolate flavours, which are suited to a particular country, for example the Austrian milk chocolate has a 'nutty' taste and the USA type a 'mature milky, slightly cheesy' taste.

20.2.3 Cocoa beans and mass

This ingredient will have potentially the biggest influence on the flavour of the chocolate, especially dark chocolate. The higher the total cocoa solids the higher the flavour influence will normally be. There are two main botanical types of cocoa beans the 'Forestero' being the main type and giving a characteristic strong cocoa flavour, which can be slightly acid and bitter if 'over roasted' or 'under conched'. The Criollo giving a much gentler and finer flavour.

To describe all the various types and regions of cocoa bean growing would take a book on its own. For a medium to high-quality chocolate, cocoa beans from West Africa may be used for example from The Ivory Coast, Nigeria, Ghana and Cameroon.

The blending of the cocoa bean/mass and grade of roasting is very important and it depends on several factors:

(a) cocoa bean quality,
(b) producer experience in blending cocoa beans and roasting times and temperatures,
(c) the equipment available, and its use,
(d) purchasing practice.

Cocoa mass is normally produced in one of two different ways. Whole bean roasting involves blending, cleaning, roasting, breaking, winnowing, pre-grinding and grinding. Alternatively nib roasting is carried out by blending, drying (or pre-roasting), breaking, winnowing, roasting, pre-grinding and grinding. Chapter 6 describes these processes in more detail.

The finer the cocoa bean such as the Criollo type is normally roasted at a lower temperature range than the bulk Forestero type. For milk chocolate the lower roasting temperatures are normally preferred.

Roasted cocoa nibs and mass can also be modified by 'heat or steam treatment'. The treatment modifies the 'roasted flavour' by reducing the undesirable 'acids' in the mass, reducing conching times and providing some sterilization of the cocoa mass.

Normally a blend of West Africa cocoa is used by European chocolate manufacturers. The ratio will depend on the type of chocolate being produced, the cocoa availability, which varies from season to season and its cost.

Currently there are many fine chocolates being made using cocoa beans from 'origin' countries, also chocolate made with cocoa beans from a specific cocoa variety. These are normally dark chocolate with a high cocoa mass content to emphasize specific flavours.

20.3 Conching to develop flavours (Chapters 8 and 9)

During conching the flavour changes or modifications are affected by the following:

(1) Type and action of the conche.
(2) Temperature of conching (white 40–50°C (104–122°F), milk 40–70°C (104–158°F), dark 50–90°C (122–194°F).

(3) Time of conching (4–36 h depending on the type of chocolate).
(4) Exposure to air.
(5) The time and amount of addition of fat and emulsifiers.

20.4 Chocolate recipes

For all these chocolate recipes, up to 5% of the cocoa butter can be replaced with CBE (cocoa butter equivalents) or fats compatible with cocoa butter, in countries where the regulations permit. The final product must be clearly labelled however that it contains vegetable fat (Chapter 25). All would also contain a flavouring. Legally this cannot be a chocolate flavour, but is normally vanilla (natural) or vanillin. For certain applications a small amount of salt may be added to enhance the overall flavour.

There are many recipes depending upon the final use. The main types are:

(1) Chocolate tablets/bars
(2) Chocolate confectionery
(3) Ice cream
(4) Bakery and biscuit products (including chocolate chips)
(5) Speciality products
(6) No added sugar chocolate
(7) Non-cocoa butter fat coatings (compound or confectionery fat coatings).

20.4.1 Chocolate bars/tablets

In this sector, many factors have to be taken into consideration, particularly regarding flavour, smoothness, snap and mouth melting profile. Multinational producers have their own 'house' flavours and there are also national and regional tastes etc.

To the customer this chocolate bar must bring the ultimate in eating pleasure, by giving the expected flavour, smoothness and melting profile.

The fineness of most bars, whether dark, milk and white, is 15–20 μm for top quality products, 22–25 μm for medium quality bars and 25–30 μm for bars with inclusions, such as fruit, nuts and cereals.

A range of different dark chocolate recipes is given in Table 20.1.

The most popular solid eating chocolate is still milk chocolate, either as a milk chocolate bar or with added fruits, nuts, cereals etc. Typical recipes are given in Table 20.2.

The milk chocolate recipes could also be made using chocolate crumb to replace some or all of the cocoa mass, milk powder and sugar. If a softer milk chocolate is required, the full cream milk powder can be replaced with skim milk powder and butter fat.

Table 20.3 contains recipes for different types of white chocolate that can be made into tablets.

Table 20.1 Recipes for dark tablet chocolate.

	Range for dark chocolate (%)	Typical medium quality bar (%)	Typical high cocoa solids recipe (%)
Cocoa mass	45– 80	55	70
Sugar	20–55	44.5	30
Added cocoa butter	0–5		
Lecithin	0–0.5	0.5	
Flavour	<0.5		
Approximate total fat content		29	38–40 depends upon cocoa type and quality

Table 20.2 Recipes for milk tablet chocolate.

	Range for bar milk chocolates (%)	Typical medium quality bar recipe (%)	Typical high-quality milk bar recipe
Sugar	34–50	48	42
Non-fat milk solids	12–18		
Full cream milk powder		24	25
Cocoa butter		19.5	24.5
Cocoa mass			8
Milk fat	3.5–6		
Lecithin	0.3–0.5	0.5	0.5
Approximate total fat (milk plus cocoa butter)	26–38	26.5	35

Table 20.3 Typical recipes for white bar chocolate.

	Range of ingredients (%)	Typical medium quality white bar chocolate (%)	Typical high-quality white chocolate bar recipe (%)
Sugar	37–50	48	37
Non-fat milk solids	18–24		
Milk fat	4–7		
Full cream milk powder		29.5	33
Deodorized cocoa butter	22–35	22	30
Lecithin	0.2–0.5	0.5	
Approximate total fat content (milk fat plus cocoa butter)	29–40	29.5	37.8

When making white chocolate it is important that good quality fresh milk powder and high-quality deodorized cocoa butter are used. It must be conched at 40–50°C (104–122°F). When a higher conching temperature is used, there is danger of 'browning' the chocolate. If a 'caramelized' flavour is preferred, the use of 'white' chocolate crumb should be considered.

When a 'softer' white chocolate is desired, the full cream milk powder can be replaced with skim milk powder and butter fat.

20.4.2 Chocolate confectionery

The chocolate used for the confectionery industry is normally split into three sectors:

(a) Enrobing
(b) Shell moulding and one-shot systems
(c) Panning.

20.4.2.1 Chocolate for enrobing

The requirements for enrobing chocolate are:

(1) Good hardness and contraction, but not too hard so that it cracks if used on firm or hard centres.
(2) Flavour profile to be in harmony with the centres.
(3) Viscosity and yield value to match the requirement of the product and processing plant.

Typical recipes for the major ingredients within milk, dark and white enrobing chocolate are given in Table 20.4.

The actual viscosity that is needed depends very much upon the type of temperer and enrober being used. It may be necessary to modify the flow properties of these recipes. A more fluid chocolate can be obtained by decreasing the sugar by 2–3% and increasing the cocoa butter. For a thicker chocolate the reverse applies, i.e. decrease the cocoa butter by 2–3% and increase the sugar by the same amount.

20.4.2.2 Shell moulding and one-shot systems

For *shell moulding* the chocolate can be similar to that used for enrobing, provided that the shell moulding plant has efficient vibrator and shaking

Table 20.4 Typical recipes for milk, dark and white enrobing chocolates.

	Milk chocolate (%)	Dark chocolate (%)	White chocolate (%)
Sugar	45	43.5	45
Skimmed milk powder	15.6		17.9
Milk fat	5.3		4
Cocoa mass	10	44	
Cocoa butter	23.6	12	32.6 (deodorized)
Lecithin	0.5	0.5	0.5
Total fat content	35	35	36.6

Where legislations permit up to 5% of the cocoa butter can be replaced by CBE (cocoa butter equivalent).

systems, so as to be able to adjust the shell thickness to suit the products. If there is a problem with the 'backing off' of the filled shells due to very high a viscosity, then a small amount of cocoa butter should be added to the 'backing chocolate'.

With *one-shot* systems (see Chapter 17) depending on the type of equipment and the product centres, a less fluid hard chocolate with good contraction may be advantageous. Typical recipes for milk, dark and white chocolates that are suitable for one-shot systems are given in Table 20.5. If a more fluid chocolate is required for any of these recipes, up to 3% of the sugar can be replaced by cocoa butter.

20.4.2.3 Panning

A wide range of chocolate types and viscosity (and yield value) can be used depending upon the panning system itself and the products to be panned. The chocolate should not be too hard to cause splitting on panning or too soft to cause sticking together of the panned products after cooling.

Typical panning chocolate recipes, for use with a spray system (Chapter 16), are given in Table 20.6.

Table 20.5 Recipes suitable for one-shot systems.

	Milk chocolate recipe (%)	Dark chocolate recipe (%)	White chocolate recipe (%)
Sugar	49	52	46
Full cream milk powder	20		20
Cocoa mass	10	35	
Cocoa butter	20.5	12.6	29.5
Lecithin	0.5	0.4	0.5
Approximate total fat	32	32	33.5

Table 20.6 Chocolate recipes suitable for panning.

	Milk chocolate recipe (%)	Dark chocolate recipe (%)	White chocolate recipe (%)
Sugar	46	54	48
Skimmed milk powder	15		10
Full cream milk powder			10
Milk fat	4	4	4
Cocoa mass	8	27	
Cocoa butter	26.5	14.5	27.5
Lecithin	0.5	0.5	0.5
Approximate total fat content	34.5	33	33.5

If using round or onion- (tulip-) shaped pans, letting the panned product 'rest' and 'harden' for 24 h before glazing may be beneficial for a good gloss and no clouding of the glaze.

20.4.3 Ice cream and frozen desserts/confectionery

Over the last 20 years, many changes have taken place in the use of real chocolate in frozen products. Despite these, the ice cream and frozen product industry worldwide still uses more chocolate-flavoured coatings than real chocolate. Adding vegetable fats and oils to real chocolate can also be beneficial to the frozen products industry, enhancing the melting profile and flavour release of the frozen chocolate in the mouth.

Both the ice cream chocolate and the coatings have to meet a wide range of applications, from enrobed choc ices to spraying cones and from after dinner ice confection to dipping lollies in real chocolate, or chocolate flavour coatings.

The rules of having to temper real chocolate and cool it slowly do not apply for cocoa butter chocolate or coating products below 0°C, where very rapid solidification takes place. Real chocolate, which may or may not contain added vegetable fats, at a temperature of 42–45°C (108–113°F) comes in contact with the frozen product, which is –25°C to –40°C (–13°F to –40°F) before enrobing or dipping.

For best results when dipping or enrobing with real chocolate, the ice cream should not have an 'overrun' (additional volume after aeration) of more than 60%. If a chocolate flavour coating is used, the depositing temperature is normally between 28°C and 35°C (82°F and 95°F) and the 'overrun' can be up to 100% or in special cases even higher.

With enrobed products, an after-freezer to rapidly set the chocolate or coating is normally used. Dipped lollies may be rapid cooled by spraying with liquid nitrogen. (N.B. For real chocolate, there is a slight softening of the chocolate after the initial hardening, which lasts about 10–15 min.)

The total fat percentage to give the correct pick up weight and cover for real chocolate dipped and enrobed ice cream, is between 42% and 48%, but up to 60% if the chocolate is used for air or airless spraying. Recipes, including real chocolate, that are suitable for dipping and enrobing high-quality ice cream and frozen confectionery are shown in Table 20.7.

The white chocolate or coatings should always be stored in stainless-steel containers and transported using stainless-steel pumps and pipe work. The container water jacket temperature must be kept below 45°C (113°F) or 'Browning' of the white chocolate will occur.

The example of a milk chocolate recipe with added vegetable fat is 'softer' at frozen temperatures and 'cracks' less on the product and at point of consumption. If local regulations do not allow the addition of vegetable fat (coconut oil, or similar soft fat) it still can be used, but with a description of 'chocolate flavoured' coating. The chocolate made as normal, but 10% of coconut oil is added at the point of use.

Table 20.7 Chocolate recipes for dipping and enrobing high-quality ice cream and frozen confectionery.

	Real milk chocolate (%)	Real dark chocolate (%)	Real white chocolate[a] (%)	Real milk with added vegetable fat (%)
Sugar	42	39	40	47
Skimmed milk powder	9		15	12
Full cream milk powder				
Milk fat	7	7[b]	8	
Cocoa mass	8	39		10
Cocoa butter	33.4[c]	14.4[c]	36.4[c]	22.4
Lecithin	0.6	0.6	0.6	0.6
Approximate total fat content	44.4	42	44	35.4 plus 10% vegetable fat 45.4

[a] The above recipes can also be used for disc spraying, but for nozzle spraying replace a total of 5% of the sugar and skimmed milk powder with 5% cocoa butter.

[b] If regulations allow, if not replace with cocoa butter.

[c] 10% of cocoa butter can be replaced by vegetable fat, where regulations allow.

Table 20.8 Coating recipes suitable for enrobing and dipping medium quality ice cream and frozen cake products.

	Milk chocolate flavoured coating (%)	Dark chocolate flavoured coating (%)
Sugar	35	40
De-fatted cocoa powder	4	10
Skimmed milk powder	7	
De-mineralized whey powder	4	
Soft coconut fat	49.4	49.4
Lecithin	0.6	0.6
Approximate total fat content	49.4	49.4

20.4.3.1 Chocolate flavour coatings for enrobing and dipping

The main fat used for ice cream coatings is soft coconut oil or a similar vegetable fat with a slip point (Chapter 4) of approximately 18–24°C (64–75°F). The percentage of fat in chocolate-flavoured coatings suitable for the frozen food sector is in a range from 45% for cone spraying to 65% for thin layer enrobing and dipping. Recipes suitable for enrobing and dipping medium quality ice cream and frozen cake products are presented in Table 20.8. If it is needed to make the milk recipe more 'creamy' up to 5% of coconut fat can be replaced with milk fat.

For air or air less spraying of wafer cones or an ice cream barrier spray an even thinner coating is needed, which means having even more fat. A typical recipe might have a total of 60% fat of which 56% might be soft coconut fat, with the remainder being about 4% of milk fat. Other ingredients could be 26% sugar, 7% skim milk powder and 7.5% de-fatted cocoa powder.

20.4.4 Bakery, biscuits and chocolate chip products

For many years only chocolate-flavoured coatings were used for cake products due to the warm atmosphere in bakeries, the exception being the Sacher Torte of Vienna with its very high butter fat content, which makes it cut-able at room temperatures and the half and fully enrobed biscuits and chocolate chip cookies, which came via the USA to the UK and Europe.

Using real chocolate on cakes requires a reasonable soft chocolate, which can be easily cut without splintering at room temperature. The trick is to use a normal medium soft chocolate and add 3–4% butter fat to the milk chocolate and up to 8% of butter fat to plain chocolate. Very little white chocolate is used for cakes, due to its sweetness. Typical milk and dark recipes for enrobing a sponge cakes, gateaux or Swiss rolls are given in Table 20.9.

Owing to their high butter fat content, these chocolates need to be tempered approximately 1°C (2°F) lower than normal chocolate and the cooling tunnel dwell time may be 2–4 min longer than a normal confectionery product.

20.4.4.1 Half coated or fully enrobed biscuits

A medium hard (relatively fast setting) chocolate is desirable for two reasons:

(1) Most biscuit plants run at a much faster speed than confectionery systems so fast setting is required.
(2) To stop the half coated or enrobed biscuits from sticking together as they are packed.

Typical recipes for enrobing or half coated biscuits are given in Table 20.10.

20.4.4.2 Chocolate chips

Chocolate chips or chunks can be used for biscuit production, or for inclusions in cakes, muffins or toppings.

Table 20.9 Typical recipes for enrobing sponge cakes, gateaux or Swiss rolls.

	Milk chocolate recipe (%)	Dark chocolate recipe (%)
Sugar	45	52
Skimmed milk powder	15	
Cocoa mass	11	30
Milk fat	7.5	7.5
Cocoa butter	21	10
Lecithin	0.5	0.5
Approximate total fat content	34.5	33

Table 20.10 Typical recipes for enrobing or half coating biscuits.

	Milk chocolate recipe (%)	Dark chocolate recipe (%)
Sugar	47	52
Full cream milk powder	7	
Skimmed milk powder	5	
Whey powder[a]	5	
Cocoa mass	8	30
Milk fat	3.5	
Cocoa butter	24	17.5
Lecithin	0.5	0.5
Approximate total fat content	33.3	33.5

[a] If regulations allow, otherwise replace with skimmed milk powder.

Owing to their relatively better baking stability, the main chocolates used in chocolate chip biscuits or cookies are dark chocolates. If milk chips/chunks are used within biscuits care must be taken in the baking temperature, baking profile and dwell time in the ovens, otherwise a 'burned milk' or 'bitter' taste will develop. White chocolate chips are prone to bitter/burned caramelizing and browning in the baking process. So that they maintain their shape during baking a lower fat, high viscosity chocolate is often used. Typical recipes for dark and milk chocolates suitable for chocolate chip production are given in Table 20.11.

Table 20.11 Typical recipes for chocolate chips or chunks.

	Dark chocolate recipe (%)	Milk chocolate recipe (%)
Sugar	49	52
Full cream milk powder		20
Cocoa mass	47	10
Cocoa butter	3.6	17.7
Lecithin	0.3	0.3
Salt	0.1	
Approximate total fat content	27.6	28

20.4.4.3 Chocolate-flavoured coatings for cakes and cake rolls

There are many chocolate-flavoured coatings used in the cake industry, due to cost or production implications (no tempering required). Most recipes are made with HPKO (hardened palm kernel oil, Chapter 19) or other hardened vegetable fats, depending on application, cost, geographical location etc.

Table 20.12 gives three recipes for chocolate-flavoured coatings based on HPKO fats, which are available in various melting profile and hardness.

Table 20.12 Typical chocolate-flavoured coating recipes, suitable for coating/enrobing cakes and rolls.

	Milk chocolate-flavoured recipe (%)	Dark chocolate-flavoured recipe (%)	White chocolate-flavoured recipe (%)
Sugar	42	48	42
De-mineralized[a] whey powder	11		6
Skimmed milk powder	5		15
De-fatted cocoa powder	5	16	
HPKO	36.5	35.5	36.5
Lecithin	0.5	0.5	0.5
Approximate total fat content	36.7	37	36.5

[a] Replace with skimmed milk powder, where regulations do not permit use of whey.

It is necessary to work with your fat supplier to evaluate the best type and melting profile fat for your products.

Chocolate-flavoured coatings with HPKO fats have a short shelf-life due to fat bloom. If the shelf-life needs to be extended beyond 4 weeks, an anti-bloom agent will have to be added to the coating fat. If further shelf-life is required alternative fat to HPKO should be considered.

20.4.5 Speciality products

Nowadays there are so many possibilities with all the new ingredients that are available, together with all the knowledge on how to use these products that a book could be written on speciality products alone. Many samples are available from the technical or development departments of the suppliers.

For chocolate bars and chocolate confectionery, there are many fillings available, some made with chocolate as an ingredient together with added moisture (cream, condensed milk, glucose, sugar syrup etc.) or fat-based products made on chocolate machinery.

This section contains recipes for soft melt chocolate bar fillings that can be made using standard chocolate machinery, including the single-stage grinding systems for example Macintyre (Chapter 9) together with a traditional shell moulding plant.

A typical soft melt chocolate filling crème, uses a soft coconut fat, or one of the many other appropriate vegetable fats to provide a 'fast melt' in the mouth and a long shelf-life. Three typical recipes are given in Table 20.13.

The light coloured recipe gives a 'milky' base coating, which will readily mix with fat-based flavours and pastes, such as hazelnut, almond praline or coffee paste. Because it contains no moisture, rice crispies or other small extruded cereals can be added, without the danger of the cereals becoming

Table 20.13 Recipes for typical soft melt chocolate filling crèmes.

	Light coloured (milk) crème (%)	White filling crème (%)	Dark filling crème (%)
Sugar	35	35	48
Skimmed milk powder	15	20	
Milk fat		2	
De-fatted cocoa powder	5		15
Soft coconut fat	44.5	42.5	36.5
Lecithin	0.5	0.5	0.5

soft and soggy. If a darker filling is required, 10% of the skimmed milk powder can be replaced with de-fatted cocoa powder. This filling compliments alcohol flavours such as rum and brandy etc. and is also suitable for strong flavours for example cappuccino paste and bitter orange. If a higher quality filling is required, the cocoa powder can be replaced by cocoa mass and 5% of coconut fat with 5% of butter fat.

The white filling crème is ideal for fat-based fruit flavours and colours, such as caramel, orange, lemon, fruit of the forest etc. If a less rich filling crème is required, some or all of the skimmed milk powder can be replaced with powdered pre-cooked rice.

The dark filling crème is ideal for a chocolate-flavoured filling and also for the addition of most fat-compatible alcohol flavours. If a really good quality chocolate filling is required, the de-fatted cocoa powder should be replaced with cocoa mass.

Cereal additions can be incorporated within all three types of filling crème, without the cereals becoming soft.

20.4.5.1 Other speciality products

Under the heading of 'speciality products' one must mention the many products sold with labels saying origin cocoa, plantation cocoa, organic, Fair Trade, Kosher, Functional etc. All of these products have a consumer following and enrich the range of products available to the consumer.

For the production of these products, both normal and specialized equipments are used, as each manufacturer wants to produce *something special*. In many cases, by giving added care and attention to the ingredients and manufacturing process, it is possible to produce special chocolates that can demand a higher price margins than standard products.

20.4.6 No added sugar chocolate

Traditional chocolate contains between 30% and 55% of sugar (sucrose), which may be from cane or sugar beet. There is also sugar that is contained in other chocolate ingredients such as milk, which is called lactose (Chapter 4). Lactose is naturally present in the milk powder and whey, which is added to make milk or white chocolate. It is possible to make sugar-free chocolates, but these are either dark or made with special lactose-free milk ingredients.

Some consumers avoid sucrose (sugar) for reason usually associated with life style or health. This may be due to concern about obesity or tooth decay, or that they are on a diet which bans added sugars (sucrose), perhaps because they are diabetic. There are many chocolates and fillings made for diabetics, which are made using manufacturing processes very similar to that for normal chocolate or fillings.

Three of the main types of sugar replacers (Chapter 3) are sorbitol, fructose and maltitol. Sorbitol is very heat sensitive, therefore difficult to use on mass production equipment. It is also very hygroscopic. Its sweetening power is also less than sugar and it has a laxative effect if more that 100 g per day is consumed.

Fructose or fruit sugar, is less heat sensitive in production, but is about 20% sweeter than sugar.

Maltitol is now widely used in no added sugar products, as its sweetness power is only slightly less than sugar, it is not very heat sensitive in production and also it has a taste profile similar to normal chocolate made with sugar. It has a lower calorific value than sugar (–40%) and is therefore used, often together with polydextrose, to make low calorie chocolate. As fat contains more calories per gram than the other major ingredients, this type of chocolate should be made with the minimum amount of fat possible, whilst maintaining adequate liquid flow and eating properties.

For no added sugar chocolate and fillings, it is possible to use normal chocolate recipes, but replace sucrose with maltitol. When using sorbitol or/and fructose, all processing, pumping and storage temperatures must be kept below 50°C (120°F).

20.4.7 Non-cocoa butter coatings

This section covers the many different types on non-cocoa butter chocolate-flavoured coatings and also what are normally called confectionery coatings. These types of coatings are normally made of a variety of fat types (Chapter 19) and are designed to replace real chocolate, but still give a relative good flavour and long shelf-life.

20.4.7.1 CBE fats

These are available in a range of hardnesses, appropriate to the product, and also to suit the environmental temperatures of the region.

Chocolate-flavoured coatings made with this type of fat are mainly used for biscuit and cake enrobing and half coating. Basic recipes are similar to real chocolate, but with the CBE replacing cocoa butter. At point of usage, the coatings need to be handled exactly as real chocolate, which includes tempering and the correct cooling profile after enrobing.

20.4.7.2 Lauric fats

The confectionery type of chocolate-flavoured coatings can be made with HPKO lauric fat. Many other lauric fat types are available, with their use normally depending upon their price and availability.

The shelf-life of these coatings is normally up to 4–6 months, before fat bloom occurs, but this can be extended by the addition of an anti-bloom ingredient. This must always be added to hot liquid fat, but it is often preferable to have it added by the fat supplier.

These coatings are normally used for enrobing sugar confectionery and wafers, due to the fact that the lauric fat is harder than HPKO and has a much cleaner melting profile in the mouth, some coatings are also used for shell and hollow moulding. They can also be used to make ganache (a high moisture paste often containing cream) and truffle paste. Three typical recipes for lauric fat-based coatings are given in Table 20.14. As with the chocolate recipes small amounts of flavourings such as vanillin are used in almost all coatings.

All three chocolate-flavoured coatings are ideal for enrobing wafer and sugar confectionery products, where the use of real milk chocolate is too expensive or likely to melt easily in the high ambient temperatures. They can be mixed with nuts, dried fruit and cereals, for a children's type of confectionery bar (sold in warm climates).

The milk coating can also be used as a base for ganache and truffle paste by the addition of condensed milk and glucose.

The white coating is often coloured and flavoured with fat-soluble colours and flavours and is widely used in the United States for very colourful cake and candy decorations.

Table 20.14 Typical recipes for lauric fat coatings.

	Milk coating recipe (%)	Dark coating recipe (%)	White coating recipe (%)
Sugar	45	53	50
Skimmed milk powder	15		15
De-fatted cocoa powder	5	11.5	
Lauric fat[a]	34.6	35.1	34.6
Lecithin	0.4	0.4	0.4

[a] If the anti-bloom is not already present in the fat, it will replace about 2% of the lauric fat.

Conclusions

This chapter has provided a guide to the many different recipes that can be used for the wide variety of confectionery products found on the market. Most if not all chocolate and coatings will contain vanilla (natural) or vanillin (artificial) to enhance the flavour profile. Very occasionally, a very small amount of salt may also be used to improve the flavour, especially of dark chocolate. There is however no substitute to trying oneself. A product can be completely transformed by changing the flavour, texture or melting profile of the chocolate. Always however use high-quality ingredients coupled with careful processing.

Chapter 21

PROJECT MANAGEMENT AND PROCESS CONTROL

U. Löser

21.1 Introduction

The production of confectionery products has become increasingly automated. The processes involved are, however, very complicated and the quality standards expected by the consumer are very high, which in turn has placed increasing reliance on the process control and instrumentation being used. In the chocolate industry this is normally the responsibility of two different types of personnel. Engineers are responsible for what is measured and where these measurements are carried out, i.e. process control. The actual instruments that carry out these measurements, which may be on-line, in-line or in the laboratory, are normally the responsibility of the quality and production team.

When buying new cocoa or chocolate machinery or indeed modifying existing plants, it is very important that the production line should be installed correctly and that it should be operator-friendly. All manufacturing companies need cost-effective solutions with modest capital outlay, low operating costs and high reliability and all machinery suppliers obviously have an interest in satisfying their customers. It is very important therefore that the manufacturer provides this supplier with as much information as possible about his product and process. The specifications in any contract must include the aims (quantitative and qualitative), the scope of the planned process controls and instrumentation and agreements regarding performance criteria when the machine/plant is handed over by the supplier.

This chapter initially focuses on the project management required to install process control for the machines/lines used for cacao and chocolate processing. It is important to take an overview of the complete process from raw ingredients to the final product and to take into account the needs of the people involved (Figure 21.1). The first part of the chapter takes an overview of project management techniques, which will help on-time installation of new plant, provide efficient operating conditions and aid fault finding. The importance of clear targets and planning are emphasized as is the need

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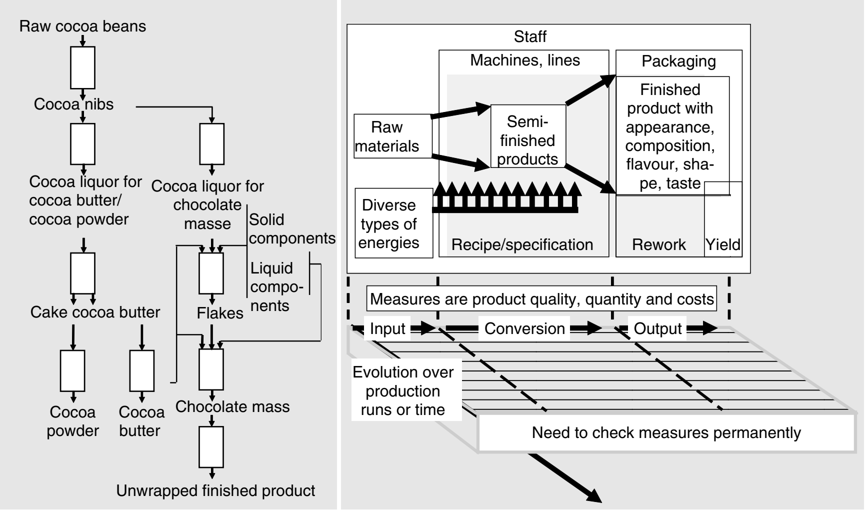


Figure 21.1 A schematic overview of the steps required to manufacture cocoa and chocolate products (left), general interactions (right).

to have good communication not only within a production team, but also between men and machines.

The final part of this chapter emphasizes on the individual processes and indicates where measurements should be taken and what they should be. The actual instruments used and how some of them operate are described in Chapter 22.

21.2 Project management

In this chapter, the term process control relates to the machines and plants used to manufacture cacoa and chocolate products. Figure 21.2 shows an existing moulding line being fitted with a new depositing head. Before deciding how to control the new line it is necessary to consider the whole process, i.e. the interaction between raw materials, machines/plants, interim products and the finished product (see Figure 21.1). This affects the manufacturing costs which are necessary to obtain a defined product quality at the desired throughput. The actual cost can be determined with the help of material and process analyses. Instrumentation of machines and plants not only directly controls the plants throughput and product quality, but also that needed to provide information for the operation of the factory overall, for example work in progress, energy requirements etc. Each plant is different however and its instrumentation must be carefully chosen following a careful decision-making process.

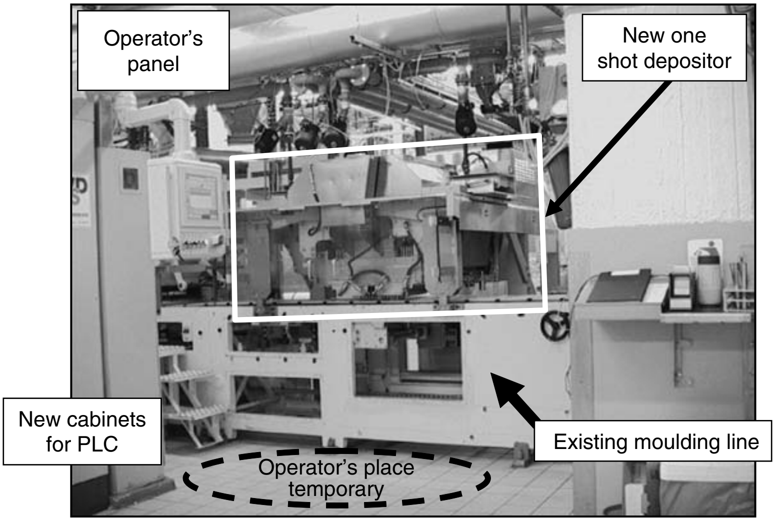


Figure 21.2 Example of a production plant in which a 30-year-old moulding line for solid products was extended by adding a one-shot depositing head to make it into a line for filled products.

When planning a project such as is shown in Figure 21.2, space is required for a new PLC (Programmable Logic Controller) cabinet and the operator's panel, which must of course be in a position where it can be reached and *easily* used. An arbitrary or random application of instrumentation will not produce any benefits for the operator of a machine or plant. Instrumentation, other than for process control, must enable extra added value to be generated, which justifies the investment. It is therefore not simply a question of making process data or general information available. What really matters is the extent to which it is possible to:

- identify relationships between the measurements, so as to aid reaching conclusions when fault finding or optimizing a process,
- make sure the data is in an useable form,
- make certain that operators and line managers want to use the new system,
- operate the new system on a permanent basis in a robust way to the standards to which it was designed.

21.2.1 Project work and individual customization

21.2.1.1 Good project planning is essential

The members of the project team play as important a role as the machine itself. They must identify suitable technical solutions for the new process. The team must come to collective decisions and not be willing to contemplate failure.

Note:

(1) Cost-effective technical solutions/concepts must always be identified before a project is launched. If none can be identified the project must stop.

(2) It is important to clearly define the aims of the project and to clearly review the existing state of the plant/machinery.

(3) Repeated project reviews should be carried out to ensure that project costs remain within the budget. Project costs are made up of:
    (a) project planning, implementation and pre-production trials,
    (b) purchase of capital equipment,
    (c) revenue expenditure such as wages etc.,
    (d) possible payments due to failing to meet contractual conditions.

Instrumentation is expensive and there are likely to be several options, although the suppliers are likely to offer a preferred variant, which tends to be chosen. It is necessary to balance current costs against the projected benefit and to do this repeatedly, taking new costings into account. The amount of instrumentation used can represent a significant cost factor and its benefits can only be realized at the final production stage. Commissioning takes place at low production outputs, so does not necessarily show these benefits. It is very important to decide on the correct level of instrumentation. Too much will waste money, too little will result in production difficulties on the final plant.

21.2.1.2 It is important to complete the project on time

In practice, the project timetable can suffer delays, for example rescheduling of the commissioning period. This can impact or even jeopardize the timing of the market launch and planned market delivery.

Project timing can be affected by the following factors:

- the ACTUAL performance of machines or plants in comparison to the SET performance,
- a high proportion of waste products,
- the microbiological condition of raw materials, intermediate products and final products,
- unsatisfactory sensory qualities of the product (taste, external condition, storage stability),
- underestimation of the original project costings and overestimation of future profit.

These factors can all affect the final project costs.

21.2.1.3 Useful tips relating to project work

- ensure project costs and deadlines are realistic,
- obtain project approval, including the budget, agreed performance targets and timetable, determination of responsible individuals and their line managers,
- document decision-making processes, by keeping minutes and naming responsible persons and dates,
- ensure participants are prepared for meetings, and set time limits for meetings,
- search for realistic technical solutions and prepare contingency plans,
- unplanned decisions require additional time, for example for internal approvals processes.

Note:

(1) every change causes delays, even if the project has been ideally prepared.

(2) after a certain point in time, no further project changes should be taken into account.

  - checks project is being conducted in accordance with ethical, moral and legal principles,
  - carry out commissioning on the basis of a plan and adhere to the agreed objectives,
  - compare the original objectives with the result which has actually been achieved,
  - document the project to prevent repeated errors and to provide employee training.

21.2.1.4 Project work

The more structured and simpler the remit is formulated, the more quickly its aims can be implemented. The selection of the right team members, their collaborators and the allocation of the various parts of the project, are the essential foundations for a successful project. Project management is also responsible for the communications, both within the team as well as externally. When discussing technical matters, arguments should focus on the facts not opinions.

21.2.2 Special aspects relating to the manufacture of cocoa and chocolate products

21.2.2.1 What is so special about the manufacturer of cocoa and chocolate products?

The manufacture of cocoa and chocolate products involves a great many, sometimes highly complex processes (see Figures 21.11–21.19 and their corresponding Tables 21.1–21.6). In addition some of the quality parameters cannot be measured using instruments for example aromas from the conching process outside of the laboratory. For this reason, it is not yet possible to break down all processes into their unit operations, or to use measurement technology to model the processing. To make matters worse, the flavour is not only affected by the raw ingredients being used, which is common to most foods, but is also at least as much determined by processing conditions. But this is not all, as further changes in texture and taste take place after the processing is complete. This makes the work of quality control significantly more difficult, requiring analytical ingenuity and qualitative testing.

The last 50 years has seen a dramatic change from craft-based small-scale production to a highly automated one, which nevertheless still relies on practical know-how. The process technology tools used in the chemical industry, such as balancing and modelling, cannot always be used, for the reasons already explained and might indeed not be cost effective in the confectionery industry. Project managers therefore need to carry out a series of systematic trials using the measuring tools that are available to them. These are of critical importance for the success of a project, and good process conditions can be determined for specific machines and plants. The following play a decisive role in this respect:

- Scope and extent of the project aims.
- Recording of complex process interactions on the basis of incomplete information.
- Time scale of the processes.
- The available instrumentation.
- Application of statistical trial planning.
- Ability to use measurement technology to record the parameter in question.
- Reproducibility.
- Ability to be scaled up.
- Interpretation of trial results.

21.2.2.2 In-house flavour

What makes the in-house flavour so special? This is the main differentiating property between different manufacturers and is normally very difficult to copy. It must be able to be reproduced in different factories, be largely independent of raw material influences and tends to be determined by in-house processing and recipe knowledge. The consumer must not notice the deviations, and the chocolate masse must be produced within defined specifications. Its set limits correspond to the average of the customer expectations with respect to the product in question, but are restricted by the know-how of the employees and the technology being used. When making these products the type, robustness and quality of the machines/plants as well as the qualifications and motivation of the operatives are very important. It is important to master the technology, not just manage it.

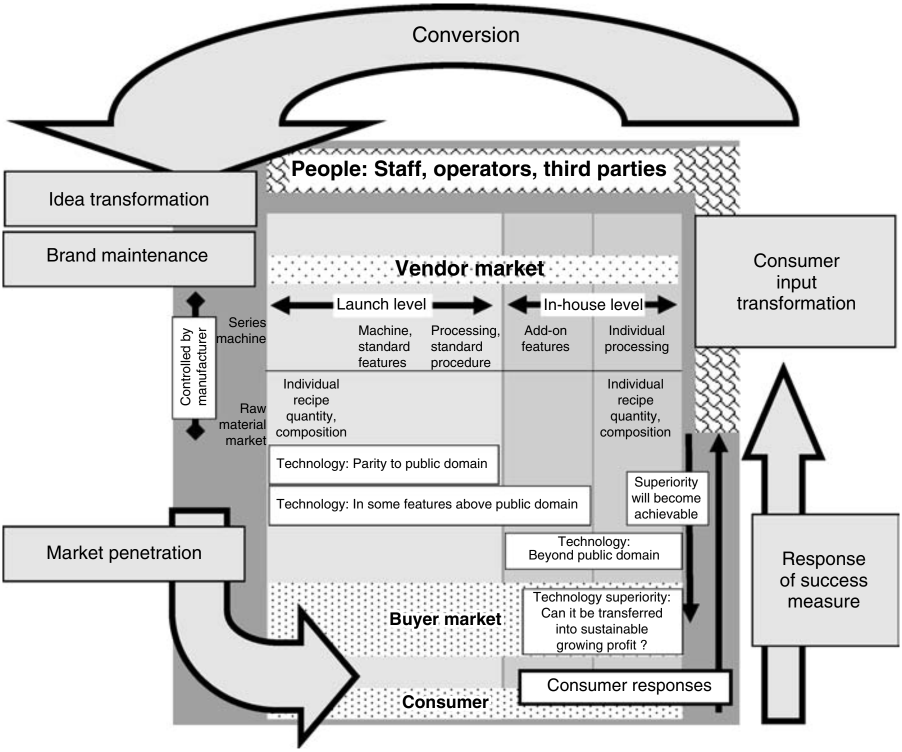


Figure 21.3 Measurement for cocoa butter and cocoa powder production.

21.2.3 Role of process control

Processing is known to significantly affect the taste/texture of confectionery products, so the ability to control it enables the manufacturer to have his own individual product from his factory machines. This interaction between customer, process and technology is summarized in Figure 21.3. When a manufacturer generates growth, then the products in question usually demonstrate the superiority of that manufacturer and results in long-term market domination. Such developments require the sustained, long-term control of the entire manufacturing chain.

Personalized process control can result in the possibility:

- to have greater diversity, and consequently more opportunities,
- to use improved process management to produce an in-house taste and to maintain the unique nature of the products,
- to influence the consistent generation of the in-house taste by guaranteeing the processes and raw materials that determine the quality,

- to cut costs for example by improving the yield relative to a standard solution,
- to help shape the unique nature of the product relative to the competition in a more sustained manner.

Many confectionery markets are becoming saturated with the result that it is increasingly difficult to obtain differentiation, especially if only standard machines and technologies are used. The possible distinguishing characteristics of manufactured products are consequently reduced to the packaging, product design (form, composition), recipes, process controls and marketing. New entrants into the market are only able to use such technical solutions which correspond to the average technological level. Existing in-house knowledge and strong links with suppliers become increasingly important in maintaining an advantage.

Process control plays an important role and is becoming increasingly costs efficient. The possession of in-house process control machinery and knowledge is important in the retention of market position/profit and the ability to respond quickly to market and consumer dynamics. This is in addition to traditional benefits such as a more consistent product, less down-time, less waste ingredients and products and quicker new product development on existing plants.

21.2.4 Machines and plants

The role of instrumentation in relation to confectionery manufacture was summarized in Figure 21.3. As was previously noted, the appropriate instrumentation of an individual machine has to be determined by project work. However, the scope and complexity of the project increases with the number of machines and plants which are to be linked together, so careful pre-planning is required. This can be aided by considering instrumentation to be divided into three levels, as illustrated in Figure 21.4.

Level 1: Commercially available measurement instruments and process control machines used in all industries. Confectionery manufacturers have the option of optimizing them for their own processes.

Level 2+3: Here the machines and production lines have been specially developed to meet the particular needs of the confectionery industry. This is simplified by using elements from level 1.

Each machine/production line has its own *life cycle,* see Figure 21.5. A variety of different products are manufactured during this period. This can only partly be taken into account when designing or modifying a plant. In most cases, the market development of the products determines the need for further investment in existing machines/plants or the need to procure

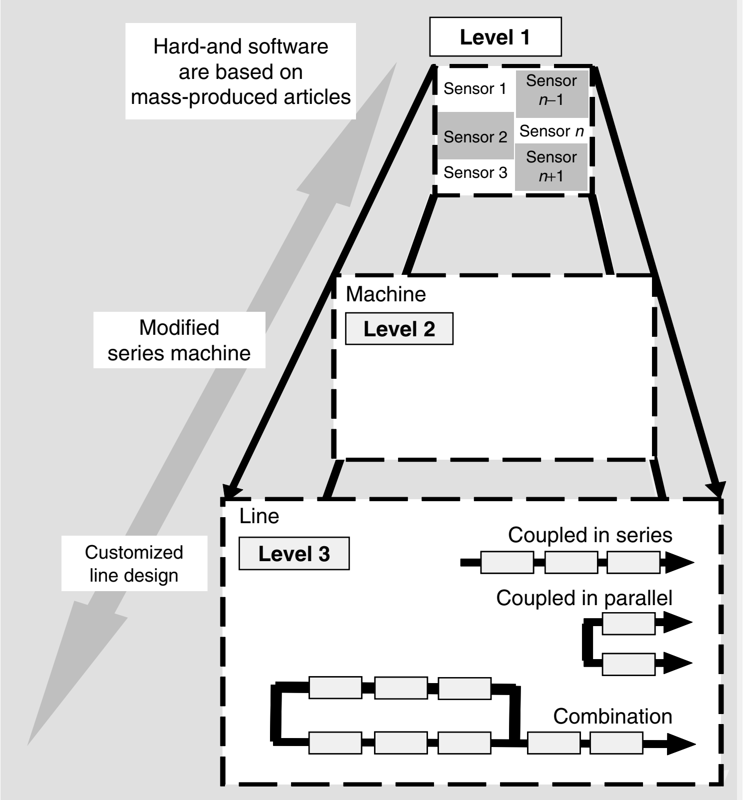


Figure 21.4 Three levels of instrumentation: (1) sensors at the machine level, (2) individual machines and (3) plant made up of individual machines linked together.

new machines/plants. It is generally only possible to anticipate short-term market developments.

Market changes may result in plant modifications. This may entail (1) restructuring, (2) addition of new machines/plants, or (3) complete new construction. Additional instrumentation is required in all three cases. A typical project is illustrated in Figure 21.2.

Reduced manufacturing costs can be achieved with existing plants if the plant is used at practically 100% capacity throughout the year. This is seldom possible as most confectionery products are seasonal, apart from a few market leading brands. It is possible to increase the percentage capacity however if the plant structure is modular and is able to respond flexibly to product changes. For example it may be possible to produce a 'family' of products on the same line. This modular/flexible approach has the added advantage of reducing maintenance costs during the plant's lifetime.

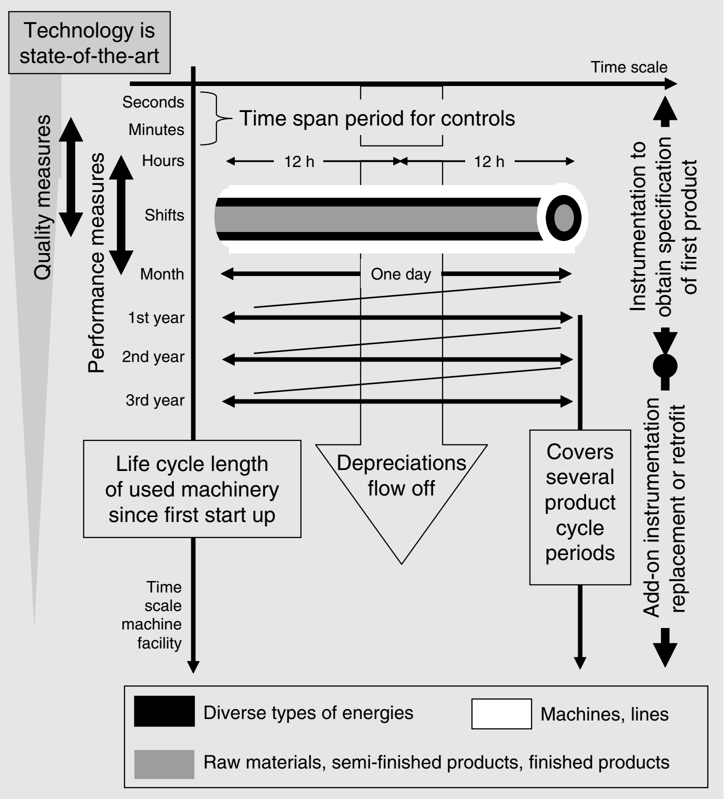


Figure 21.5 Schematic representation of the lifecycle of a machine/production line.

Figure 21.5 also shows the different time spans associated with product quality and product throughput. Both of these aspects should be taken into account when providing instrumentation for a plant. If the interrelations between the performance of the plant and the product quality are known, then the production process can be monitored in appropriate measurement data time spans, for example within seconds or minutes. These data can then be compared to target parameters. The main task of instrumentation project work is to implement this interrelation between product quality and machine performance with the help of

- adjustment and control circuits,
- operator interfaces for example the output of information, instructions for operators,
- recognition and ejection of sub-standard partly produced or finished product,

- providing clear instructions for plant operators and maintenance personnel. This will of course be different for manual control, and semi-automatic and complete automatic operation.

Note: For confectionery products the price of the ingredients and raw materials is far more important than other costs. It is therefore very critical that materials are monitored carefully during processing.

21.3 Material and process analyses

Material and process analyses can be used to monitor quality and costs with greater transparency. The instrumentation provided on confectionery plants, or within company laboratories is able to continuously provide management with the required information.

21.3.1 Data collection and process

Types of data available:

- *Analytical results*
  (1) Obtained from routine analyses during standard production.
  (2) Data gained during trials and fault finding etc.
  (3) Off-line produced analysis for example by an in-house laboratory located outside the production area.
  (4) Additional information with a high degree of specialization and corresponding technical equipment.

- *Process analysis*
  (5) Process analyses conducted during regular production at varying intervals.
  (6) Process analyses conducted in the regular production at less frequent intervals for example in conjunction with trials or non-standard operating conditions.

Note: It is very important to archive the data in a manner in which it can be easily accessible. In addition production and test product samples should be kept under appropriate conditions for further analysis, should this be required.

Process analyses should be an integral part of the production facilities and continuously used. If a production process is not systematically analysed on an ongoing basis, then the level of the quality and/or throughput of the manufactured products will change. Corrective action needs to be taken at the earliest possible stage otherwise this may result in a rise in customer complains or the permanent loss of market share.

The analysis of the causes of product disruptions tends to be the responsibility of technical employees from a variety of specialist fields and increasingly from different countries using different languages. External advisors may also be drawn in. However, in the experience of the author, this is rarely done in practice.

Material and process analyses are requested for a wide variety of reasons:

- Malfunction analyses, rectification of the causes of malfunctions, plant start-up, avoidance of fault repetition.
- Search for technical solutions to optimize manufacturing costs and production qualities, applicable to existing plants as well as to new plants.
- Preparation for, and performance of, modifications to existing production lines.
- Construction of new production lines and their commissioning.

Machines/production lines from which these data are obtained often consist essentially of:

- Machines with local control, display and operating elements.
- Line controls with displays and operating elements.
- Sensors for data recording and forwarding to controls or display elements.
- Interconnected controls for data exchange and data storage purposes.
- Connections to the intranet, internet.

Although apparently similar basic process control instrumentation can be purchased with machines supplied by one manufacturer, they can vary considerably in performance, for example depending upon their age.

21.3.2 Fault finding and plant optimization

Product and process differences can be due to a variety of causes. These include both the reliability of technical systems, as well as operator efficiency (man–machine relationship). Figure 21.6 schematically illustrates the lost production time resulting from the repeated failure of a production plant from a fault that has not been completely rectified. Certain time intervals are influenced by technical measures, while others are not.

The shortfall of the produced finished products caused by out of specification production conditions is determined by the length of time between the occurrence and the successful correction of the anomaly, as well as the number and quantity of affected products. In addition to the lost production there may be costs related to recalling the products, or remedial work such as unpacking the goods, returning these for reworking in the regular production, or destroying some of them. Additional possible damage to the image of the product goes without saying.

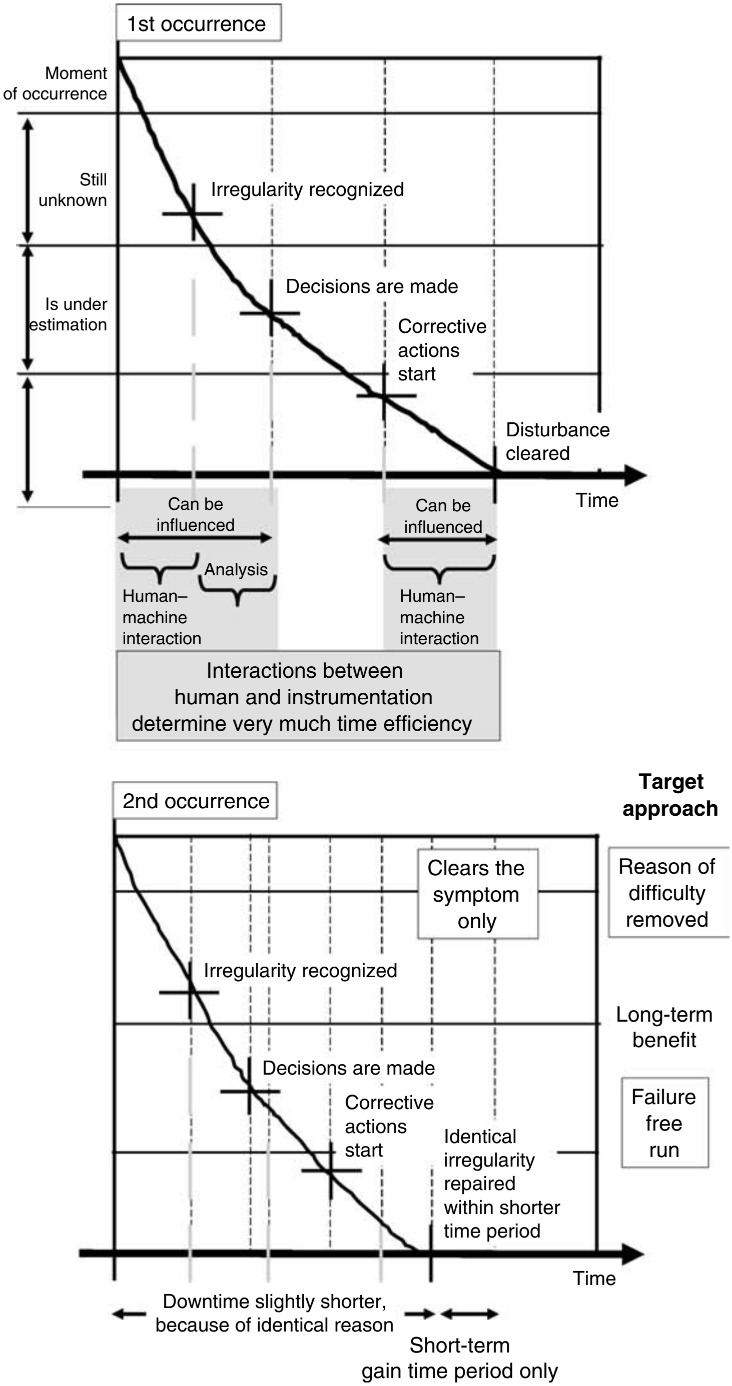


Figure 21.6 Possible production time gain by the systematic application of corrective measures.

21.4 Relationship between man and machine

The advance of the information society at the global level has also had a far-reaching and fundamental impact on the manufacture of confectionery products since the 1990s. In comparison to earlier times, the ubiquitous nature of the Internet has radically altered the conditions and opportunities for adding value in terms of the availability of information. People are able to use information instantly anywhere on the globe and so there is now a great opportunity to standardize. Instrumentation and process control is able to provide information now that the exchange of information is vital for the interaction between man and machine.

This man–machine relationship represents a central element within the exchange of information, see Figure 21.7. In overall terms, the exchange of information includes both the raw materials, intermediary products, finished products and machines on the one hand, as well as all the associated personnel on the other. People depend on instrumentation to monitor the production. In addition machines need to be self-monitoring through circuits and controls, with quality specifications determining the magnitude of the permitted fluctuations. Good man–machine relationships result in faster implementation of decisions, provide the potential for identifying further cost-cutting actions and aids the delivery of products on time to the required quality and quantity.

In his capacity as a machine operator, maintenance personnel, manager, or engineer etc. a person can apply his knowledge and experience as well as use a variety of test instruments or auxiliary sources. These can be permanently installed display units or portable communications platforms providing instant access to networked machines, plants, control equipment and primary control units. In addition, databases with the results of studies for example relating to machine optimization, new machine offers etc. can provide useful information.

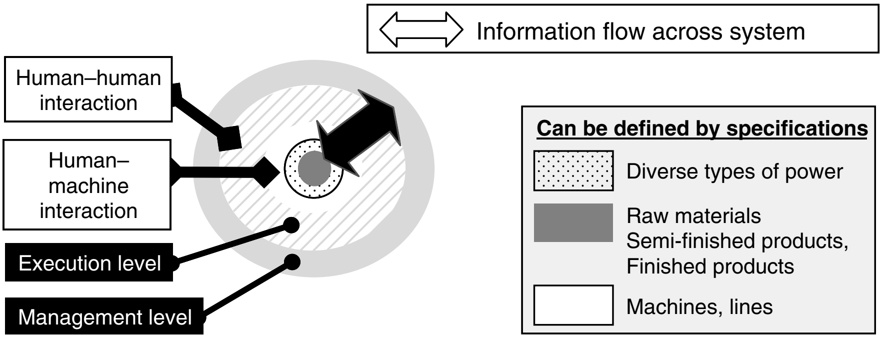


Figure 21.7 Schematic representation of the importance of man–machine interactions.

21.4.1 Control of the production processes

It is critical for confectionery manufacturers to master their production technology, not just use it. There are several systems available to aid this that are helpful not only during routine operating conditions, but also for fault finding and production trials.

21.4.1.1 Material and process analyses

This enables the degree to which a particular manufacturing process is being controlled to be determined. When something happens on a production line, it is initially uncertain whether the cause is a simple one or very complex and the operators consequently have to rely on experience. Usable results are obtained more effectively and faster when they use measured data in their analysis. The more clearly it describes the association between what has happened and the possible solution, the more valuable is the information content of these data. Process data, however needs to be representative and the number of the data points statistically sufficient and precise. Process data for the purpose of process controls are deemed sufficient if its distribution is known over a long period of time for example using SPC (Statistical Process Control).

This becomes particularly useful when used with process models incorporated within PLCs (Programmable Logic Controller) installed directly inside the machines/plants. This enables the connections between real process results, process models and process simulation to be produced and, if necessary, the process to be controlled.

Before each data analysis, it is recommended that the information be checked with respect to the quality of the available data and that data material which is available from past production activities be evaluated. The quality of the data has a significant impact on the validity of the calculated conclusions. Tools such as PAT (Process Analytical Technology) can be used to aid the analysis of these data.

The experience of the team carrying out the analysis should not be underestimated. In general, the wider the knowledge and the experience the quicker will be the solution. Team work is also essential. As team members may have had contradictory experiences or conflicting knowledge, sufficient time must be allowed for all opinions to be taken into account. This provides unrecognized but valuable training for all concerned.

21.4.1.2 Decision making

The individuals involved in the project must have the authority to take decisions and to implement these promptly. It is important in this conjunction that this process is conducted quickly, on logical grounds and in accordance with set targets. This approach requires effectively functioning

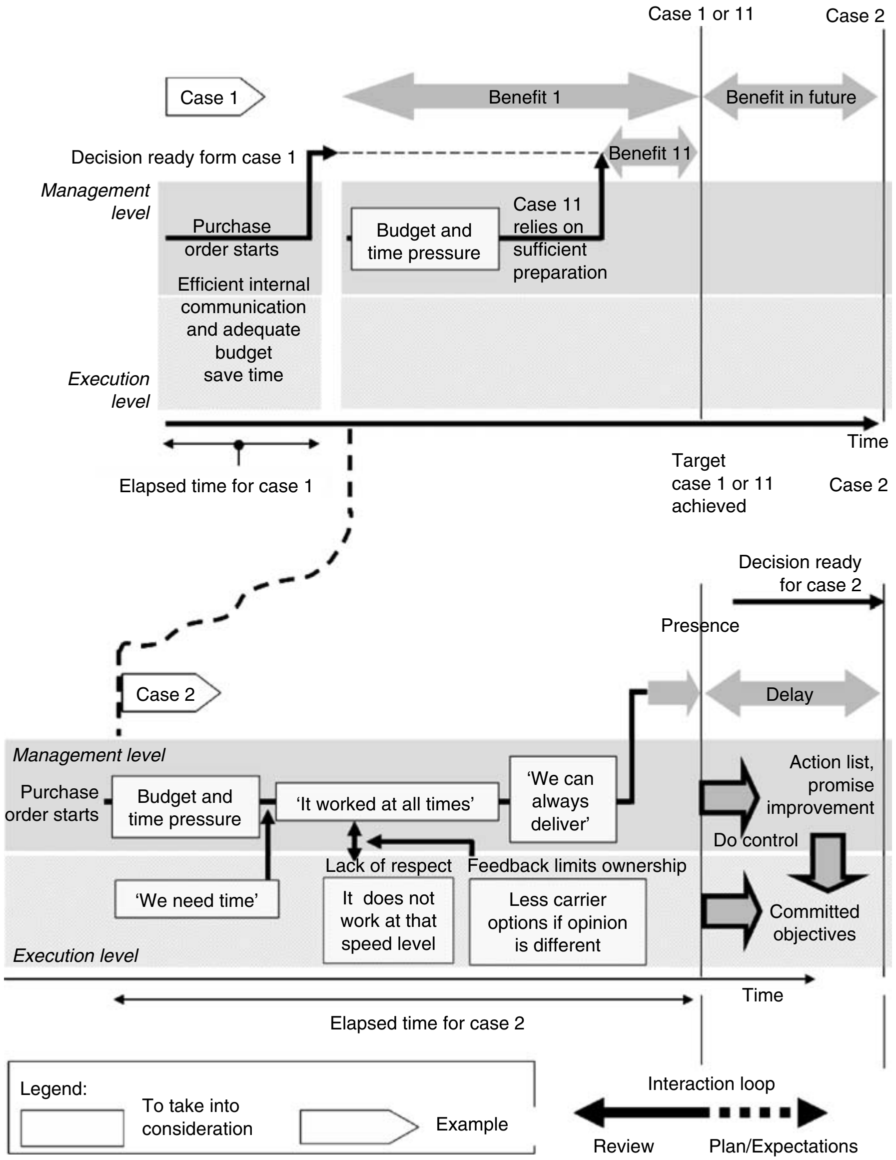


Figure 21.8 Illustration of two very different decision-making processes.

communication between all the staff involved. This is illustrated by two different examples in Figure 21.8. The actual chance of success will not only depend upon the time spent on project planning, but also upon company culture, and budget and market pressures.

21.4.1.3 Inter-factory comparisons

Many companies have several factories often situated in different parts of the world and management often wish to compare throughputs and other efficiency parameters. This can be done by producing the so-called waterfalls for each individual plant, see Figure 21.9.

Such operating data can be recorded both manually as well as automatically, but the quality of such data can vary considerably and should always be checked as should its comparability. In the case of parameters such as plant malfunctions, which have a wide variety of causes, it is not possible to accurately compare them statistically.

21.5 Measurement types and locations

This section looks in detail at the typical processes involved in the production, storage of packaged chocolate products. Each individual stage for example cocoa liquor production (Figure 21.1) is illustrated by a process flow diagram showing the individual processes that take place within it. Key unit operations are shown together with their relative importance, as are critical features which control subsequent processing efficiencies, product safety or are needed for marketing claims for example origin of cocoa. Where appropriate each process is given an identity number to denote that a measurement should be made here. The key to this number is given in a subsequent table (Figure 21.10 illustrates the connection between the figures and tables). For each control it shows whether the measurement is online or in a laboratory and what is being measured. Typical units of measurement are then given together with comments as appropriate. Many of the parameters measured are the result of interactions between the different processes, so the process can only be controlled by regulating all of them. Figures 21.14, 21.16 and 21.19 show where this occurs for important parameters in the cocoa processing, chocolate making and chocolate usage processes.

Experience has shown that knowledge of measurement positions is not in itself enough to successfully solve tasks such as for example the optimization of machine performance and product qualities or other complex problems. For this reason, it is recommended that process parameters be systematically recorded, that the specific know-how be recorded locally and that this be allocated to a process diagram. Unknown parameters should be indicated as such (see Figures 21.11–21.19).

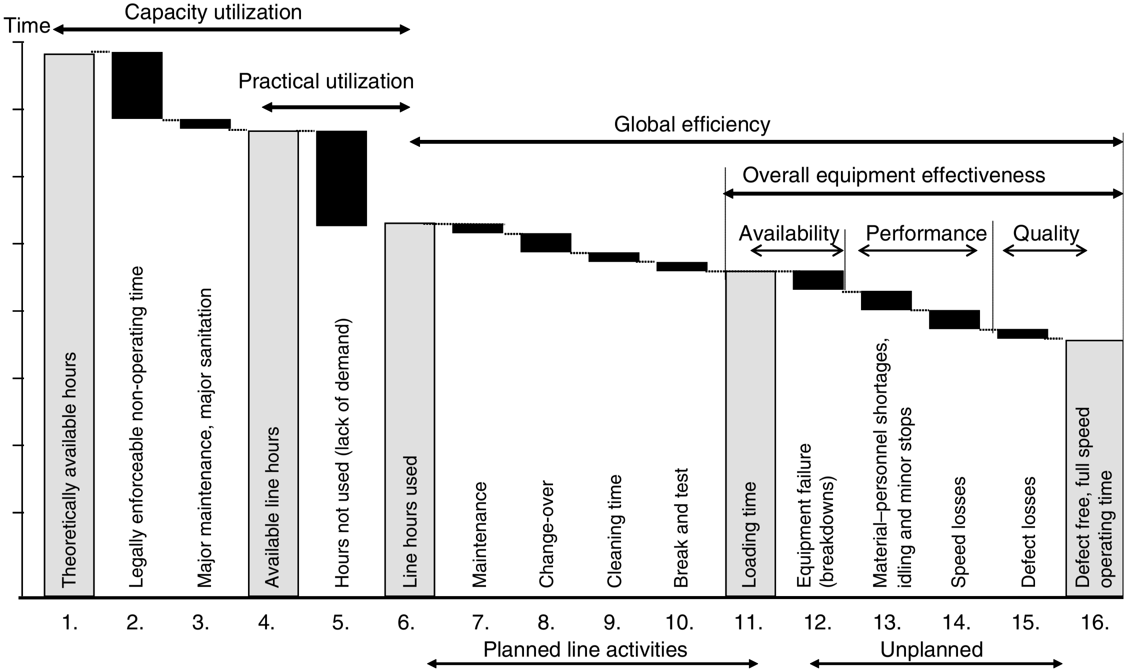


Figure 21.9 Example of a waterfall for a one-bar plant with several packaging machines and storage units.

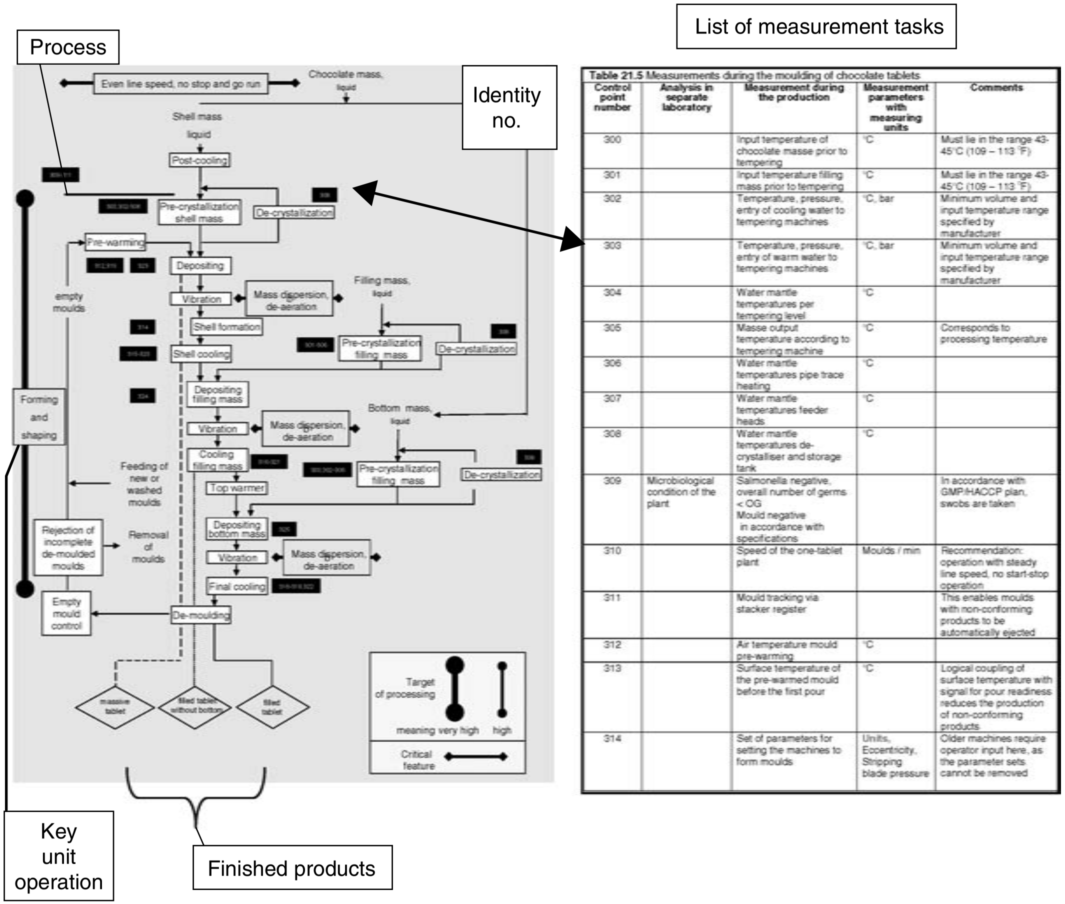


Table 21.5 Measurements during the moulding of chocolate tablets

Control point number	Analysis in separate laboratory	Measurement during the production	Measurement parameters with measuring units	Comments
300		Input temperature of chocolate masse prior to tempering	°C	Must lie in the range 43-45°C (109 – 113 °F)
301		Input temperature filling mass prior to tempering	°C	Must lie in the range 43-45°C (109 – 113 °F)
302		Temperature, pressure, entry of cooling water to tempering machines	°C, bar	Minimum volume and input temperature range specified by manufacturer
303		Temperature, pressure, entry of warm water to tempering machines	°C, bar	Minimum volume and input temperature range specified by manufacturer
304		Water mantle temperatures per tempering level	°C	
305		Masse output temperature according to tempering machine	°C	Corresponds to processing temperature
306		Water mantle temperatures pipe trace heating	°C	
307		Water mantle temperatures feeder heads	°C	
308		Water mantle temperatures de-crystalliser and storage tank	°C	
309	Microbiological condition of the plant	Salmonella negative, overall number of germs < OG Mould negative in accordance with specifications		In accordance with GMP/HACCP plan, swobs are taken
310		Speed of the one-tablet plant	Moulds / min	Recommendation: operation with steady line speed, no start-stop operation
311		Mould tracking via stacker register		This enables moulds with non-conforming products to be automatically ejected
312		Air temperature mould pre-warming	°C	
313		Surface temperature of the pre-warmed mould before the first pour	°C	Logical coupling of surface temperature with signal for pour readiness reduces the production of non-conforming products
314		Set of parameters for setting the machines to form moulds	Units, Eccentricity, Stripping blade pressure	Older machines require operator input here, as the parameter sets cannot be removed

Figure 21.10 Illustration of the interpretation of the following processing diagrams.

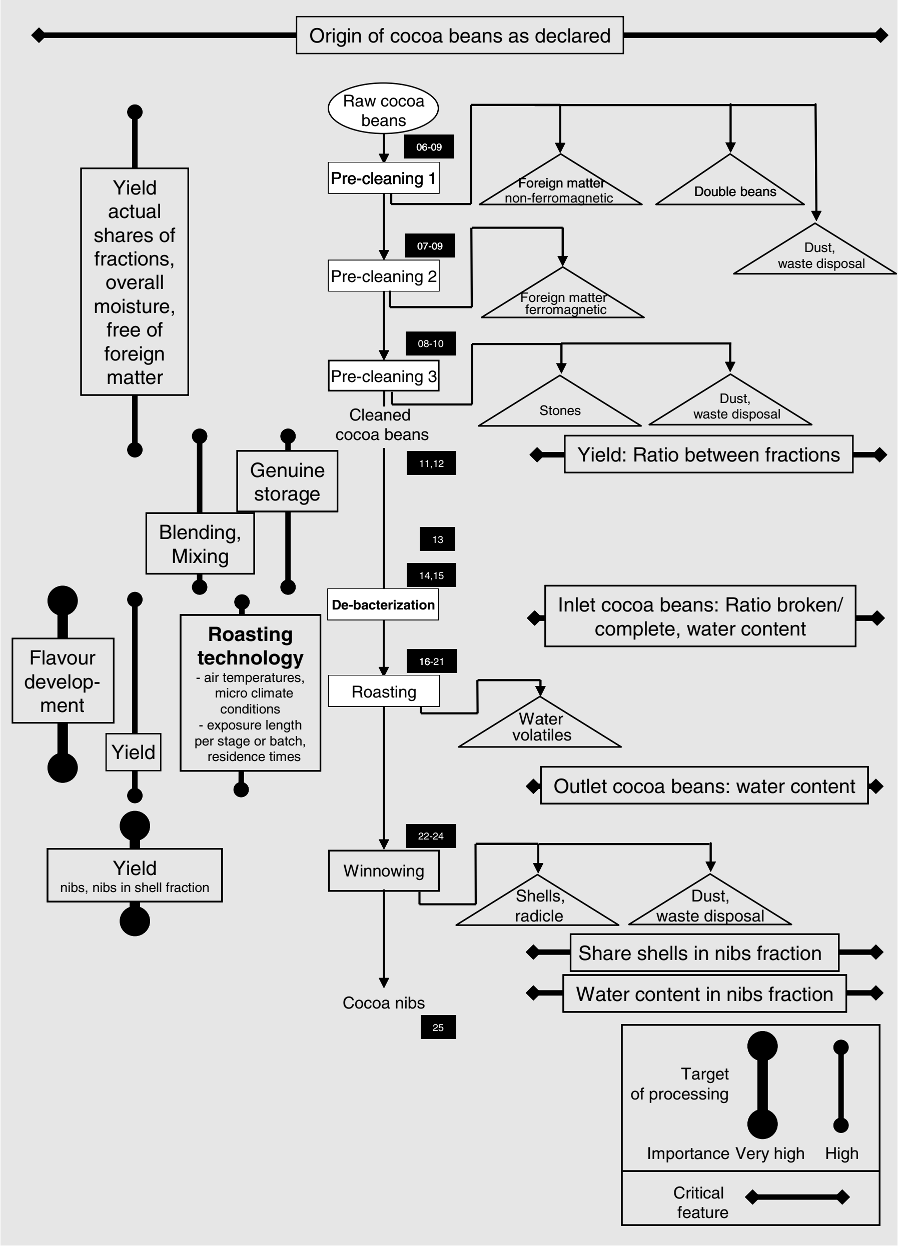


Figure 21.11 From raw cocoa to cocoa nib production.

Table 21.1 Measurements from raw cocoa beans to cocoa nib production.

Control point number	Analyse in separate laboratory	Measurement during the production	Measurement parameters with measuring units (example)	Comments
01	Cut test		Number of beans of specific class	Bean quality
02	100 bean weight		Mass in g	
03	Moisture	Possible	Per cent	
04	Fat content		Per cent	
05	Taste			Exclusion of off flavours
06		Acceptance volume	Mass in kg, tonnes	
07		Under-pressure suction air pre-cleaning machine	mbar	Need to operate the pitch sifter
08				Cleaning the sieve floors
09				Cleaning the permanent magnets
10		Under-pressure suction air stone separator, machine parameters	mbar	Movement of the stones along a trajectory causes particles of the same shape but higher density than cocoa beans to be separated
11		Volume following prior to cleaning	Mass in kg, tonnes	08–06 results in the first loss rate
12		Filling quantity, filling level silo	Mass in tonnes, %, max. position, empty	Decoupling the incoming material prior to further processing

(*Continued*)

Table 21.1 Continued.

Control point number	Analyse in separate laboratory	Measurement during the production	Measurement parameters with measuring units (example)	Comments
13		Mixing ratio	Mass in kg	Producing mixtures of different cocoa bean qualities
14		Steam input		De-bacterization
15	Microbiological condition		Reducing the number of bacteria	De-bacterization, stage 1 and stage 2 possible
16		Inflow volume of beans prior to roaster	Mass in kg, number of weightings is counted	In addition to input volumes of cocoa beans, air volume, air temperatures and waiting periods are the decisive parameters
17		Pressure difference	mbar	Air monitoring
18		Air temperature	°C	Separately for each zone
19		Temperature cocoa bean	°C	Separately for each zone
20		Moisture content	%	Determining the residual moisture
21	Taste of roasted cocoa beans		Valuation scale	Allocation in conjunction with the in-house taste
22	Shells in nib fraction		%	Sometimes limited by law, in proportion to silica ratio
23	Nibs in shell fraction		%	Loss ratio laborious to determine
24	Volume ratios of the individual nib fractions		% of the total fraction	Makes it possible to draw conclusions about the ability to separate shells from nibs
25		Volume of nibs	Mass in kg, tonnes	Total loss 24 – 06

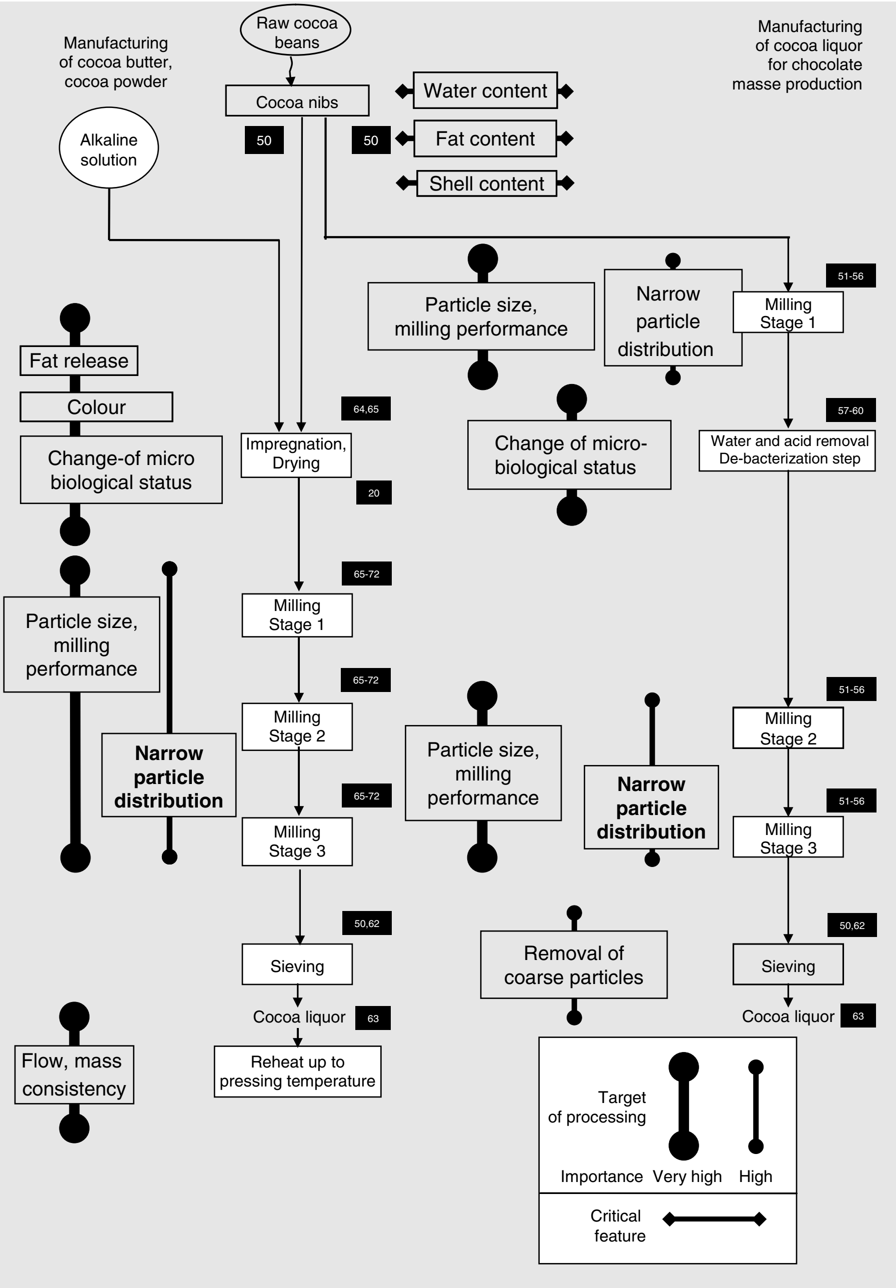


Figure 21.12 From cocoa nibs to cocoa liquor.

Table 21.2 Measurements from processing of cocoa nib to cocoa liquor.

Control point number	Analyse in separate laboratory	Measurement during the production	Measurement parameters with measuring units (example)	Comments
50				Cleaning the permanent magnets
51		Throughput	kg/h	Input to first mill: cocoa nib fracture in accordance with specifications
52		Under-pressure extraction	mbar	Extraction of gasses, mostly during 1st + 2nd milling stage
53		Cooling water temperature	°C	Water cooling essential for all cocoa mills
54		Cooling water pressure	bar	Provision of the necessary flow volume
55		Knife or ball wear	Service life	Changing the knife or balls
56		Keep sieve free	Visual check	Following ball milling
57		Water content following injection	%	De-bacterization by thin-film evaporation, e.g. in a Petzomat
58		Reactor temperatures	°C	
59		Resting times	Units according to pump setting	
60	Microbiological condition		Salmonella, overall germ number <upper limit in accordance with specifications	De-bacterization

61		Fineness	$D(90) = 18$ µm (90% of particles <18 µm)	
62		Visual checks of the process of sieving the cocoa mass		Sieve mesh size approx. 200 µm, sieve undamaged, regular removal of residues (large cocoa shell particles)
63	Taste of cocoa mass		Valuation scale	Allocation in conjunction with the in-house taste
64		Preparation of alkali solution	g/m^3,°C	Alkali solution both for cocoa mass as well as for cocoa nib particles
65		Throughput	Min per application	Impregnation + drying
66				Milling the prepared cocoa nib fracture
67				Cleaning the permanent magnets
68		Throughput	kg/h	Input to first mill: cocoa nib fracture in accordance with specifications
69		Underpressure extraction	mbar	Extraction of gasses, mostly during 1st + 2nd milling stage
70		Cooling water temperature	°C	Water cooling essential for all cocoa mills
71		Cooling water pressure	bar	Provision of the necessary volume
72		Knife or ball wear	Service life	Changing the knife or balls

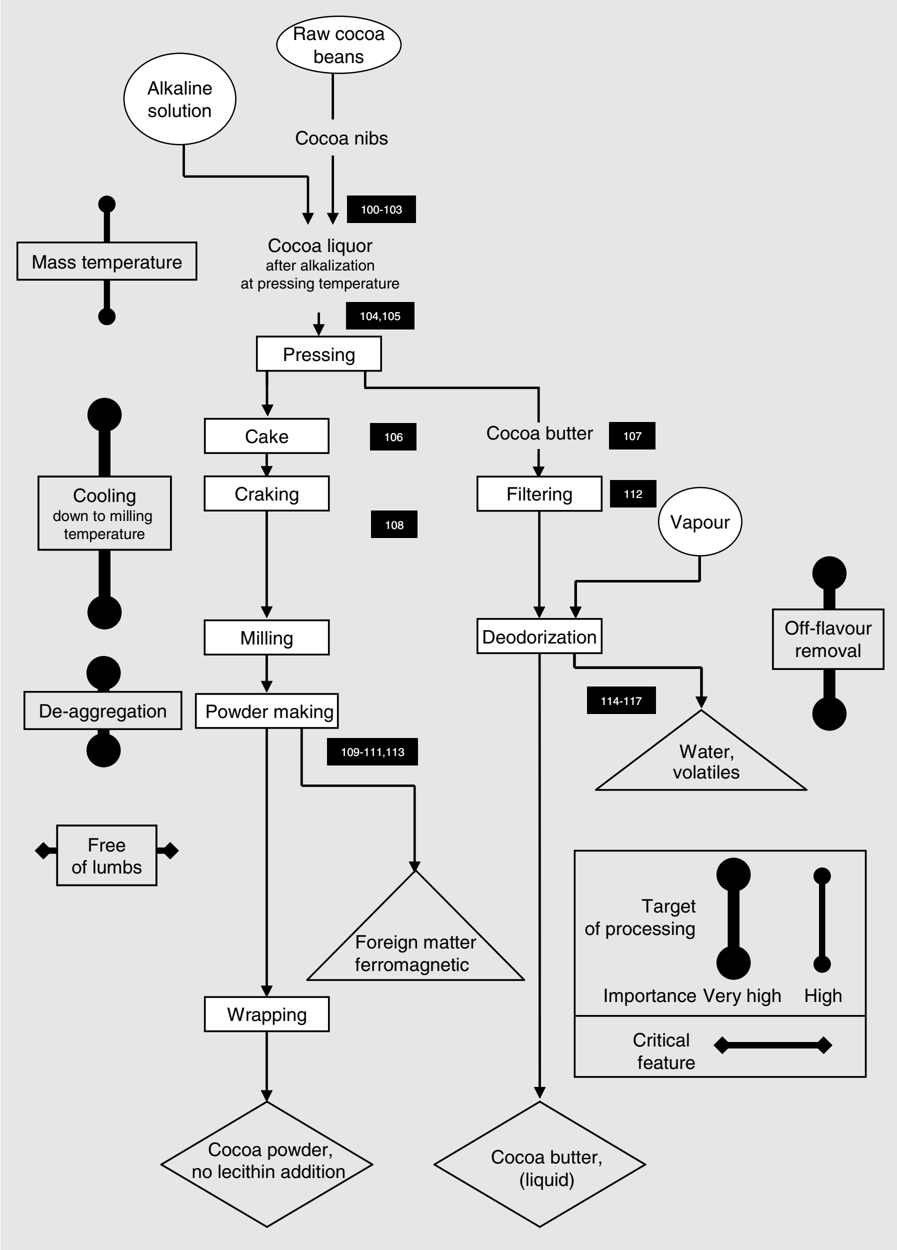


Figure 21.13 Cocoa butter and cocoa powder manufacture.

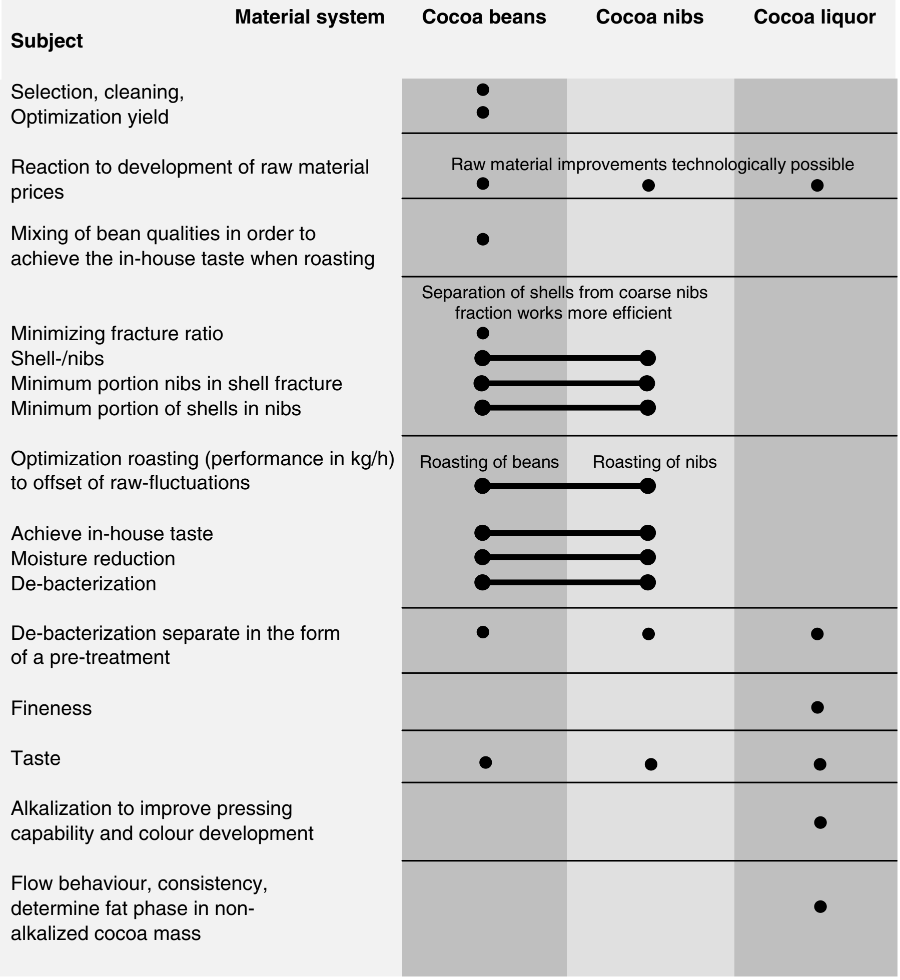
Table 21.3 Measurements for cocoa butter and cocoa powder production.

Control point number	Analyse in separate laboratory	Measurement during the production	Measurement parameters with measuring units (example)	Comments
100		Moisture content of prepared cocoa mass	%	Residual moisture determines pressing ability
101		Fat content of cocoa mass	%	Determines pressing time
102		Mass input temperature	°C	Important for pressing ability
103		Input volume of cocoa mass per pressing chamber	kg	
104		Cycle time	min	Derived from the working diagram for the recipe in question
105		Pressing time in accordance with program controls and residual fat content	min	Derived from the working diagram for the recipe in question
106	Residual fat content of cocoa pressed cake		%	In accordance with specifications
107		Quantity of cocoa butter per pressing	kg	
108		Temperature of the broken cocoa pressed cake	°C	Controlled cooling

(*Continued*)

Table 21.3 Continued.

Control point number	Analyse in separate laboratory	Measurement during the production	Measurement parameters with measuring units (example)	Comments
109		Temperature of the cocoa powder	°C	Controlled cooling
110	Colour of the cocoa powder			Comparison vis-à-vis colour scale and preparation process
111	Taste of the cocoa powder		Relative units	Comparison relative to standard
112		Cloudiness of cocoa butter before and after filtering		Comparison relative to standard
113	Microbiological condition of the cocoa powder		*Salmonella*, overall germ number <upper limit in accordance with specifications	De-bacterization
114	Taste of the de-odorized cocoa butter			Comparison relative to standard
115		Aroma profile before and after de-odorizing		Comparison relative to standard
116		Temperature of the cocoa butter	°C	According to specified storage conditions
117	Microbiological condition of the de-odorized cocoa butter		*Salmonella*, overall germ number <upper limit in accordance with specifications	De-bacterization



Material system Subject	Cocoa beans	Cocoa nibs	Cocoa liquor
Selection, cleaning, Optimization yield	● ●		
Reaction to development of raw material prices	Raw material improvements technologically possible ●	●	●
Mixing of bean qualities in order to achieve the in-house taste when roasting	●		
	Separation of shells from coarse nibs fraction works more efficient		
Minimizing fracture ratio	●		
Shell-/nibs	●	●	
Minimum portion nibs in shell fracture	●	●	
Minimum portion of shells in nibs	●	●	
Optimization roasting (performance in kg/h) to offset of raw-fluctuations	Roasting of beans ●	Roasting of nibs ●	
Achieve in-house taste	●	●	
Moisture reduction	●	●	
De-bacterization	●	●	
De-bacterization separate in the form of a pre-treatment	●	●	●
Fineness			●
Taste	●	●	●
Alkalization to improve pressing capability and colour development			●
Flow behaviour, consistency, determine fat phase in non-alkalized cocoa mass			●

Figure 21.14 Summary of the main reactions and where they occur during cocoa processing.

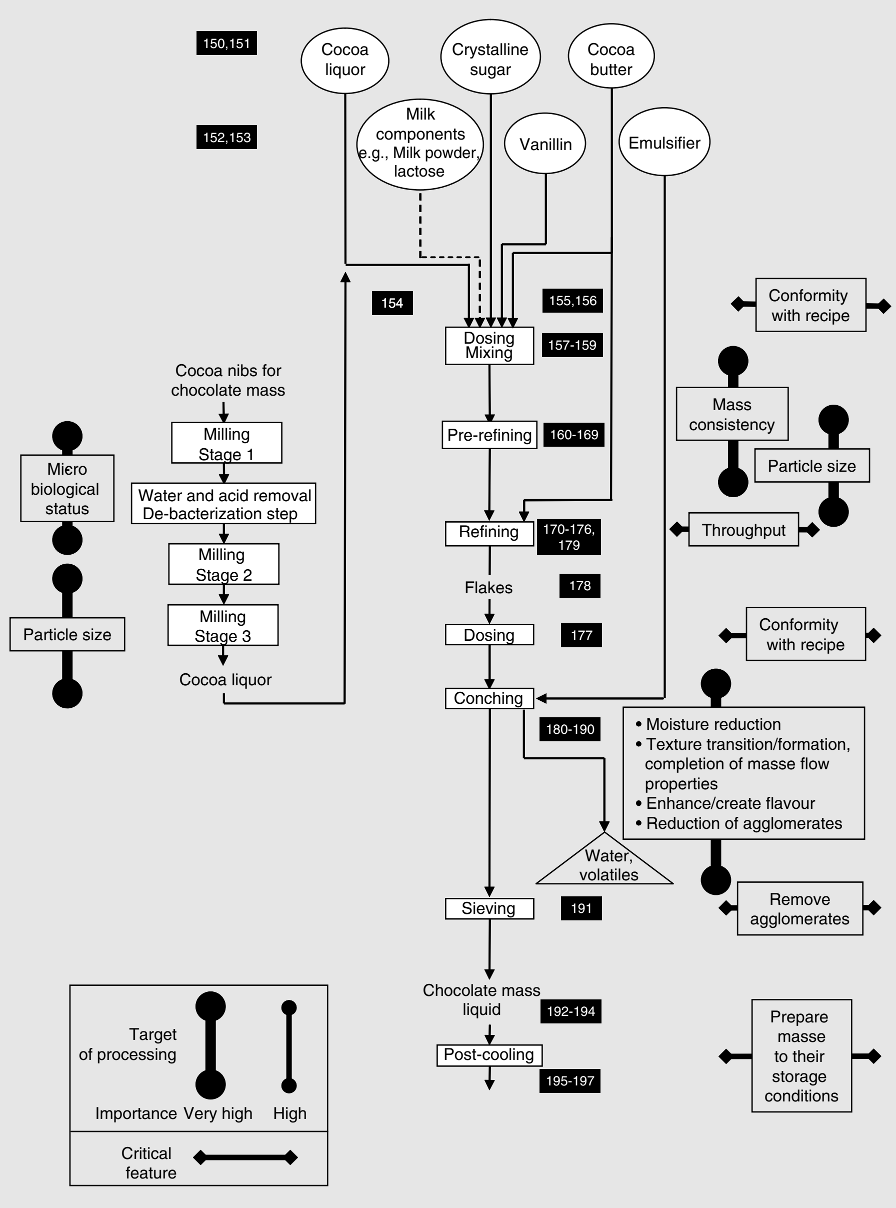


Figure 21.15 Chocolate masse manufacture.

Table 21.4 Measurements during chocolate masse manufacture.

Control point number	Analyse in separate laboratory	Measurement during the production	Measurement parameters with measuring units (example)	Comments
150	Microbiological condition of all raw materials	*Salmonella*, overall bacteria count <upper limit in accordance with specifications		
151	Taste of all raw materials		Relative units	Comparison relative to standard
152	Moisture content of milk powder, cocoa mass		%	Comparison vis-à-vis specifications
153	Fat content of milk powder, cocoa mass		%	Comparison relative to standard
154		Temperature of liquid components	°C	Comparison vis-à-vis specifications
155		Air temperature of production areas	°C	Comparison vis-à-vis specifications
156		Air humidity of production areas	% r.h.	Comparison vis-à-vis specifications
157		Mixing ratio according to mixing protocol	Mass in kg	Production of mixtures in accordance with recipe, obligation to produce supporting documentation
158		Report: mixing process fully completed	Yes/No	
159		Temperature of water mantle mixer	°C	
160		Inflow of cooling water temperature pre-refiner	°C, bar	Minimum volume and input temperature range specified by the manufacturer
161		Hydraulic pressure Pre-refiner	bar	
162		Filling level pre-container fine mill	%	Influences mass distribution

(Continued)

Table 21.4 Continued.

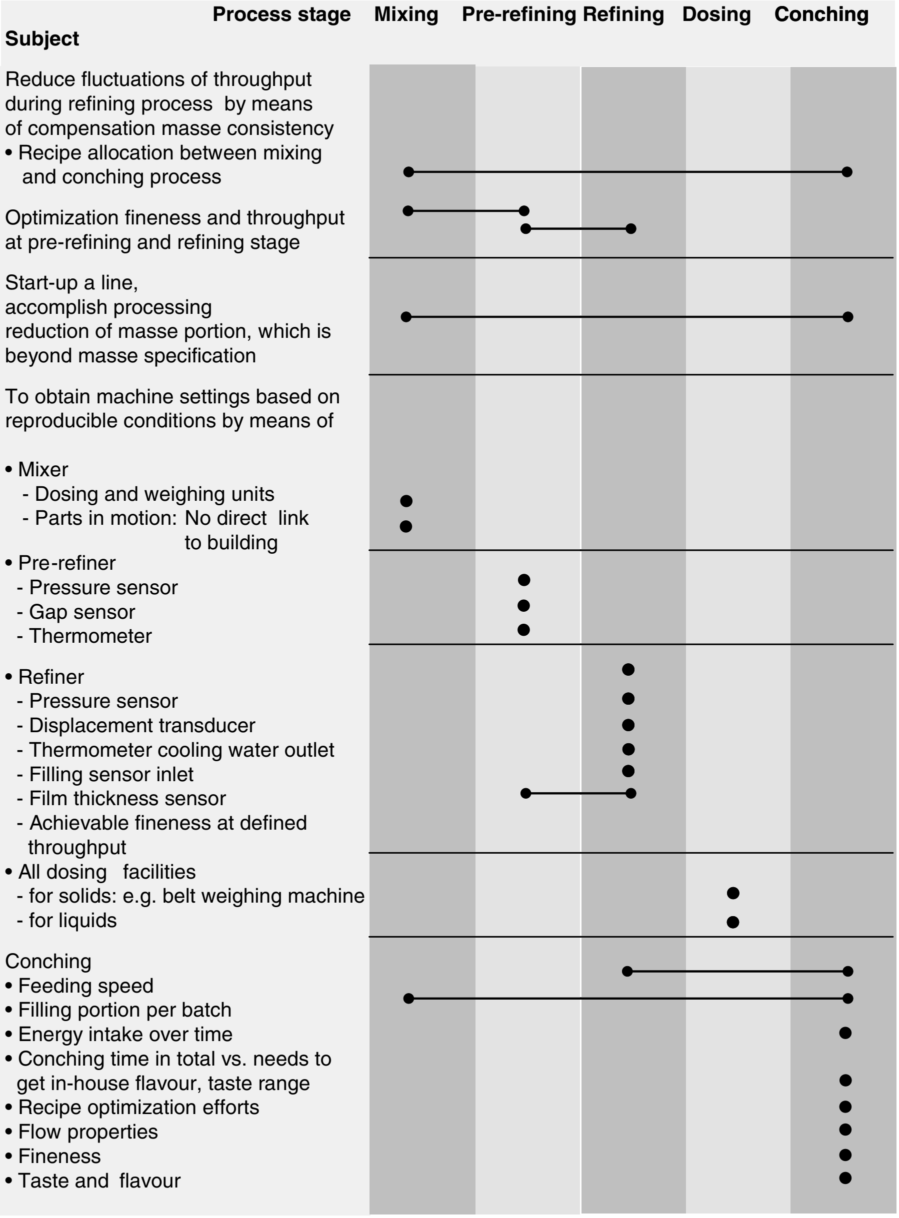
Control point number	Analyse in separate laboratory	Measurement during the production	Measurement parameters with measuring units (example)	Comments
163		Opening angle, opening time of pre-container flap	°, ms	Influences inflow volume
164		Changing the stripping blade on the roughing mill	Yes/No	
165		Consistency of rough milled mass		
166		Fineness of the rough milled mass	μm (screw micrometer)	Precision only rough guide
167		Pressure left, right pre-refiner	bar	Consistency of the rough milled mass can be influenced
168		Cooling water exit temperature for each milling of the pre-refiner	°C	Fineness of mill slit adjustable by operator
169		Mill slit of pre-refiner	Units	Consistency of the rough milled masse can be influenced
170		Filling level pre-container fine mill	%	Influences masse distribution
171		Opening angle, opening time of pre-container flap	°, ms	Influences input volume
172		Inflow cooling water temperature fine mill	°C, bar	Minimum volume and input temperature range specified by manufacturer, decisive process parameters for fineness and throughput
173		Cooling water output temperatures for each mill	°C	Fineness per mill slit adjustable by operator

174	Pressure left, right separate for each mill	bar	Fineness per mill slit adjustable by operator
175	Useful life stripping blade	h (approx. 8 h)	Influences the formation of a film
176	Useful life mill set	h (approx. 5000–8000 h)	Linked to finesses, throughput, professsional operation, amount of silica
177	Throughput of milled material using band scales or by measuring the time required for a mixer unit	kg/ph (e.g. 1000 kg/ph)	Only way to determine the throughput without further aids such as beam scales, a decisive process parameter along with fineness.
178	Fineness milled material overall sample	μm using micrometer or *D*(90) using laser diffactometry	Routine checks, sample frequency directly linked to the desired setting precision with respect to cover degree and throughput
179	Fineness of milled material removed from water side, centre, drive side	μm (screw micrometer) *D*(90) laser diffractometry	Checking the parallelism of the mill settings
180	Temperature, pressure of cooling water	°C, bar	Minimum volume and input temperature range specified by the manufacturer
181	Temperature, pressure, hot water	°C, bar	Minimum volume and input temperature range specified by the manufacturer
182	Start conching cycle time	h : min : s	Delivered time basis
183	Dosage rate cocoa butter and/ or emulsifier (lecithin)	kg/h	Reduced risk of agglomeration
184	Inflow volume milled material for dosage in the conching unit	kg/h	Continual feed
185	Dosage of fat input	kg per application	Adherence to recipe, timing

(*Continued*)

Table 21.4 Continued.

Control point number	Analyse in separate laboratory	Measurement during the production	Measurement parameters with measuring units (example)	Comments
186		Dosage input emulsifier	kg per application	Adherence to recipe, timing
187		Current consumption in conching unit	A	Comparison with recipe specifications
188		Masse temperature in conching unit	°C	Comparison with recipe specifications
189		Length of time between end of loading and reaching maximum masse temperature	h:min:s	Comparison with recipe specifications
190		Begin pumping out the finished conched masse	h:min:s	End of the conching process
191		Sieve residues	mg/kg	Removal of agglomerate
192	Flow characteristics		Pa s Pa	Viscosity Yield value
193	Microbiological condition of the finished chocolate masse	*Salmonella*, overall bacteria (germ) number <upper limit in accordance with specifications		
194	Taste of the finished chocolate masse		Relative units	Comparison relative to standard
195		Cooling of the masse to storage temperature	°C	Standardization required to ensure masse entry temperatures into the tempering machines remains within narrow limits
196		Masse temperatures when storing liquid masses	°C, storage duration limited	White chocolate must be stirred at certain intervals
197		Water mantle temperatures when storing liquid masses	°C	Heatable tanks suitable only for stabilizing the input temperature of a masse



Subject / Process stage	Mixing	Pre-refining	Refining	Dosing	Conching
Reduce fluctuations of throughput during refining process by means of compensation masse consistency • Recipe allocation between mixing and conching process	●				●
Optimization fineness and throughput at pre-refining and refining stage	●	● ●	●		
Start-up a line, accomplish processing reduction of masse portion, which is beyond masse specification	●				●
To obtain machine settings based on reproducible conditions by means of					
• Mixer					
- Dosing and weighing units	●				
- Parts in motion: No direct link to building	●				
• Pre-refiner					
- Pressure sensor		●			
- Gap sensor		●			
- Thermometer		●			
• Refiner			●		
- Pressure sensor			●		
- Displacement transducer			●		
- Thermometer cooling water outlet			●		
- Filling sensor inlet			●		
- Film thickness sensor		●	●		
- Achievable fineness at defined throughput					
• All dosing facilities					
- for solids: e.g. belt weighing machine				●	
- for liquids				●	
Conching					
• Feeding speed			●		●
• Filling portion per batch	●				●
• Energy intake over time					●
• Conching time in total vs. needs to get in-house flavour, taste range					●
• Recipe optimization efforts					●
• Flow properties					●
• Fineness					●
• Taste and flavour					●

●—● Shows interactions between the different processes

Figure 21.16 Summary of the main reactions and where they occur during chocolate masse manufacture.

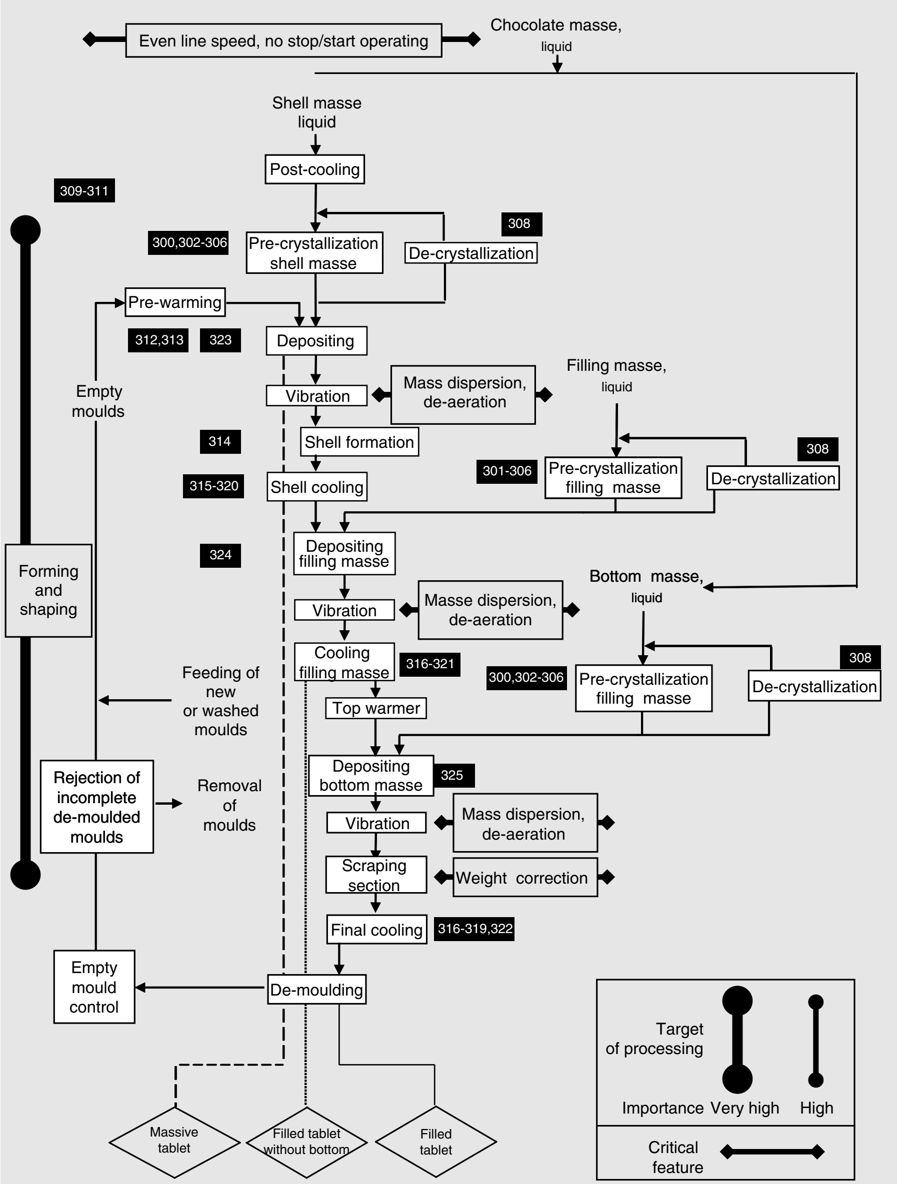


Figure 21.17 The moulding of chocolate bars and filled tablets.

Table 21.5 Measurements during the moulding of chocolate tablets.

Control point number	Analysis in separate laboratory	Measurement during the production	Measurement parameters with measuring units	Comments
300		Input temperature of chocolate masse prior to tempering	°C	Must lie in the range 43–45°C (109–113°F)
301		Input temperature filling mass prior to tempering	°C	Must lie in the range 43–45°C (109–113°F)
302		Temperature, pressure, entry of cooling water to tempering machines	°C, bar	Minimum volume and input temperature range specified by the manufacturer
303		Temperature, pressure, entry of warm water to tempering machines	°C, bar	Minimum volume and input temperature range specified by the manufacturer
304		Water mantle temperatures per tempering level	°C	
305		Masse output temperature according to tempering machine	°C	Corresponds to processing temperature
306		Water mantle temperatures pipe trace heating	°C	
307		Water mantle temperatures feeder heads	°C	
308		Water mantle temperatures de-crystallizer and storage tank	°C	
309	Microbiological condition of the plant	*Salmonella* negative, Microbiology standards Mould negative in accordance with specifications		In accordance with GMP/HACCP plan, swabs are taken
310		Speed of the one-tablet plant	Moulds/min	Recommendation: operation with steady line speed, no start–stop operation
311		Mould tracking via stacker register		This enables moulds with non-conforming products to be automatically ejected
312		Air temperature mould pre-warming	°C	

(*Continued*)

Table 21.5 Continued.

Control point number	Analysis in separate laboratory	Measurement during the production	Measurement parameters with measuring units	Comments
313		Surface temperature of the pre-warmed mould before the first pour	°C	Logical coupling of surface temperature with signal for pour readiness reduces the production of non-conforming products
314		Set of parameters for setting the machines to form moulds	Eccentricity, Stripping blade pressure	Older machines require operator input here
315		Air temperature of shell cooler, applied mostly identically to all other refrigerators	°C	Model determines the number of measurement points, refrigerators can also consist of several zones
316	Microbiological condition	Temperature register, coolant input and output, identical with all other refrigerators, functioning condensation outflow	°C	Modern systems operate using glycol/water mixture, entry temperature >0°C, to prevent ice formation
317	Microbiological condition	Drip cutter	–	Ensure cleaning, re-move condensed water
318		Air sieve	–	Ensure cleaning
319		Ventilator speed, adjustable, identical application in all other refrigerators		Should be operated in accordance with the operating speed
320		Surface temperature, performance per mould	°C, W/mould	Quick warming ensures a secure link between the product surface of the mould + filling
321		Air temperature Filling cooler	°C	Model determines the number of measurement points, refrigerators can also consist of several zones
322		Air temperature Final cooler	°C	Model determines the number of measurement points, refrigerators can also consist of several zones
323		Shell depositing, parameter set		Depending upon model
324		Filling depositing parameter set		Depending upon model
325		Bottom depositing, parameter set		Depending upon model

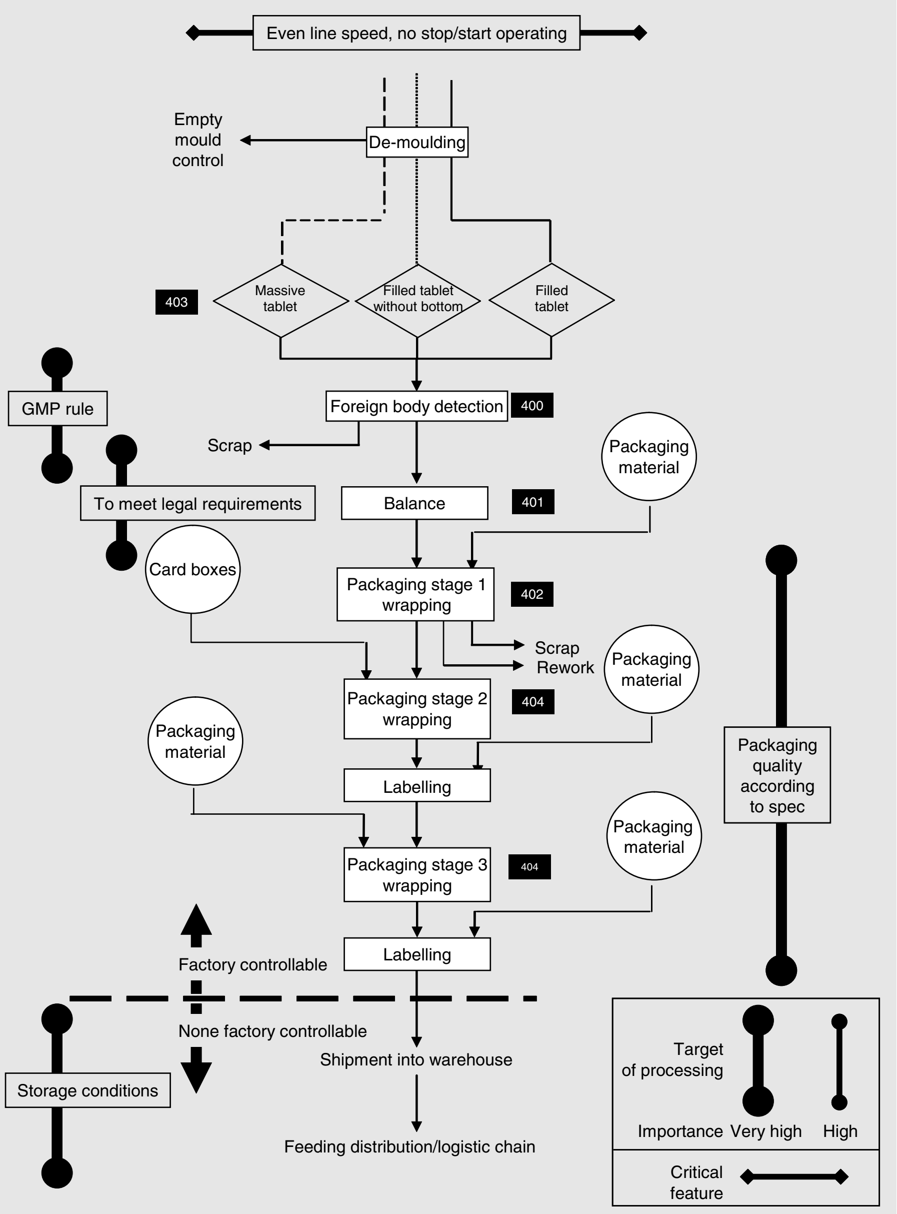


Figure 21.18 Packaging, storing and transport.

Table 21.6 Measurements during packaging and transport.

Control point number	Analysis in separate laboratory	Measurement during the production	Measurement parameters with measuring units	Comments
400		Standard test before start of shift		Efficiency testing of the metal detectors
401		Sampling for weight tests	g	Even if no in-line scales systems are available, it is nevertheless essential to document the weight of the tablets
402		Checks of packaging material and coding		Use of the correct packaging material/coding in accordance with the terms of the order
403		Separating out of irregular, bent tablets		Shape measurements must be adhered to. This is to ensure that the outer box can be packed automatically without disruption
404		Checking the coding		Use of the correct coding on the labels in accordance with the terms of the order

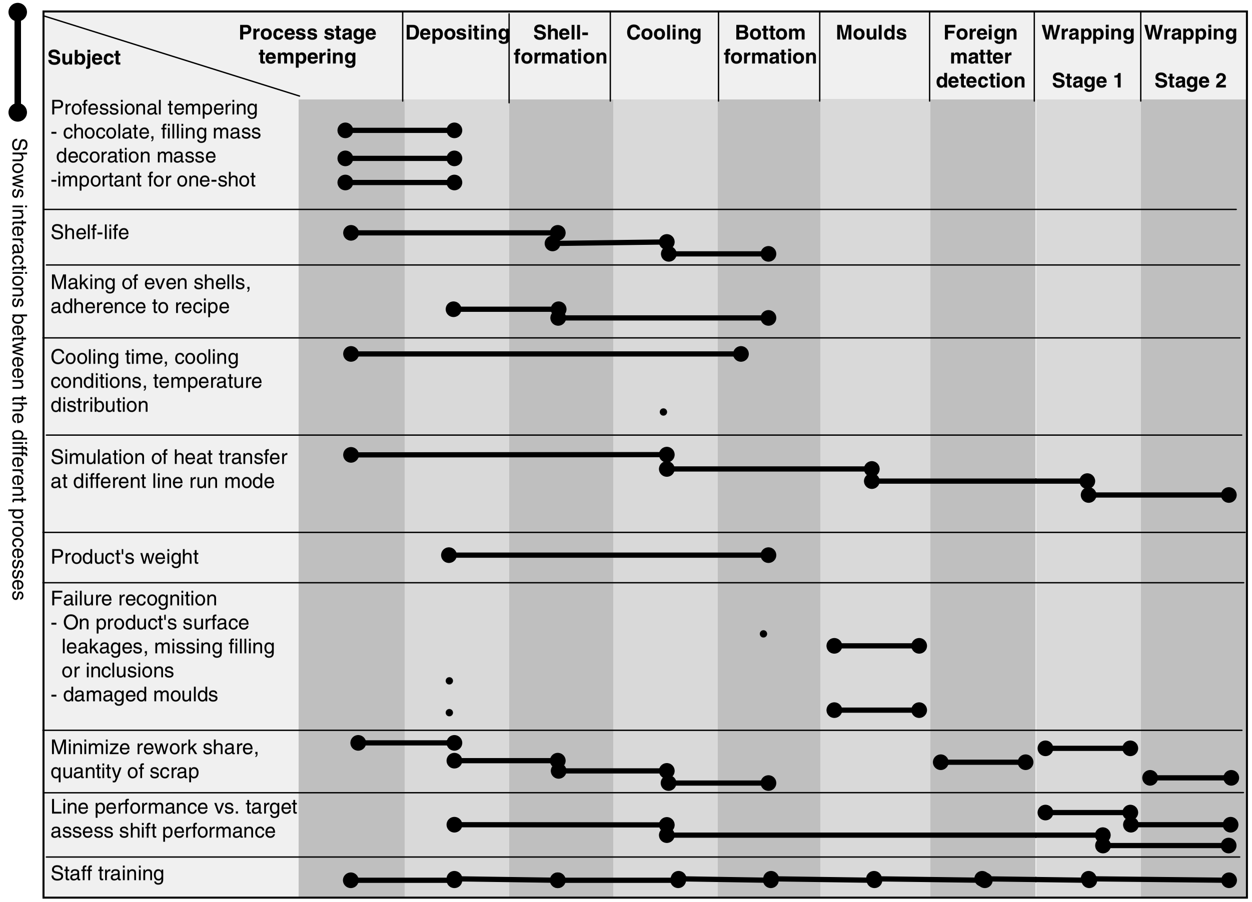


Figure 21.19 Summary of important parameters and where they occur during chocolate moulding and packing.

Conclusions

Good project management is essential before installing any process control systems. The importance of having a team with a wide experience of all the different parts of confectionery processing cannotbe overestimated, nor can the need for good communications and user-friendly instrumentation.

Projects tend to have the following structure:

(1) planning, implementation and analysis of the CURRENT state,
(2) preparing cost-effectiveness studies, for example analysing raw material losses,
(3) introducing new process controls or optimizing existing process controls to achieve/maintain specifications, such as specific quality characteristics, or for example the in-house taste.

The process control point overviews in Section 21.5 have been specially developed to help explain complexities of producing cocoa and chocolate products. These provide users with information and examples based upon current standard processing technologies. Although many other processes exist, much of it is common to most manufacturers and in addition it is possible to tailor this information to suit different applications.

Further reading

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Chapter 22

INSTRUMENTATION

U. Löser

22.1 Introduction

Confectionery production involves the measurement of a large number of parameters and many instruments already exist on the market. To use these instruments correctly, however, it is very important for the production team and project technicians to have the required knowledge and skill to understand the operations and also to interpret their data to provide meaningful solutions to production-realted problems. In addition it is desirable to be able to work together with instrument manufacturers so as to further develop improved instrumentation.

22.1.1 General measurement tasks

It is legally and economically imperative that all companies comply with ISO Standards, laws and regulations concerning food safety and HACCP, GMP/QA/SS&E etc. (Chapter 23) and measurements concerning these become part of our daily life. Food safety standards need to be continuously improved and implemented throughout the entire factory, not only in production areas but also in the laboratory. To ensure an appropriate hygiene standard among employees and suppliers, measurements are stipulated in documents relating to GMP and QA/SS&E. These include, for instance, employee training and instructions to suppliers prior to repairs, installation and commissioning etc. Large-scale cleaning operations must be performed at regular intervals and this provides information concerning the current hygiene situation. Long-term preventive measures, for example rodent or insect traps, produces useful data regarding trends, which should be analysed on a regular basis.

22.1.2 Microbiological measurements

Measurements of the microbiological conditions are required to ensure product safety. Raw material must be checked for compliance with

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specification. In addition, the microbiological condition of intermediate products, for example cocoa mass after de-bacterization, is examined. The microbiological conditions in the surroundings (machinery, equipment, storage areas) as well as the environment around a production site are determined with the aid of smears collected on a systematic basis. The condition of finished products is the most important and must be determined in accordance with in-plant guidelines and food safety laws and regulations. This includes routinely determining the overall bacteria count and ensuring the absence of *Salmonella.* Very often these specialized analyses are carried out at a central laboratory or out-sourced and they are not described in this chapter.

22.1.3 Use of data analysis

Instrumental results, called measured values, give a numerical value for each individual measurement together with a unit of measure. The error of the value must be taken into account and depends upon the accuracy of the measurement and reading, as well as such things as the bit width and scanning rate of the analogue-to-digital converter, where they are used. It is possible to establish the overall error of the measurement method.

After the measurements have been performed and the data have been recorded, the collected measured values are subjected to statistical analysis in order, for instance, to assign the type of mathematical distribution characteristic of each series of measurements. Distribution functions, confidence intervals and standard deviations can be determined from measured process data. It is important that the appropriate statistical evaluation procedure be correctly used for example parametric hypothesis test for quantitative variables, proportion hypothesis test for qualitative variables, Chi-squared fit test (test for type of distribution), Chi-squared test for independence, *F*-test for significant differences of location (means), or correlation test for linearity of a relationship in order to be able to interpret it correctly. It is then possible to explain the important parameters more certainly on the basis of graphic representations and also to distinguish between primary and secondary effects. In this way, misinterpretations can be largely excluded and improper handling of the data becomes detectible. Such an analysis is required when determining the cause of problems, before for plant optimization, and for new product/process development.

22.1.4 Use of results of data analysis to provide long-term production stability

The determination of measured values with a known distribution function and known errors represents the first step towards automated production using programmable-logic controllers (PLC), as control circuits can then be designed, tested and engineered by the technical staff.

Customers' trust in the manufacturer and the manufacturer's products is very important to develop a long-term relationship. Even though the manufacturing process is not of interest to the customer, it is nevertheless a necessary prerequisite for guaranteeing a definite product quality. Manual or mechanical (automatic) process controls represent one component of the manufacturer's specification and serve as the means to achieve reliable quality assurance. The actual value of a measurement depends upon how the data are obtained and used by the manufacturer's management and production team.

22.2 Production measurement technology – in/on-line, off-line

There are a huge number of instruments and it is impossible to cover it all within a single chapter. The following sections are therefore limited to selected principles of measurements using examples that are important to the confectionery industry.

The following measurement applications are used as part of machinery control systems.

22.2.1 Recording time

When monitoring product throughput for example counting packaged bars, the elapsed time is measured. In this way, machine operating hours can be specified for specific lot sizes. Determining the useful life of individual refiner rolls is another example. A time period is obtained for which desired product features or machine settings can be maintained. Time measurements can be obtained automatically, for example in the case of synchronized measurements based on trigger signals and can be saved in machine-readable form. Typical examples of time-dependent measurements are shown in Table 22.1.

22.2.2 Recording position (location)

Position (location) is recorded as a part of many measurement tasks. Programming a mould stacker register to automatically determine the current position (location) of a specific mould in a moulding plant represents an important application. Alternatively, moulds can be fitted with RFID (radio frequency identification) sensors in order to determine the position (location) more accurately.

A further example involves knowing the position of individual products/product series along a feed conveyor. This can be used, for instance, to control the feeding of several packaging machines and storage units.

The handle position on directional control valves indicates the current port size in relation to the fully open port. The change in handle angle with time

Table 22.1 Typical time-dependent measurements.

	Dimension as an example	Typical examples
Time as basic variable		
Day:Hour:Minute:Second	dd:hh:min:s	Start of a cycle time, e.g. a fill, Time stamp from a database,
Second	s	Time interval
Frequency		
Hertz	Hz = 1/s	Line frequency, Scanning rate of a scanner
Number	units bars/min moulds/min	Quantity produced, Output of packaging machine, Output of a moulding plant
Revolutions/time	rev./min	Speed of a motor
Velocity, speed	m/s	Belt speed, Air velocity in a cooling tunnel, Flowpack – packaging rate
Angular velocity	rad/s	Feature of a stepping motor
Acceleration	m/s^2	When re-starting packaging equipment
Angular acceleration	rad/s^2	Feature of a stepping motor
Volumetric flow rate	m^3/h	Cooling water flow rate, Volumetric air flow from a fan

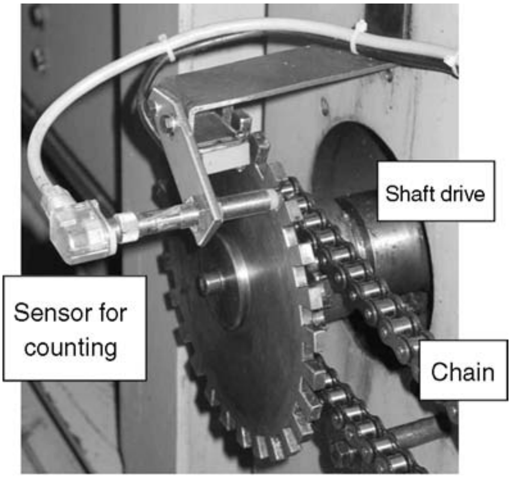


Figure 22.1 Incremental encoder on a drive shaft.

is an indication of variations in throughput in a control loop. Alternatively rotary motions can be monitored for example by attaching an incremental encoder to the drive shaft of a conveyor belt, see Figure 22.1.

Typical location/position measurements are listed in Table 22.2.

CCD (charge coupled device) cameras are often used where two-dimensional information is required. Depending on the measurement task, a CCD

Table 22.2 Typical examples of length/position-based measurements.

	Dimension as example	Typical examples
Dimension		
Length as basic variable,	mm	Effective roll length in a roll mill
Distance	mm	Crown: increase in roll diameter in a roll mill
Gap size	units	Gap between two matched rolls in a roughing mill
Diameter	mm	Diameter of balls in a ball mill
Surface area	m^2	Surface area in a heat exchanger
Volume	m^3	Volume of air provided for ventilation

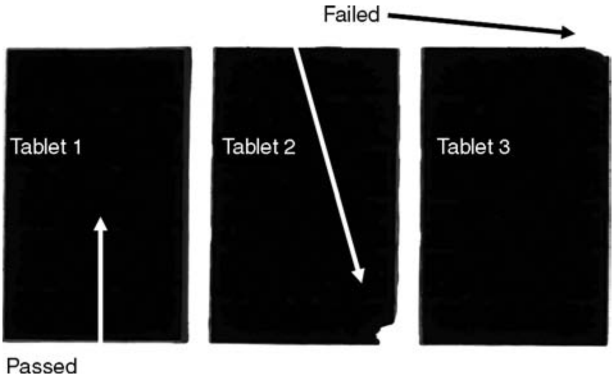


Figure 22.2 Result from a CCD linescan.

linescan or a CCD array camera can be used. Triggering ensures undistorted information, which is then converted into an image by a computer system (see Figures 22.2–22.6).

Imaging methods record specific areas of the product, as well as detecting defects and their type, for example Figure 22.2 (chocolate tablet 1 without damage, chocolate tablet 2 with damage at the lower right, chocolate tablet 3 with damage at the upper right). As a further refinement, 3-D sensors can obtain height information for specific locations in order to provide complete spatial imaging of surfaces, see Figures 22.3, 22.5 and 22.6. The principle of operation employed in 3-D sensors is based on triangulation, see Figure 22.4.

22.2.3 Recording by numbers

Counting can be a relatively simple measurement. A few applications are as follows:

- Rotary motion is recorded using the individual segments of a disc with a specially manufactured edge. A predetermined number of teeth produce counting pulses in a sensor during rotation (see Figure 22.1).

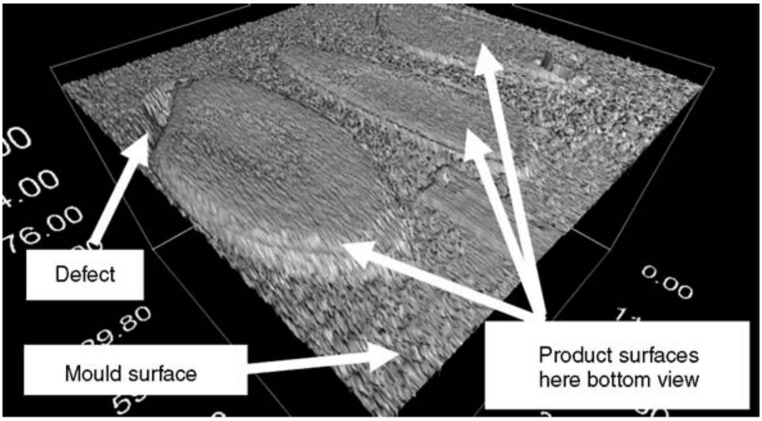


Figure 22.3 Use of a 3-D scanner. Reproduced with permission of Rohwedder AG, Germany.

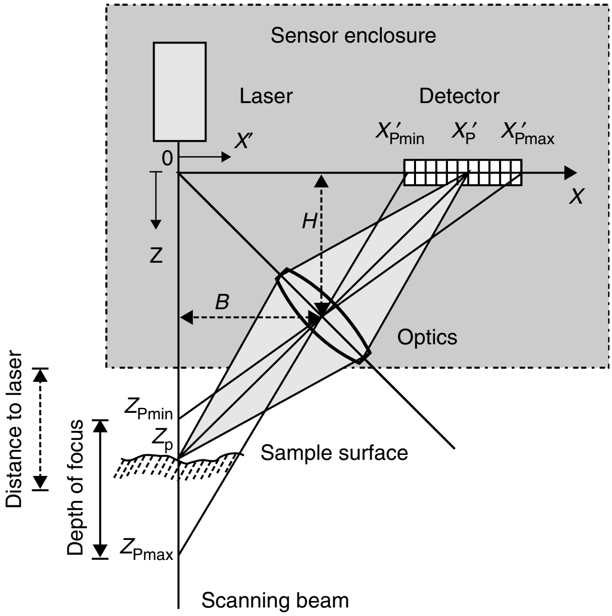


Figure 22.4 Triangulation. Reproduced with permission of Rohwedder AG, Germany.

- For deliveries, the number of tankers, pallets, bigbags etc. are counted.
- Determining the number of loaded conching units, when producing the masse in batches.
- Counting the number of unpackaged products entering and leaving a storage unit.

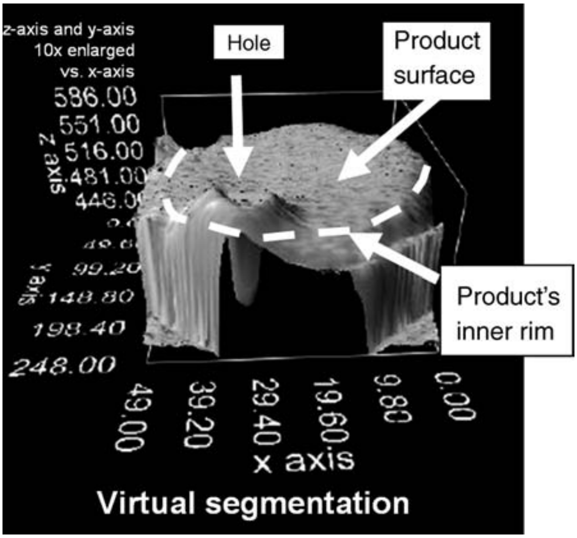


Figure 22.5 Example of a 3-D scan. Reproduced with permission of Rohwedder AG, Germany.

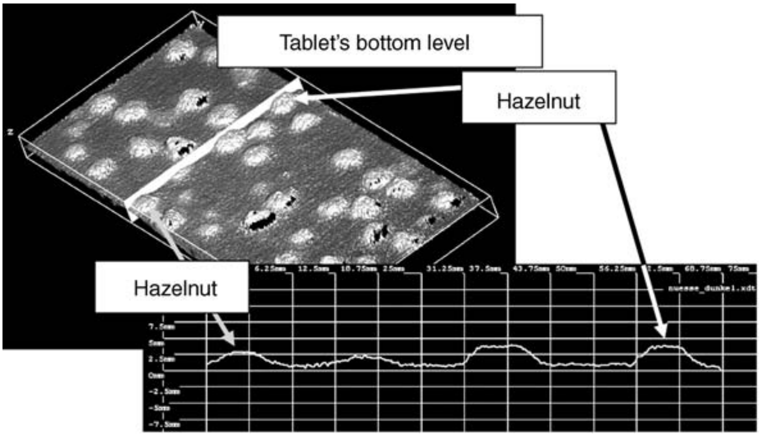


Figure 22.6 Nut distribution in a bar. Reproduced with permission of 3D-Shape, Erlangen, Germany.

- Calculating the number of finished products in final stock department by weighing the container (SKU, Stock Keeping Unit), 5-count package, filled box of chocolates, multipacks etc.
- Guaranteeing components in the overall recipe for example by counting the mixing batches per conche unit.

22.2.4 Recording 'patterns'

This involves recording a complex measurement parameter. The term 'pattern' covers the results of measurements such as intensity diagrams of spectra, the reproduction of product images as grey-scale distributions and their comparison with a specified range for such a pattern. Principles of pattern recognition are used to recognize foreign matter, to identify defined defects, to read alphanumeric characters (e.g. best before date coding), to read a barcode or codes invisible to the human eye. Many different methods of data analysis find application here, including mathematical statistics and artificial intelligence.

22.2.5 Recording the degree of filling (fill level)

The term 'degree of filling' (fill level) can apply in many situations. It is usually recorded as a percentage and often refers to a volume. Some examples are as follows:

- In a silo for bulk goods: comparison of the measured amount added to the silo.
- In a tank for liquids: level in a sight glass, weighing before and after filling, ultrasound probes.
- In a tank or hopper for tempered masse, dropping below the minimum sensor or rising above the maximum sensor.
- In a cooling tunnel, before emptying after a breakdown.
- Within a storage unit for chocolate bars, prior to feeding the packaging machine: tracking the difference between entering and exiting items.
- On a feeding conveyor inside a packaging system: tracking the difference between items entering on the feeding conveyor and those leaving it.
- Ball mills: volume occupied by the balls inside the milling chamber.
- In a gas bottle filled with N_2 for aerating of the filling masse: by determining the total weight, for example at the start and at the end of a shift or by means of a consumption sensor.

22.2.6 Recording by weighing

In addition to counting and temperature measurement, determining the weight or mass is one of the most common measurement tasks (examples of operations based on mass and force are given in Table 22.3). The weight of bulk goods such as sugar, milk powder, fractured cocoa nibs is determined using bulk material scales or belt conveyor scales. Mixers are connected directly to weighing systems. This takes place in a continuous or semi-continuous manner. Automatic weighing systems can be employed throughout, from cocoa processing to the final bar. For example, they can be located downstream from a conventional winnower in order to check

Table 22.3 Typical examples mass/force-based measurements.

	Dimension as example	Typical examples
Mass as basic variable		
in grams	g	Product weight, e.g. 100 g
in kilograms	kg	Weight of balls in a ball mill
in tonnes	t	Amount of raw material to be processed
Density		
Mass/volume	g/cm^3	Density of aerated chocolate
Force		
in Newtons	$1\ N = 1\ m/kg/s^2$	Moment for non-positive connections, such as nuts or screws
Moment of force		
Force*distance	N m	
Pressure, tension		
Force/area in Pascals	$1\ N/m^2 = 1\ Pa$	Mass pressure downstream from a pump, Contact pressures between rolls in a refiner and in a cocoa press, air pressure
Dynamic viscosity, Kinematic viscosity = dyn. viscosity/ density	$1\ N{*}s\ /\ m^2 = 1\ Pa{*}s$ $(N{*}s\ /m^2)\ /\ (kg/m^3) = m^2/s$	Is used to describe the flow characteristics of chocolate masses, cocoa butter, special fats
Work, energy		
in Joules	$1\ J = 1\ N\ m = 1\ Ws = 1\ m^2\ kg/s^2$	Installed refrigeration capacity
Power		
in Watts	$1\ W = 1\ J/s = 1\ m^2\ kg/s^3$	Motor performance
Mass flow rate		
Mass/time	kg/h	Output of a moulding plant, throughput of a ball mill,
Mass/Mass	dimensionless	Proportion of shell in the nibs (%)
Mass flow density	$kg/s{*}m^2$	Related to fat migration

and track the level of shell (Chapter 6). All further weight measurements, for instance, when adding other ingredients such as nuts, and maintaining the specified ratios to ensure adherence to the recipe. Comparisons between TARGET and ACTUAL values within the recipe database, product database, weighing records, process control charts can be automated and documented. Finished products are weighed once again in their package, before being placed in the multipack.

Often, the addition (metering) of solid recipe ingredients relies upon weighing operations. This is especially true, for the process steps of

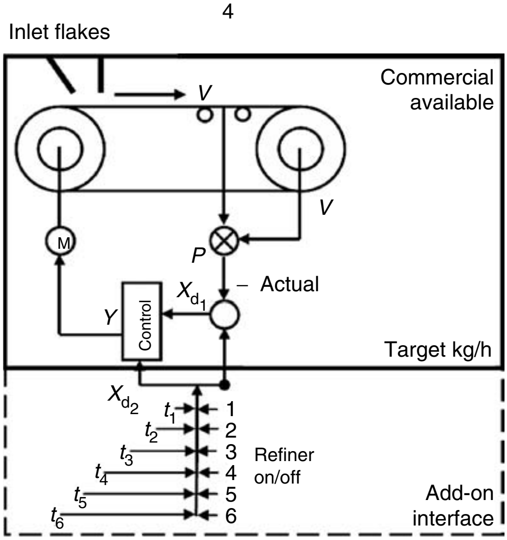


Figure 22.7 Belt weigher.

ingredient addition and mixing when producing the initial chocolate masse, but also applies to ingredients being discharged from silos with the aid of feeders. The equipment used includes, for instance, belt weighers and weigh feeders. With the aid of belt weighers (see Figure 22.7) milled material can be fed directly into the mixer, pre-refiner or conches exactly in accordance with the recipe. The principle of operation requires regular cleaning and calibration. Smaller amounts of dry material, such as free-flowing vanillin, are added to the mixer automatically with the aid of screw feeders.

The belt weigher in a refining line, shown in Figure 22.7, has an additional control circuit installed to automatically adjust the belt load. By changing the speed of the belt drive motor, it can always measure the load on the belt within its optimum operating range. The result is that the error in measurement is independent of the number of operating refiners, as well as their location. The time it takes for the masse to reach a particular refiner is dependent upon its position in the refining line and is stored in a PLC.

22.2.6.1 Weighing liquids

Often, the addition (metering) of liquid recipe ingredients is coupled with weighing operations. This is particularly true for ingredient addition (metering) during mixing and conching. With some liquids, the amount to be metered can easily be adjusted using solenoid valves in conjunction with a weighing scale. The type of metering pump chosen depends strongly upon the viscosity of the material, in particular its yield value (see Chapter 11).

Smaller amounts of liquid ingredients, such as lecithin, can be added using rotary piston meters. In contrast to piston-type metering devices, rotary piston meters generate no signal when idle and so are more useful for control systems.

22.2.7 Measuring temperatures

Temperature represents the most important measured variable in cocoa and chocolate production (see Table 22.4 for typical temperature measurement units).

A few examples of frequently used temperature measurements are:

(1) In case of conventional tempering to ensure the de-crystallized condition of the chocolate prior to entry into the tempering machine.

Table 22.4 Examples of the units used for temperature-based measurements.

Temperature as basic variable	Dimension as example	Typical examples
in Kelvin,	K	Usually in °C: masse temperature, air temperature in refrigerator, Surface temperature Internal (core) temperature of the finished product during cooling in a refrigerator
in degrees Celsius,	°C	
in Fahrenheit	°F	
Tempermeter application Rise from the inflection point of temperature over time under isothermal measurement conditions	Scale divisions	Determining the degree of tempering of tempered masses
Amount of heat in Joules	J	Example: amount of heat released during crystallization
Specific amount of heat	J/kg	
Heat capacity	J/K	Material property
Specific heat capacity	J/(kg*K)	
Entropy	J/K	Entropy change in a system
Specific entropy	J/(kg*K)	
Heat flow	W = kcal/h	Process variable
Heat flow density	W/m^2 = kcal/m^{2}h	
Heat transfer coefficient	W/ m^2*K	Material and process condition
Heat transmission coefficient	W/(m*K) = Kcal/(m*h*K)	
Thermal conductivity		Material property
Thermal diffusivity	m^2/s	Material property

(2) The viscosity of chocolates and filling masses depends directly on their temperatures.
(3) Correct temperature levels of air temperatures, refrigerants, the water heating jackets on piping, depositing heads, holding tanks.
(4) The dewpoint results and other relative humidity measurements.
(5) Product surface temperature and internal product temperature are important criteria for evaluation of the cooling process.
(6) Uniformity of the mould and product temperature after cooling and uniformity of the mould temperature after the re-warming indicate process variability.
(7) During conching, texture changes and formation of enhanced aroma can be influenced by altering the temperature and shear conditions.
(8) By changing the temperature of alkalized cocoa mass/fractured cocoa nibs, the release of the cocoa butter from the cell structure is altered.
(9) Changing the temperature during the roasting of cocoa beans is the decisive process parameter for expelling water, enhancing aroma and loosening the shell.
(10) Temperature and time are critical in controlling microbiological growth.

In *the gaseous state*, for instance, temperatures are measured for the ambient air, the chilled air in refrigerators and for steam. In other situations, solid–gas mixtures are present for example milling and cooling cocoa press cake and powder. Here the temperature measurement is essential for controlling the process.

The most common temperature measurements involve *liquid* masses. With tempered chocolates and filling masses, it is especially important to know the accuracy of measurement. Digital converters operate in conjunction with Pt 100 sensors with an accuracy of +/–0.3°C. Older devices can often only achieve accuracies of +/–0.7°C. This must always be kept in mind when reading temperature displays.

Apart from measuring the temperature at individual locations by thermometers, it is also important to monitor the temperature distribution over an area for example a mould surface to detect hot or cold spots. This can give rise to sticking of the bars in the mould, the so-called cooling stress marks or cooling spots, or bloom in the final product. Pyrometers are often employed to record such surface temperatures. Images of two production situations in the visible and infrared regions are compared in Figure 22.8. The use of such measurement systems permits tracking of individual mould positions over time, as individual images are available in digital form and in this way permit reading of surface temperatures at specific locations. The emission coefficient (emissivity) of different material should be taken into account on a material-specific basis.

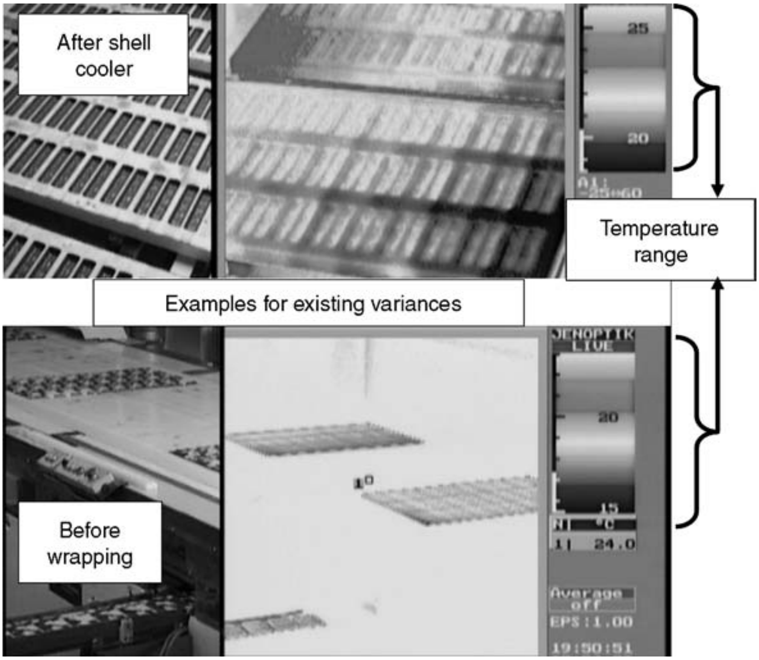


Figure 22.8 Black-and-white imaging in the visible and infrared regions. Through false-colour imaging, the surface temperature becomes visible.

22.2.8 Recording the degree of temper (see also Chapter 12)

It is always necessary to determine the degree of temper of masses containing fats that solidify polymorphically. These include cocoa butter and other special fats with similar fatty acid compositions. The tempered condition is the result of pre-crystallization, a process also known as tempering.

If correct pre-crystallization does not take place, many problems arise for example lack of contraction (sticking in moulds) and gloss on the product. In addition fat bloom can appear earlier leading to customer complaints. The sensitivity to incorrect tempering depends upon the chocolate recipe and it is very important for the manufacturer to know the robustness of the process for particular products in order to be able to minimize these faults.

22.2.8.1 Preparing to measure

The frequency of sampling and the accuracy of the measurement are important when monitoring tempering systems. The degree of temper can be determined manually or automatically, but the use of automatic sampling permits more measurement cycles per hour and complete tracking of fluctuations in the temper. If correction is necessary, the degree of temper can be influenced by changing the temperature settings for the individual stages of the tempering machine (further details are given in Chapter 13). If this is not adequate, the residence time within the temperer can be changed, but the throughput will then be affected. Machine settings should be stored in recipe databases.

Every temper measurement normally assumes that all the equipment is installed and operating correctly. This is not always the case however, and some common faults are given in Figure 22.9.

Typical positions for measurements connected with conventional tempering are:

- Decrystallization: Masse temperature at the inlet for new masse and/or of the masse from the return line must be between 43°C and 45°C (109–113°F) for the masse not to contain any crystals. The water temperature in the water jacket of pipe systems should be 50–55°C (122–131°F), or preferably 60°C (140°F). Depending on the design, the decrystallizing unit can also be part of the inlet to the tempering machine.
- Water circuits for the cooling stage and warming stage: ensuring stable water temperatures within the range specified by the manufacturer, water pressure and water temperature level without any seasonal variations and independent of usage by other production lines.
- Return flow of masse must always be maintained so that no buildup of masse occurs near the depositing head during production shutdown.

22.2.8.2 Tempermeter

A typical tempermeter is shown in Figure 22.10. The measuring cup is filled with chocolate and then placed into the pre-warmed sample holder (Figure 22.11) and the temperature sensor positioned exactly with the aid of a spacer (not shown). This temperature sensor is normally connected to a computer able to record the change in temperature over time. Upon completion of the measurement, the position of the inflection point illustrated in Figure 22.12 is read out automatically and the temperature rise calculated. The degree of temper can be established from the position of the inflection point in the tempering curve, which is governed by the amount of heat released during crystallization (see also Chapter 12).

Although such systems can quantify the degree of temper the information is limited. It cannot for instance determine if certain crystal modifications are taking place and it can be distorted when incompletely decrystallized masse is present.

22.2.9 Pressure measurement

Pressure sensors usually operate by converting the movement of a diaphragm into an electrical signal. They can be used, for example, for checking the masse pressure for aerated masses, the air pressure of the compressed air supplied to the infrastructure and, in hydraulic drives, the hydraulic

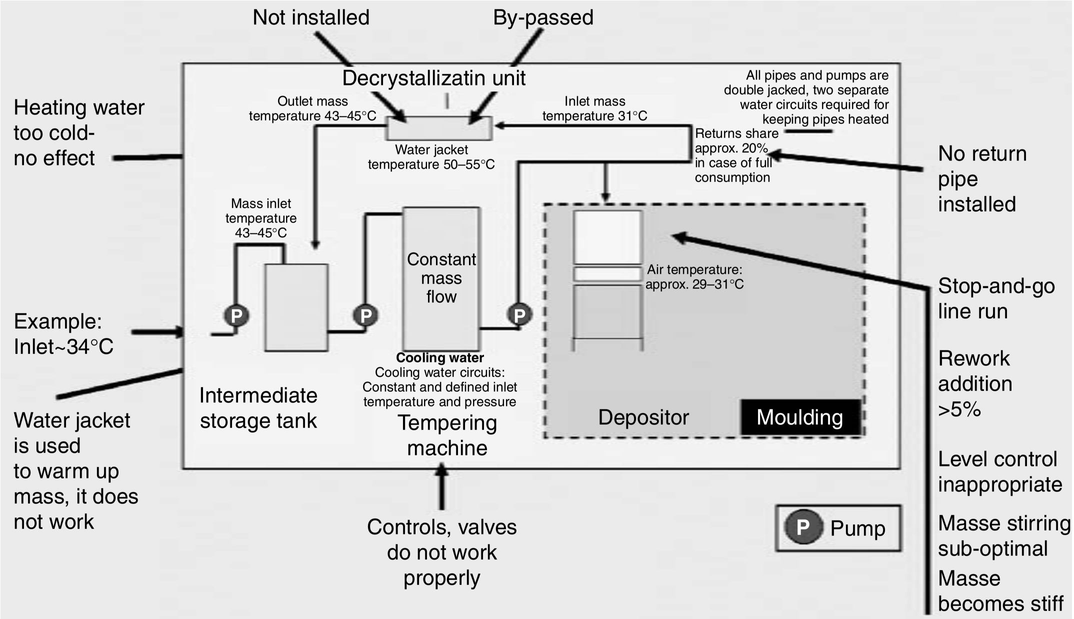


Figure 22.9. Common faults found in conventional tempering systems.

Figure 22.10 Typical tempermeter.

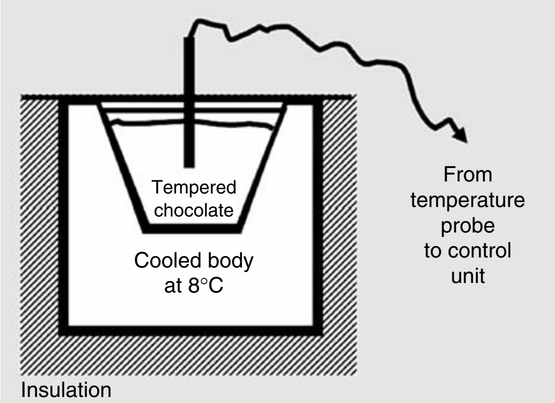


Figure 22.11 Schematic diagram of measurement head of tempermeter.

pressure. Within the confectionery industry they are particularly important to ensure a minimum pressure when providing cooling water to mills, roll refiners, tempering machines and conche units. Without this cooling flow, the output and quality are reduced and wear increases. In addition pressure sensors are often placed in closed circuit flow systems for example the masse within a circuit of ball mills; the hydraulic circuits to the rolls in roll refiners, cocoa presses and hydraulically driven depositing systems; the reactor contents in alkalizing units; refrigerant circuits in chillers and refrigeration equipment with direct evaporators; pneumatic systems; and pressure relief

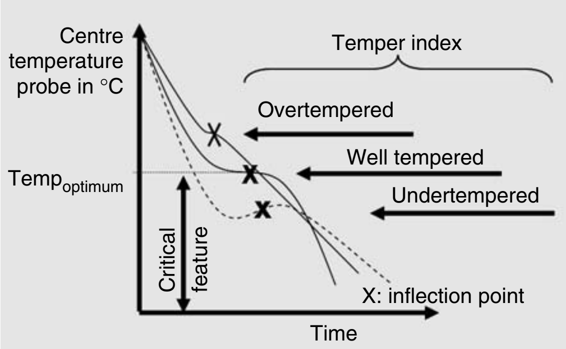


Figure 22.12 Typical temper curves from tempermeter.

valves in pump systems. They can even be used as a means of determining the fill level in storage tanks. Examples of different pressure measurement applications are summarized in Table 22.5.

22.2.10 Measuring moisture/relative humidity

Water content of cocoa beans/cocoa nibs: In order to optimize the yield it is important to measure the moisture content at regular intervals. As a natural product, the composition of cocoa beans can vary. This applies to the fat and water content as well as the attainable yield. Under production conditions, the water content of cocoa beans and cocoa nibs can be determined by halogen moisture analysers. These heat the sample uniformly and the moisture present is determined from the loss in weight.

Water content of cocoa mass: When adjusting cocoa masses to a specific fat content, the moisture content must first be measured. This can be determined by measuring the absorption/reflection of IR radiation at the surface; the typical accuracy of measurement is 0.3–1%. This method of measurement requires a special calibration regime.

Relative humidity: Water in the gas phase (air) is often recorded as relative humidity (%) or as a concentration (g/kg). In combination with the air temperature, it is then possible to determine the dewpoint, the temperature below which condensation sets in, see Figure 22.13. Every time condensation forms on the product's surface there is a danger of mould growth or sugar bloom.

22.2.11 Recording flow characteristics

Flow characteristics of chocolate and filling masses are described in simplified form by means of the term 'viscosity' (η). It is obtained by determining

Table 22.5 Examples of different pressure measurement applications (F.B. Lehmann, Aalen, Germany).

Application	Medium	Type of device	Installation	Bar	Accuracy (%)
Monitoring the pressure in the milling chamber of agitator ball mills	Liquids	In-line seal with analogue transmitter and sensor signal evaluator	Directly in pipe between feed pump and milling chamber	0–2.5	0.3
Pressure monitoring in barrier pressure systems for mechanical shaft seals	Compressed air, nitrogen	Pressure switch with adjustable contacts	Directly on the barrier fluid reservoir in the air line	0–7	0.5
Pressure differential in filter systems as an indicator of the degree of filter clogging	Air	Differential pressure transmitter with diaphragm	In the vicinity of the filter	0–0.05	0.2
Fill level measurement in vessels with an agitator	Liquids	Piezoresistive pressure transmitter	At the bottom of the container in direct contact with the product	Depends on application	0.3
Weight sensing in silos and vessels with an agitator	Bulk goods liquids	Pressure sensor (load cell) with analogue transmitter and sensor signal evaluator	Under the feet of silos and containers	Depends on application	0.3
Airflow regulation on winnowing equipment	Air	Differential pressure transmitter with diaphragm	Separately in a control cabinet	$2x10^{-5}$ – 0.002	0.07

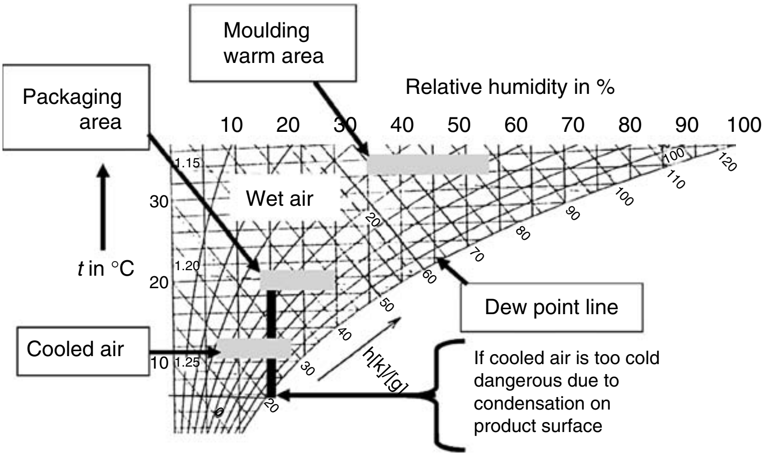


Figure 22.13 Extract from a Mollier i,x diagram showing the relationship between temperature and relative humidity when condensation occurs (dewpoint line).

the interactions involving the shear stress (τ) at different shear rates (*D*). Viscosities are often measured either in separate laboratory rooms close to production or directly in the laboratory. Various models exist for describing flow curves mathematically, see *Windhab*, *Tscheuschner* and Chapters 10 and 11. Single-point measurements are not suitable when determining the viscosity of non-Newtonian fluids such as chocolate. Measurements should be made at least at two shear rates, with great care being taken with the sample preparation and in using the viscometer to standardized procedures.

Flow characteristics depend on the condition of the material (texture) and the processing conditions (such as temperature and shear etc.). If production is being adequately controlled (raw material specifications, defined processing) when manufacturing chocolate masses for making tablets, it is not necessary to conduct viscosity measurement on a continuous basis. It is, however, common to record related variables, such as power consumption at the conche drive shaft to draw conclusions about the condition of the masse during processing, thereby permitting automation of the process and the automatic correction of the flow properties. When making chocolate masses where more precise flow properties are required, for example enrobing to an exact weight or decorating efficiently, the viscosity often needs to be modified by adding fat. In this case, off-line batch measurements should be made. These measurements are also required when manufacturing aerated masses, and the yield value is lowered by adding an emulsifier, such as PGPR (Chapter 10).

In-line viscometers can be used and Figure 22.14 shows possible positions for installing a process viscometer to measure non-Newtonian flow. Most concentric instruments pose the problem that the same chocolate remains

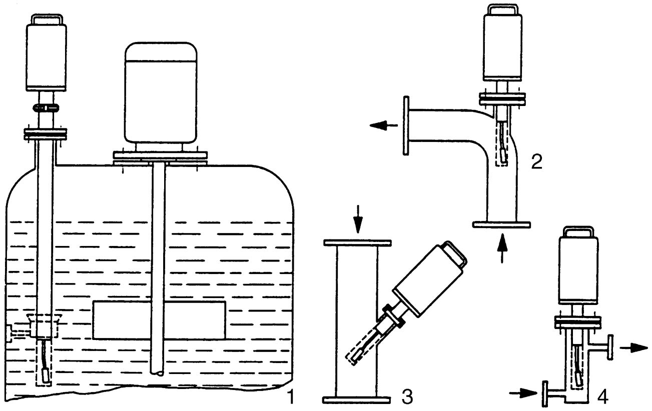


Figure 22.14 Typical installation positions for the Convimeter type of viscometer.

between two cylinders, while the product intended to be measured flows by. The Convimeter (Figure 22.15) overcomes this by having the bob set at angle and so acting as a pump and changing the sample.

22.2.12 Recording particle size

This is the most commonly measured quality parameter, since it can be perceived directly by the consumer with chocolate tasting grainy if the particles present are too coarse. This even overcomes the expected pleasant melting sensation. On the other hand, if extremely fine particles are present in excess, a large amount of free fat can be bound up, or the particles can come in contact with one another, for example form clusters, resulting in a sticky feeling in the mouth. In this case as well, the pleasant melting sensation is masked. Both of these situations must be avoided by correct processing. To accomplish this, it is necessary to determine the fineness of the particles and monitor it appropriately.

The particle size is measured for raw materials and intermediate products as well as for finished products. Various measurement methods can be used. The micrometer and laser diffractometry methods are used in both the laboratory and production. Both methods are described in greater detail in Section 22.3.

The expression of the results usually depends on the method of measurement as shown below:

- Laser diffractometry: Here the measured value $D(90) = 25\,\mu\text{m}$ means that 90% of the particles are less than or equal to $25\,\mu\text{m}$ in diameter.
- Micrometer: Here the measured value = $20\,\mu\text{m}$ means that the largest particle is $20\,\mu\text{m}$ in diameter.

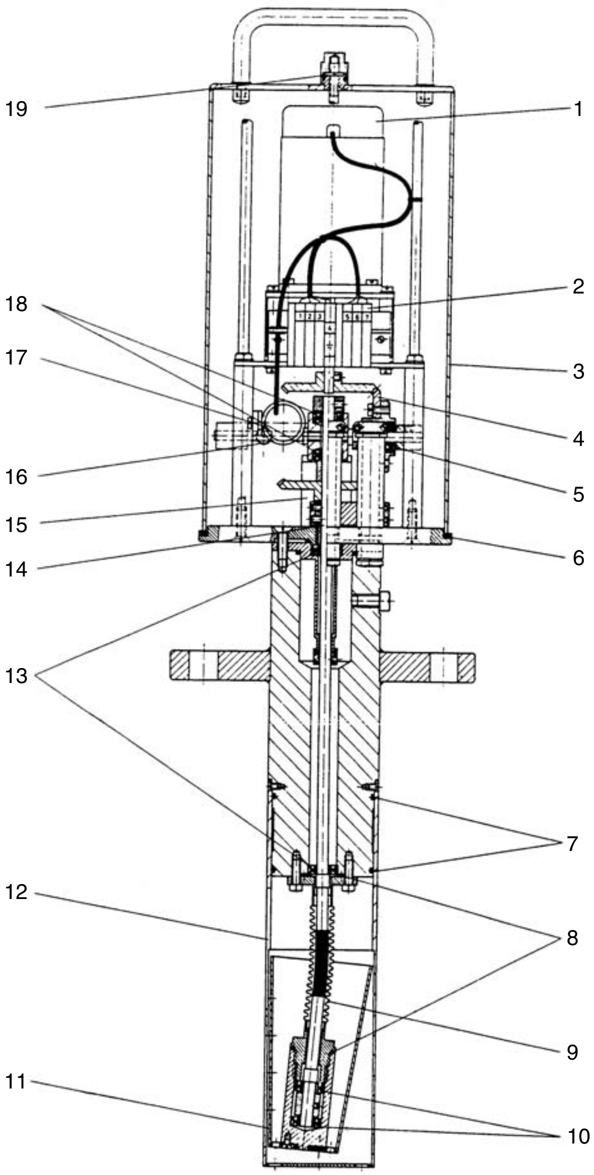


Figure 22.15 The Convimeter: 1, Geared motor, with gear control; 2, terminal, explosion proof; cover, 4, bevel driving pinion; 5, 2 ball bearings, 6/19mmφ, for nylon bevel driving pinion; rubber gasket; 7, 2 O rings, Viton, for seat of protection sheath; 8, 2 O rings for connecting pieces metal bellow; 9, metal bellow, with connecting pieces; 10, 2 ball bearings 7/19 mmφ, for drive shaft, lubricated with special oil; 11, conical mantle, with 3 screws M 4 × 6 12, protection sheath, with 2 screws M4 × 6; 13, 2 ball bearings 7/19 mmφ, for drive shaft, lubricated with special oil; 14, drive shaft, with Teflon sleeve; 15, dash pot, with Teflon sleeve; 16, metering spring, Nr. 1,11, or 111, with barrels; 17, inductive transducer, explosion proof, with drive eye; 18, 2 ball bearings 7/19 mmφ, for dynamometer drive shaft; 19, cap nut for cover, with spring washer and O ring.

- Wet screen method (sieving): Here the measured value 1% > 75 μm means that 99% of the sample is less than 75 μm in size. This is based on the residue remaining on the 75 μm screen. The traditional sieving method can only be used within a separate laboratory because of the organic solvent employed. It has mainly been replaced by laser diffractometry.

Particle size measurements are also made on *cocoa masses*. In this particular case, in addition to determining the particle size distribution, oversized particles need to be removed. They can form during passage through ball mills and are retained by sieving the entire batch prior to further processing.

Milled material is produced during the manufacture of chocolate or filling masses. In order to measure its particle size, a bulk sample is often taken at the discharge from the milling line in order to determine the *D*(90) value. To check the settings of a five-roll refiner, for instance (Chapter 7), as part of a throughput-fineness test, samples are taken after the removal blade from the left and right sides as well as the centre of the upper roll. The current throughput of the five-roll refiner can be determined with the aid of a belt weigher or similar monitor. In this way, it is possible to chart fluctuations in the milling results over time graphically. This procedure assumes that the throughput of the refiner can be held constant. It must be remembered that achievable fineness, operating hours of a roll set, consistency of the masse after the two-roll refiner, throughput, roll wear and five-roll refiner settings are all interrelated.

Chocolate: Determination of the particle size can be made from samples of conched masse as well as finished products. Sample preparation is similar to that for milled material and cocoa mass.

22.2.13 Production monitoring

Example 1: This involved the operation of a thickness gauge to automatically control the particle size of milled material. For use in-line during production, a thickness gauge was installed by the machine manufacturer at the centre of the fifth roll in a commercially available roll refiner. It was connected by a controller to the controls for the variable drive motor of the second roll. By sensing the thickness at this location, the roll refiner could react, within a certain speed range, to changes in the consistency of the masse at the in-feed nip, see Figure 22.16. As the thickness gauge is placed at only one location along the roll, the monitoring of the effective coverage on the whole length is limited.

Example 2: In a pilot study (Figure 22.17) aimed at optimizing the degree of coverage of the rolls in five-roll refiners, an alternative strategy for achieving fully automatic control was tested. It gave fully automatic operation without any highly specialized machine operators.

Figure 22.17 shows schematically the light source and the line camera. An incremental encoder on the fifth roll (not illustrated) synchronizes the line

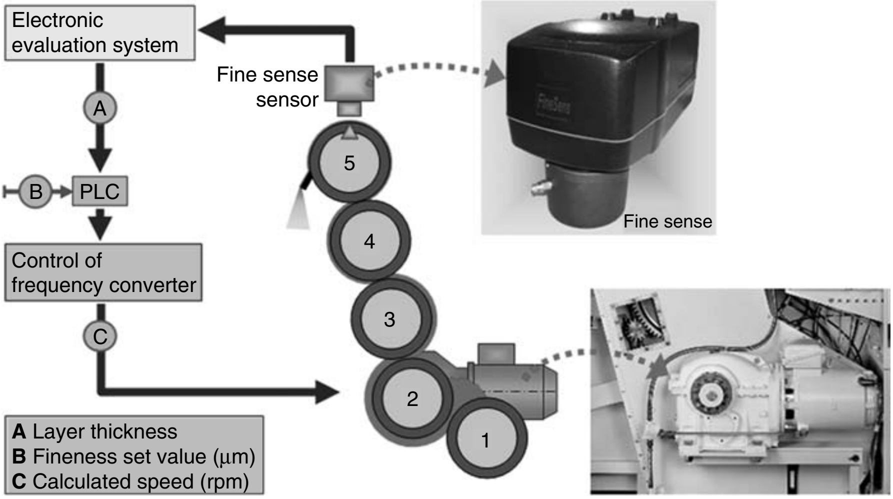


Figure 22.16 Automatic five-roll refiner. Reproduced with permission of Bühler, Uzwil, Switzerland.

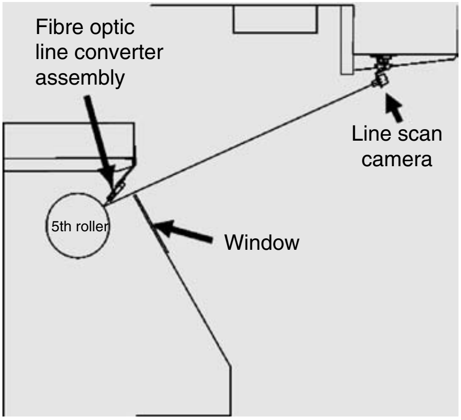


Figure 22.17 Experimental pilot set-up for Example 2. Reproduced with permission of Kraft Foods R&D Inc. Munich, Germany.

camera with the aid of a frame grabber card. Conclusions about the particle size can be drawn indirectly, if the relationship between recipe, intensity of the reflected light and the data for reference samples for coverage values at optimal settings are known. Automatic adjustment of all machine settings to optimal values can be achieved in this way much more frequently and more accurately, than would be possible with the best machine operator (Figures 22.18–22.20). However, the extra technical investment required for a similar solution (compared with normal refiners) becomes economical

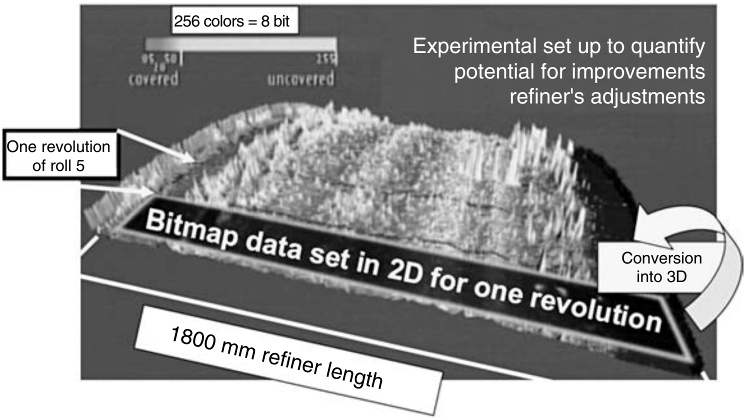
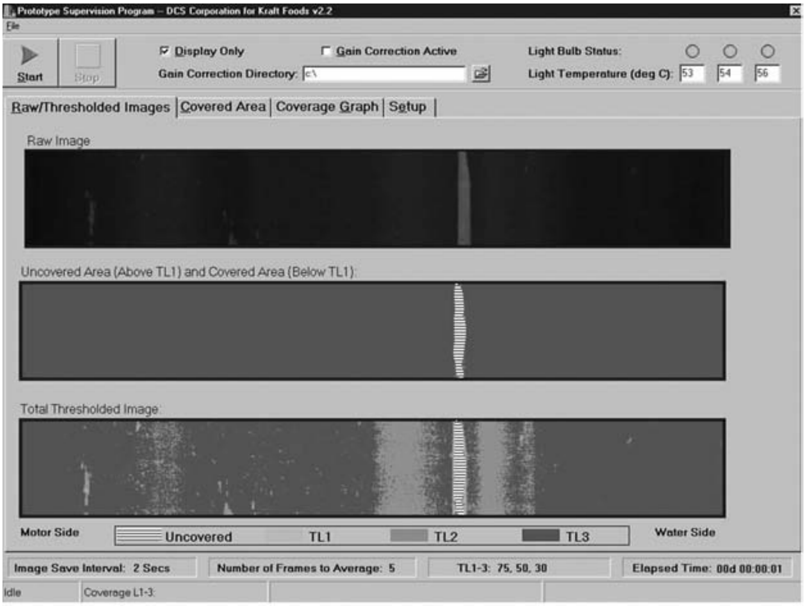


Figure 22.18 Black-and-white image of computer illustration of the degree of coverage of the refiner rolls generated from results obtained with the experimental pilot set-up shown in Figure 22.17.


Prototype Supervision Program – DCS Corporation for Kraft Foods v2.2

☑ Display Only

☐ Gain Correction Active

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Idle

Coverage L1-3:

Figure 22.19 Black-and-white image of the output unit of the experimental pilot set-up. Electronic evaluation of the reflected light surpasses by far the capabilities of a human, even when viewing the raw data from a single revolution of the fifth roll (see Figure 22.20).

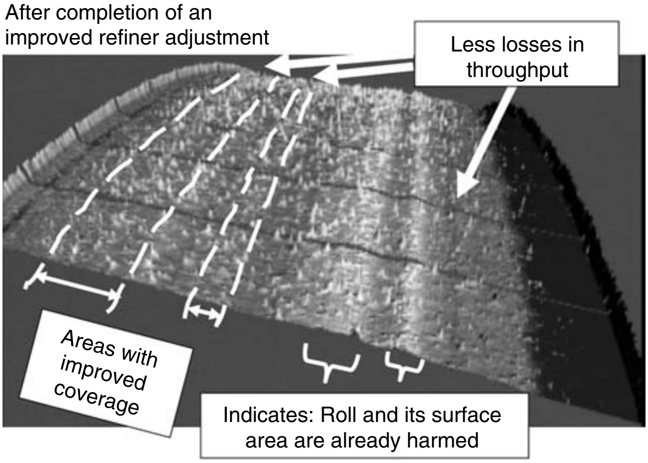

Figure 22.20 Black-and-white image of the degree of coverage after improving the original machine settings (cf. Figure 22.18).

only if the improved uniformity of solids distribution can be justified by the products being manufactured.

22.2.14 Detecting foreign matter

External matter management occupies an extremely important position in ensuring the safety of food products. It involves not only control of foreign matter, but also the processing guidelines for chocolate, filling masses and rework. Depending upon the processing stage, foreign matter can be removed manually or by equipment such as metal detectors, separators, magnets, filters, screens, traps, optical detectors.

Metal detectors are always coupled with reject devices to divert non-conforming products. The product is carried on a non-metallic conveyor through an aperture around which are wound three coils. An operating and analysis technique (differential transformer method) enables ferrous metals, non-ferrous metals and stainless steel to be detected within the chocolate. A second technique (magnetic field method) is capable of distinguishing ferrous metals in products packaged in aluminium foil.

When using the differential transformer method to detect pieces of metal, three coils encircle the detection aperture. An oscillator drives the signal voltage in the primary coil. Two secondary coils, on a common axis with the primary, are coupled into the field of the primary coil in such a manner that the system is in balance and the induced voltage in the two secondary coils cancel each other out. A piece of metal introduced into the detection aperture will distort the primary field and cause a difference in induced voltage in the secondary coils. This voltage difference constitutes a signal that is amplified and manipulated to extract the amplitude and phase angle with respect to the oscillator input signal. This information is used to decide whether the signal represents metal or the product. If it represents the product, it is ignored and if it represents metal and if the signal exceeds a pre-set level, the metal detector generates a detection signal which is used to activate the reject mechanism.

22.3 Laboratory analysis

The examples of laboratory analysis presented in this chapter are as would be found in the laboratories of a large chocolate manufacturer. Smaller production sites may have to out-source analytical testing and rely on suppliers to deliver raw materials to certificated standards. The methods described are based on the technologies and processes presented in Chapter 21 (see Figures 21.11–21.19). It is intended to give the reader an overview of the complexity of the quality assurance measurements that are required within the confectionery industry and is not able to cover the huge range of methods actually available or indeed the recent technological advances that are currently taking place.

22.3.1 Moisture measurement

As was noted in Chapters 9 and 10, a very small amount of moisture can greatly increase the viscosity of chocolate and indeed the presence of an extra 0.3% water needs approximately another 1% of fat to compensate for it. Any analysis used must be repeatable to better than about 0.2%. Two methods are often used within the industry, namely oven drying and Karl Fischer titration. The former measures the 'free' moisture that affects the flow properties, whereas the titration also measures 'bound' moisture for example that in crystalline lactose monohydrate (in milk) that has little, if any, effect on the viscosity.

Oven drying involves mixing a small sample of chocolate with a weighed quantity of dried sand in a metal tray. This is then reweighed to determine the weight of the chocolate before being placed in a hot oven for set time and temperature. Typically this will be about 98°C (208°F) for about 12 h, or a lower temperature if vacuum is used. The result obtained will depend upon the time and temperature, but provided a strict regime is followed within a laboratory, results can be obtained with a good enough repeatability to monitor factory production.

Karl Fischer titration is based upon the reaction between sulphur dioxide, iodine and water shown in equation (22.1)

$$I_2 + SO_2 + H_2O = SO_3 + 2HI \qquad (22.1)$$

The reaction takes place with pyridine in another solvent, which may be methanol and is such that one molecule of water reacts with one molecule of iodine. Automatic systems exist that can produce results within a few minutes. In these systems a pre-weighed amount of chocolate is dispersed in a liquid (e.g. formamide, chloroform and methanol) in a reaction vessel. This is tightly sealed to stop moist air entering the containers, a stirrer and two platinum electrodes. Any iodine present will depolarize the cathode and allow a current to flow between the electrodes. A Karl Fischer reagent containing pyridine is then added slowly in controlled amounts. Once the iodine is used up the current will stop. At this point the amount of added reagent corresponds to the amount of water present in the original chocolate. The result is normally higher than for oven drying, because it includes the bound water, but it is highly reproducible and the turn over time is shorter.

22.3.2 Determination of fat content (Soxhlet)

In-line fat measurement systems, such as those based on near-infrared reflectance, are used in the industry especially for ingredients such as milk powder. Often they are affected by other parameters such as particle size and colour and they need recalibrating for each product. In order to carry out this calibration, or to perform routine laboratory fat analysis on chocolate, the traditional Soxhlet method is often used (Beckett 2000).

The principle of the method is to use a solvent to dissolve the fat out of chocolate, before evaporating the solvent. This leaves the fat, which can be weighed directly. This is normally carried out in a glass system, like the one illustrated in Figure 22.21.

The chocolate sample is weighed and cut into small pieces before being wrapped in a filter paper, which is in turn placed in a permeable thimble. It is now ready for placing the central part of the extraction system between the flask and the water-cooled condenser. The flask contains the solvent, normally petroleum ether, which is heated on an electric mantle. The boiling ether evaporates and passes through the side arm into the condenser. Here it condenses and runs back into the thimble dissolving the fat. The fat containing liquid passes through the filter paper and collects in the middle container. Eventually the quantity of liquid builds up until it reaches level A in the siphon (Figure 22.21), when it empties back into the flask. In this way the solid particles are retained within the filter paper and the fat is collected in the flask, where the temperature is high enough to evaporate the ether, but not the fat itself.

After about 12 h the top two sections are removed and replaced by the petrol distillation unit. This collects all the petroleum ether and does not let it run back. The fat remains at the bottom of the flask, and can be weighed.

This technique measures both free and bound (contained within cocoa or milk particles) fat. When investigating viscosity problems it is sometimes necessary to determine the bound proportion (Chapter 10). An estimate of

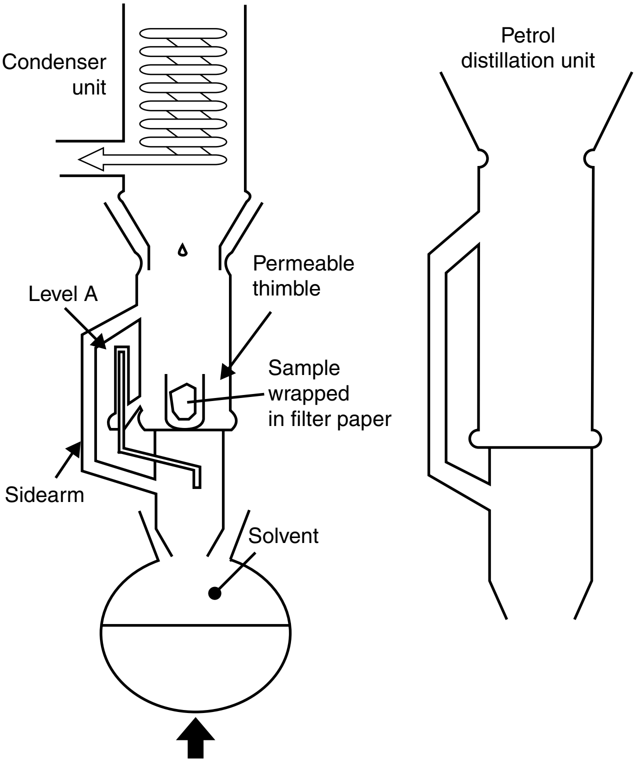

Figure 22.21 Schematic diagram of Soxhlet fat extraction apparatus (reproduced from *The Science of Chocolate*, 2000).

this can be obtained by first treating the chocolate with a mild solvent for a short period to extract the easily soluble fat. The more tightly bound proportion is then determined by the standard procedure.

22.3.3 Solid fat content

22.3.3.1 Nuclear magnetic resonance (NMR)

Two techniques are employed when using NMR to measure the solid fat content (SFC) of cocoa butter and other fats: pulsed NMR and the continuous scanning method. Both are more reliable when carrying out measurements on pure fat systems. When chocolate is being analysed, account must be taken of the other solid components present, for example sugar, milk proteins, etc. which result in reduced sensitivity. When absolute values are required, very strict calibration techniques are needed, especially if a significant amount of water is present together with the fat.

Today for SFC measurements *pulsed NMR* is applied. In pulsed NMR, the sample is held in a uniform magnetic field, which causes the protons in it to become polarized and magnetization to occur. A short radio frequency pulse, at a pre-selected frequency, causes a rotation of this magnetization vector around an axis normal to the original magnetic field. After the pulse, the longitudinal and transverse components of this rotating, magnetism return to equilibrium over different periods – known as relaxation times. Owing to their greater mobility, the relaxation time for molecules in the liquid state is much longer than for those in the solid state. It is therefore possible to determine the relative proportions of these two states in the sample.

The solid fat content is expressed as the percentage of the total fat that is measured as being solid. The value depends on which of the two standard methods has been used, and the method should be quoted along with the result. The direct method AOCS method (1993) Cd 16b-93, ISO 8292) requires calibration with a control containing paraffin/acrylic glass, whereas the indirect method AOCS method (1981) Cd 16–81 compares measured signals with those coming from a de-crystallized sample. According to Padar St. (2006), for cocoa butter samples the accuracy of indirect method is higher but more time consuming than the direct method. The direct method results are available within seconds, but needs a correction factor which depends on crystal type and temperature. This causes a systematic bias, which has to be taken into account.

It must be remembered that even at room temperature a substantial proportion of the fat phase is still liquid in fat sample, as well as in a normal milk chocolate. When vegetable fats are used, it is important to know how the chocolate will behave at higher temperatures to be sure of good eating properties. This can be determined by carrying out NMR measurements at a series of temperatures. The samples must be carefully prepared beforehand, with the fat taken through prescribed temperature cycles to ensure correct temper.

22.3.3.2 Differential scanning calorimetry (DSC)

Not only can this measure the amount of solid fat present in a sample, but it can also determine its crystalline state, which is vital to obtain good quality product (see Chapter 12). DSC enables the relative amounts of each of the crystalline states to be determined. This relies upon the fact that when a crystal melts, large amounts of latent heat are taken in (the reverse to solidification). In DSC measuring cell the sample (N.B. the sample weight, approx. 10–20 mg, must be measured with accuracy of +0.1 mg) is taken relatively quickly (the order of 0.5°C or 1°F/min) through a predetermined temperature range, and the energy change monitored. Peaks (see Figure 22.22) occur in the temperature ranges corresponding to the crystalline state present. The onset of a peak corresponds to the temperature at which a particular crystal form starts to melt, while the peak maximum corresponds to the temperature at which the rate of melting is greatest. This information can be

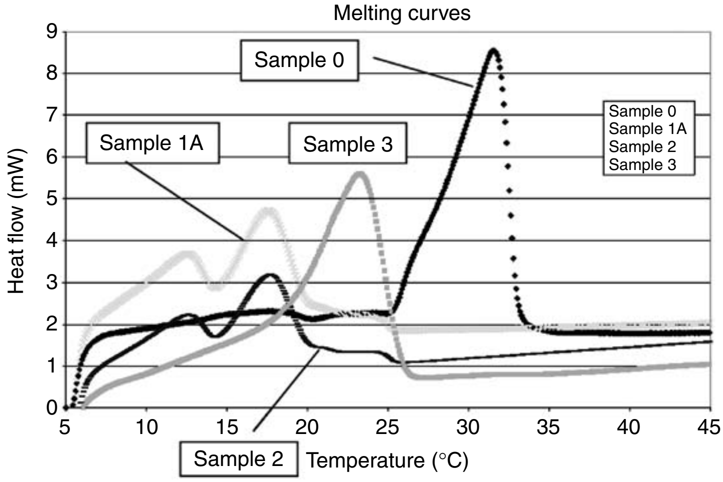

Figure 22.22 DSC plots of milk chocolate samples obtained using different cooling rates (sample 0: control, sample 1A: cooling rate 10°C/min, sample 2: cooling rate 1°C/min, sample 3: cooling rate 0.1°C/min).

used to indicate the crystal type. The peak height, position and resolution are strongly dependent upon the scanning speed (rate of temperature change) (see Cebula *et al.*, 1992).

A common technique used with chocolate is to plunge the sample into liquid nitrogen. Any liquid fat remaining then takes up the very unstable crystal form. When the sample is heated, peaks in the range 28–32°C (85–90°F) enable the proportion of the more stable forms to be determined.

22.3.4 Particle size measurement

The original methods employed for determining particle sizes in milled material, chocolate masses and filling masses, such as the micrometer and wet sieving have been largely replaced in the laboratory and/or production areas by laser diffractometry. For approximate fast on-line measurements however, micrometers are still commonly used, although laser diffractometry does provide more useful and accurate information. Measurements of the particle size distribution are more comprehensive than ones of the largest particle, which is all that a micrometer can indicate. Previously, only the laborious wet sieving approach was available for determining particle size distributions and then only at the larger end of the size spectra. Laser diffractometry can produce the results in about 10 min and is largely independent of the operator. This has helped the manufacturer to optimize both processes and recipes.

Laser diffractometry: The optical components of a laser diffraction particle size instrument are shown in Figure 22.23. Prior to each measurement, the particles from the sample to be measured are dispersed in a liquid

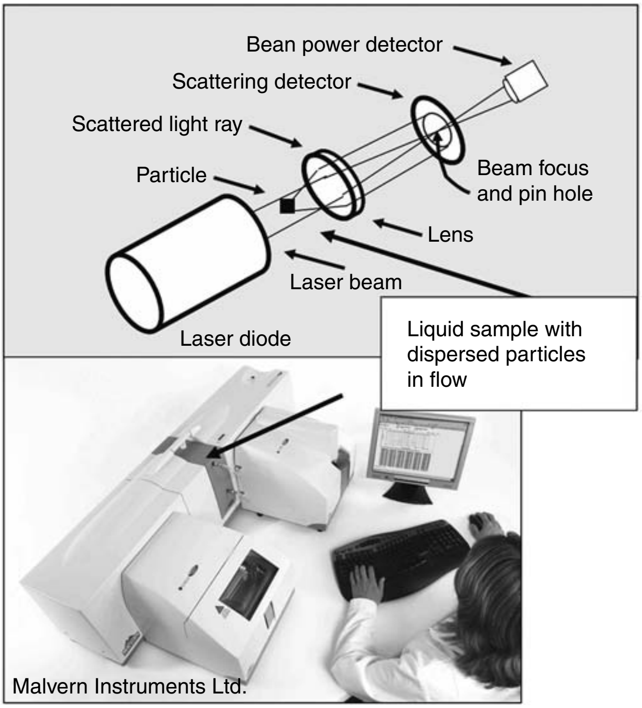

Figure 22.23 Overview of the principle of operation of a laser diffractometer.

phase for example a special oil or, in certain cases, an organic solvent. This dispersion is aided ultrasound treatment, which also breaks up agglomerates. The sample is then recirculated through a cell located in the optical path of the laser. This movement prevents particles from separating. Although the dispersed particles are in motion, the diffraction pattern of the beam of coherent monochromatic light (laser illumination) is stationary, and contains information on the particle size distribution. The laser beam is between 5 and 20 mm diameter, and the image of the diffraction pattern is formed in the focal plane of the lens and sensed by a photodiode array (scattering detector). The intensity of the light that is not scattered is monitored by a beam power detector. The scattering patterns with which to compare the detected signals can be calculated assuming simple Fraunhofer diffraction. The choice of lens determines the size range that can be detected. The model used for calculating the particle size distribution is critical for interpretation and estimating the errors. These models use an assumed form factor. Differences between particles having the same size, but a different shape are not taken into account. The results are usually presented in table form as volume distribution or number distribution with a statement of the calculated percentage per particle size class. The particle size is usually plotted logarithmically along the *x*-axis, see Figure 22.24.

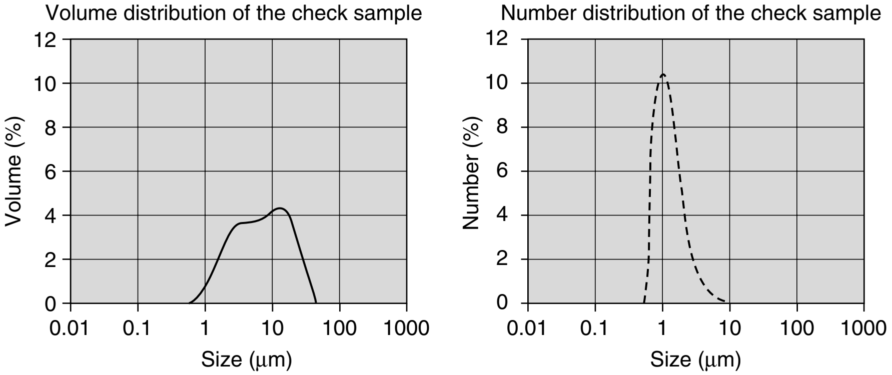

Figure 22.24 Typical particle size distributions for a sample of milled material shown as volume and number distribution curves.

22.3.5 Triglyceride (triacylglycerides) composition – vegetable fat content

The new EU cocoa regulations (Chapter 25) limit the types and amounts of vegetable fat that can be added to chocolate and it therefore becomes important to be able to distinguish between these fats and cocoa butter. Chapter 19 gives further details about the raw materials and properties of these special cocoa butter equivalents (CBEs) that are permitted in chocolate (Approved raw materials are: Illipe butter, palm oil, sal oil, shea butter, kokum and mango kernel oil). No other type CBEs may be used in the EU (legislation elsewhere varies from country to country) and if the amount of these CBEs exceeds the maximum limit of 5%, then the product can no longer be called chocolate.

The special fats classified as CBEs contain no lauric acid, but possess large amounts of symmetrical and simple unsaturated triglycerides (POP, POS, SOS), and are completely miscible with cocoa butter. Generally, the determination of the triglyceride distribution is made analytically by means of high-temperature gas chromatography (see Figures 22.25 and 22.26).

As part of the implementation of the EU cocoa regulations, the Joint Research Center (JRC) of the European Commission has over the past few years prepared a database of triglyceride distributions from hundreds of samples (cocoa butter, CBEs, milk fats) from various geographic regions, as well as from fat mixtures of these in a wide range of proportions. With the aid of existing analytical data, multivariate statistical formulas were established and validated. They are now available for practical use for the quantification of cocoa butter, milk fat and CBEs from fat mixtures; however have the constraint that no additional fats must be present.

Other problems arise from the presence of fats from other fat sources such as nuts, almonds or filling fats. In addition to the distribution of

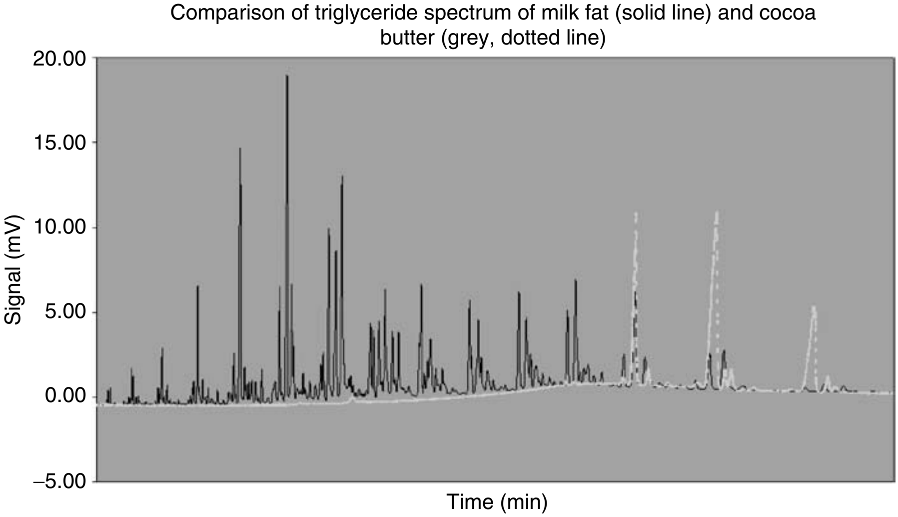

Figure 22.25 Superimposed triglyceride profiles for milk fat and cocoa butter.

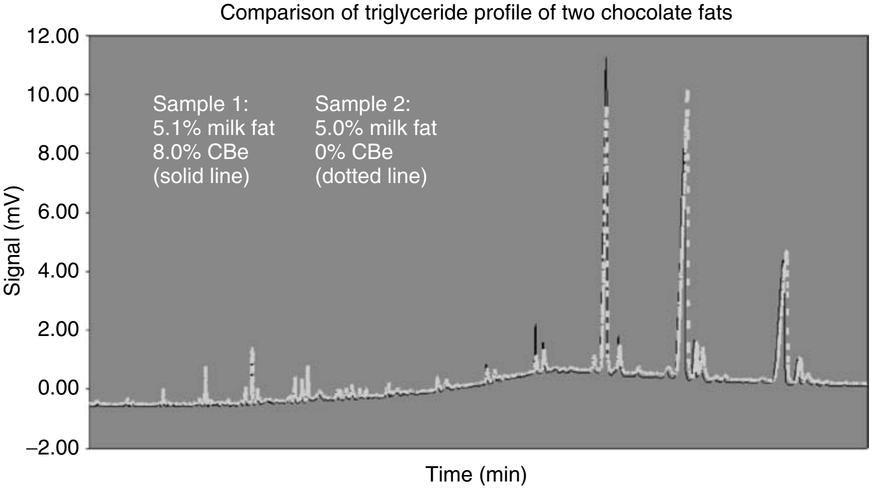

Figure 22.26 Superimposed triglyceride profiles from two fat mixtures. Sample 1 does not comply with Directive 2000/36/EC Sample 2 is chocolate in compliance with Directive 2000/36/EC.

triglycerides, other complementary methods exist, for example analysis of the fatty acid distribution (after their hydrolysis from triglycerides and steric esters), tocopherols, sterols, and steric esters. When evaluating the data, however, the natural variation in the content of these fatty substances must always be taken into consideration. Existing reference (comparison) data for fats and fat mixtures of known origin and/or known composition are important when evaluating the data from unknown samples.

22.3.6 Viscosity

The flow characteristics of chocolate masses are usually determined using a rotary viscometer. Great care must be taken to prepare the sample correctly and to carry out the measurement according to a strict procedure. The calibration of the viscometer must also be checked at regular intervals. Flow curves are produced using rotary viscometer. Either these are reported directly as viscosities at a defined shear rates, for example $2\,s^{-1}$ and $60\,s^{-1}$ or by applying a model chosen according to the purpose and required accuracy of the measurement for example Casson, Windhab or Tscheuschner to calculate individual flow parameters that are specific to each model. Further details are given in Chapter 10, Section 10.6.

22.4 Summary of important analytical procedures in a typical quality assurance laboratory

22.4.1 General: Organisation of sampling, sample storage, sample preparation

- Sampling technology including random sampling plan and sampling schedule
- Maintain store of raw materials, semi-finished products, finished products

22.4.2 Analysis

Organisation of the calibration of laboratory equipment

- Calibration of burettes (digital)
- Calibration of laboratory balances
- Calibration of viscometers

Subject of analysis: General measurements

- pH value
- Determination of total ash
- Ash content (conductivity meter)
- Settled and compacted apparent density
- Colour measurement
- Determinatiosn of viscosity

Subject of analysis: Sensors for raw materials, intermediate products, finished products

Sensory Analysis

- Cut test (cocoa beans)
- Acetone-soluble fraction (lecithin)
- Lipase activity (milk)
- Sensory protocol
- Triangular test
- Record complaints for raw materials and intermediate products

Subject of analysis: Sensors for packaging material/finished products unpackaged
Robinson test

- Develop a complaint system related to packaging material.
- Set up an archive of quality defects and complaints about packaging material.

Subject of analysis: Visual inspection
Dirt test of milk powder

- Set up defect list and defect evaluation table for unpackaged products and packaging material.
- Set up defect list and defect evaluation table for unpackaged products and MHD (usual terms for this in English are expiry date, minimum durability or best before) for packaged products.

Subject of analysis: Water (moisture) content

- Dry matter in a drying cabinet
- Moist dry matter in a drying cabinet
- Dry matter in samples containing sugar
- Brabender moisture (fast method)
- Water activity (AW value)
- Moisture according to Karl Fischer analysis

Subject of analysis: Fat phase

- Fat content using the Soxhlet method
- Iodine number
- Peroxide number
- Oxidation stability
- Composition regarding triglycerides
- Surface fat in milk powder
- Degree of acidity of milk powder
- Fat content using NIR
- Lipase activity
- Determination of the melting point

Subject of analysis: Sugar

- Sucrose and glucose
- Sucrose (double polarization)

Subject of analysis: Particle size

- Particle size distribution (laser diffractometry)
- Fineness determined with a micrometer
- Fineness determined by wet sieving
- Fineness determined by dry sieving (particle size distribution plot)
- Size determination with hazelnuts (particle size distribution plot)
- Wet sieving with water (particle size distribution plot).

Conclusions

This chapter explained some of the many analytical tools that are available to the confectionery manufacture. Every company will have its own procedures and instruments, many developed in-house. The most important thing is that they are used correctly to finally provide the consumer with high-quality safe products.

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Chapter 23

FOOD SAFETY IN CHOCOLATE MANUFACTURE AND PROCESSING

F. Burndred

23.1 Introduction

The aim of this chapter is to present the major potential food safety hazards to be considered during chocolate manufacture and use, and to suggest methods of their control. Although it is not intended to be an exhaustive account, it should provide the reader with an overview of the breadth of this subject and of the importance and wide scope of the different food safety controls within the chocolate processing industry.

23.2 The importance of food safety management in chocolate processing

According to ISO22000: 2005, a food safety hazard is a biological, chemical or physical agent in food, or condition of food, with the potential to cause an adverse health effect. In other words, it can be defined as anything related to the food that might cause harm to the consumer. Implementation of a Food Safety Management System and control of such hazards in chocolate processes is essential; the consequences of its failure can be illustrated by a number of serious and high profile incidents and recalls over recent decades. Such incidents can cause illness, injury, or, in the most severe cases, death to the consumer. Chocolate manufacturing companies must strive to maintain the consumer's trust in their products, as the consequences of a major food safety incident not only affect their own business, but can also have a negative impact on the reputation of the confectionery, and food industry, as a whole.

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23.3 HACCP and pre-requisite programmes

Although this chapter will not describe in detail the principles of a good food safety management system, it is important to note that food safety in chocolate processes should be managed through the implementation of pre-requisite programmes, and HACCP. It is for this reason that the hazard categorization used in this chapter to define the different types of food safety hazards follows that used by the HACCP methodology – namely physical, chemical (including allergen hazards) and biological (microbiological) hazards.

For those readers unfamiliar with the concept, HACCP is the acronym for Hazard Analysis and Critical Control Points, which is a systematic and science-based approach to the identification, assessment and control of food safety hazards. The principles of HACCP have been clearly defined by Codex Alimentarius, and it is considered to be one of the most useful tools for the proactive identification and control of hazards in foods. Prior to the application of a HACCP system, it is essential to have basic pre-requisite programmes in place, which include what are commonly referred to as Good Manufacturing Practices (GMP). Therefore pre-requisite programmes include, for example, personal hygiene routines, pest management systems, and foreign body prevention schemes.

23.4 Physical hazards

Foreign bodies can be defined as matter that is present in a food, but which, whether of intrinsic or extrinsic origin, is undesirable (George, 2004). An intrinsic foreign body is associated with the food itself, for example nut shell or raisin stalk. An extrinsic foreign body is introduced from external sources, and includes matter such as glass, metal, wood, plastic, insects and human hair.

Physical hazards are foreign bodies that are hard and/or sharp. They may cause physical injury, such as cuts to the mouth, throat or digestive system, or choking.

The sources of physical hazards during chocolate manufacturing and processing usually fall into one of the following categories:

- Incoming raw materials
- Processing equipment
- Failures in pre-requisite programmes.

23.4.1 Physical hazards in incoming raw materials

It is important to ensure that all ingredients used in the manufacture of chocolate are received free of foreign materials. Any ingredients derived from raw materials of an agricultural origin, such as cocoa products, nuts, or sugar, must have suitable control measures in place during processing by the supplier to remove physical hazards.

A major potential source of foreign materials is unprocessed cocoa beans. The fermented, dried beans may be contaminated by many foreign materials, including stones, wood, metal, glass, fibrous material, loose shells, dust and sand. An essential step in the processing of cocoa beans is cleaning, where various methods are used to separate out the foreign bodies, including air separation, vibration, sieving and magnets.

Additionally, further removal of foreign material occurs after the beans have been broken. During winnowing, the shell is separated from the nib, and at this point it is important to remove any other hard residues such as sand and dried pulp remains, as well as the shells.

In addition to the intrinsic hazards present in the incoming raw material crops, it is also possible that the plant, equipment and manufacturing practices used to process the ingredient could contribute extrinsic physical hazards.

It is important to have confidence that the suppliers of such ingredients have effective foreign body management systems in place, both for the intrinsic hazards in the ingredient and for their own manufacturing processes; this can be achieved by audits of the supplier's food safety controls, and the building of a relationship between supplier and chocolate manufacturer.

Incoming raw materials should be adequately protected during transport and storage to ensure that foreign materials such as dirt and wooden splinters from pallets etc. cannot contaminate the material. Metal staples should not be used as part of the ingredient packaging. The condition of incoming ingredients should be checked on delivery and damaged goods rejected.

23.4.2 Physical hazards during processing

Figure 23.1 shows some examples of foreign materials that could inadvertently enter the production process if suitable preventive measures are not in place. These are soft and hard plastic, paper, foil wrapping material, wood, rubber, metal wire and shavings, loose screw, string and threads.

Attention should be paid at the intake and tipping points of ingredients into the chocolate making process to prevent the addition of physical hazards. Operators must be careful during unpacking and tipping of non-bulk ingredients, such as those delivered in paper or plastic sacks, or boxes, to make sure that wrapping materials, string, knives and ingredient scoops do not unintentionally enter the process at this stage. Any entry point of ingredients into the process, such as bulk ingredient delivery points, dry ingredient tipping stations and fat melters, should be designed to minimize the risk of physical hazard entry.

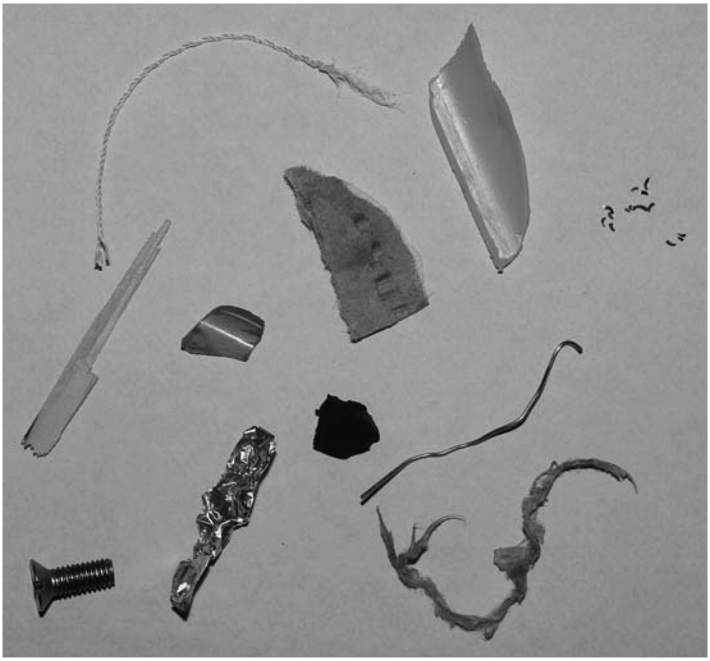

Figure 23.1 Some examples of foreign materials. Reproduced with permission of Paul Davies. See Plate 19 for the colour image.

It is common to have additional physical hazard controls in place at such intake points, including in-line filters and magnets for liquid ingredients and sieves for dry ingredients such as milk powder. These controls should be regularly inspected, both for the accumulation of any foreign material and for any damage to this equipment, such as a broken sieve mesh.

The complex nature of the chocolate manufacturing process can lead to further sources of physical contamination. Many items of equipment have moving parts, which can, if problems occur, come into contact with other parts of the equipment and cause metal shavings to enter the process. Examples of such equipment are storage tanks with stirrers, conches, screw feeders, pumps, mixers, temperers and depositors. Other sources of metal contamination include nuts, bolts and other fixings that can wear loose over time and fall into the process, enrober grid wires, which can be prone to breakage, and sieves, which although providing protection against foreign material, can themselves become a source of metal contamination if they break.

Sources of physical contamination are not only metal – problems can also occur through the failure of rubber seals and gaskets, the damage and fraying of conveyor belts and the breakage of plastic moulds, mould carriers and other hard plastic items.

The most effective way to control such contamination is through preventative maintenance – the identification of potential equipment failures and implementation of a regular schedule of inspection and upkeep. Also, prompt reaction to breakages and equipment failures is essential to minimize contamination – there should be, for example, a procedure to deal with mould breakages, whereby the line is stopped, broken moulds removed and replaced, plastic pieces cleared from the area and a number of moulds either side of the breakage removed to prevent mould fragments potentially entering the product.

23.4.3 Physical hazards from failures of pre-requisite programmes

The diligent, attentive behaviour of all personnel associated with the production process is essential to minimize the risk of physical contamination of the product. Depending on the nature and scale of the operation, the manufacture and packing of chocolate products can be quite labour intensive, with significant amounts of product handling, for example the hand packing of assortment boxes. Also production plants can often have areas where the product is exposed to the general environment, such as conveying and wrapping processes. Because of this, there is a risk that foreign material could enter the production process and it is essential that Good Manufacturing Practices are thoroughly applied in the production room. Important procedures are described below.

23.4.3.1 For the factory employees

It is necessary to provide suitable overalls without buttons and ideally only those with inside pockets. In addition effective hair coverage (which may include beards) is required, together with restrictions on the wearing of jewellery, nail varnish and false nails. Loose items must be avoided, other than those essential for the job for example suitable one-piece pens without lids. Employees must avoid placing loose items, such as pens or tools, on top of processing equipment.

23.4.3.2 In the factory

The use of glass in the production rooms should be minimized and essential glass items protected. such as lighting. A register should be maintained of glass and hard shatterable plastic items, which must be regularly checked for damage. The use of wood should be very limited, as it is prone to splintering. Wooden pallets should be restricted when possible to the end of the production line, where the product is already wrapped and hence protected.

23.4.3.3 Provision of suitable tools

Cleaning materials should be fit for purpose and designed to minimize the generation of physical hazards – for example brushes should have resin-bonded bristles, cleaning scrapers and shovels should be disposed of if they become damaged. Wire brushes should be avoided. Tools used in the production room, such as knives, scrapers and scoops, should be sturdily constructed, and have clearly identified storage locations. Regular checks should be carried out to ensure that they are present and in good condition.

23.4.3.4 Use of suitable containers

Storage containers for ingredients, rework and part processed materials are commonly made of plastic and can become damaged by regular use. Such containers should be on a system of regular inspection, for example after washing, and damaged tubs should be disposed off.

23.4.3.5 Minimizing product exposure

The production process should be enclosed where possible, for example tanks, hoppers, ingredient containers and other vessels should have lids. Where the production line is exposed, the risk of foreign body contamination must be carefully assessed and if necessary, the line should be modified to cover the product. This particularly applies where walkways cross the production line, or where there is further processing equipment above the line that could present a physical hazard. Rework must be carefully handled, containers should be lidded, and any wrapping materials removed from rework before reprocessing.

23.4.3.6 Care during maintenance and building work

Maintenance procedures should include the protection of exposed food contact surfaces during work, careful cleaning of the area afterwards, and the control of screws, nuts, bolts and the like. Operations that involve the generation of potential foreign materials, such as drilling, should be carried out away from the production line. Buildings should be maintained in a state of good repair, to avoid the risk of flaking paint and other debris. Temporary repairs and ‘cardboard and tape engineering’ should be avoided, or where present, swiftly replaced with a permanent, food safe solution.

23.4.3.7 Prevention of pests

Chocolate processing equipment is generally dry cleaned, making it difficult to remove all traces of residue. Insects such as cocoa moth and grain beetle are attracted to such residues and can cause infestations. Other ingredients used in confectionery manufacture, for example sugar syrups, are very attractive to insects such as wasps and it is therefore very important to effectively pest-proof the production building and to ensure that external doors are kept closed. In addition it is necessary to minimize residues, quickly clear leaks and spills and to keep waste covered.

23.4.3.8 Staff awareness

A high level of awareness of the factory staff can play an important role in prevention of foreign material contamination. Different means of encouraging such awareness can be used, for example having loose part boxes in the production room for the collection of stray items (such as nuts and bolts), displaying foreign materials picked up by metal detectors or sieves, and setting up feedback notices about the foreign materials returned as consumer complaints.

23.4.4 Detection of physical hazards

In addition to the methods of control, described in the above sections, it is important to apply foreign body prevention and detection equipment to the production line. A combination of techniques provides the best armoury against the ingress of foreign materials.

These techniques can include sieves and filters, typically at ingredient intake points and other key points in the process, such as at the end of the chocolate making process and importantly, during rework processing. The size of the mesh should be sufficiently small (e.g. 2 mm (0.1 in.)) to ensure that significantly sized foreign material fragments cannot pass through it. The sieve mesh should be constructed as sturdily as possible to minimize the likelihood of it breaking; punch-plate styles are particularly robust. Sieves and filters should be subject to regular inspection, to ensure they are still intact, and to monitor levels of foreign material present.

Magnets can also afford a defence against ferrous metal contamination. They should be situated in parts of the process downstream from equipment that may be prone to failure; for example in the troughs of enrobers that are subject to grid-wire breakages. As with sieves, magnets should be regularly checked to remove build up of the fine metal dust that is commonly present from the chocolate making process and to check for any unusual levels of metal pieces. These serve as an early warning system for equipment failures or other sources of metal hazards.

Metal detection is an important step of the production process, and is best situated as near to the end of the production process as possible for the optimum detection of metal hazards that may be generated during manufacturing and packing operations. Metal detectors should be carefully specified to suit the production process, in close consultation with the metal detector supplier, to ensure that the most appropriate detector and position in the production line are selected. However it is important to note that metal detectors will not remove all the metal fragments that may be generated by the production process (see also Chapter 22). They have limitations in sensitivity with regard to the metal size and type. Some types of metal such as stainless steel are particularly difficult to detect, and long, thin metal fragments of metal may not be detected, depending on the orientation in which they pass through the detector (George, 2004). Metal detectors are the last line of defence in the process and it is essential that effective foreign body prevention measures are in place.

23.5 Chemical hazards

There are two main sources of chemical contamination during chocolate manufacturing and processing – the intrinsic contamination of incoming raw materials, and contamination that may occur during the production process (Allergen hazards are addressed later, in Section 23.7). At high doses, the exposure to chemical contaminants can cause toxicity to the consumer, for example acute poisoning from the ingestion of high levels of lead; at lower doses there are generally long-term adverse health consequences that will affect the consumer, such as kidney dysfunction, skeletal damage or reproductive deficiencies when cadmium builds up in the body for many years (Commission Regulation, 2001).

23.5.1 Chemical hazards in incoming ingredients

Raw materials of plant and animal origin are potentially affected by a number of environmental contaminants.

23.5.1.1 Heavy metals

Cadmium is a heavy metal that exists naturally in low concentrations and is absorbed from the soil by many plants, including cocoa beans. Levels of cadmium can vary by growing region, according to the type of soil: soils of volcanic origin for example, tend to contain higher than average cadmium content. This can be illustrated by data showing that cadmium levels in African cocoa kernels have been found to typically contain 0.08–0.14 mg/kg, while levels in fine cocoa varieties from Venezuela and Ecuador, where soil is volcanic, have been found to contain 0.18–1.5 mg/kg (ICCO, 2006).

Lead is also widely present in the environment, due to both natural occurrence and human activities, such as the use of leaded petrol. Levels have reduced in food in recent years due to efforts to reduce lead emissions. Raw materials may become contaminated with lead if they are grown, stored or processed under conditions that could introduce larger than typical levels of lead in the food, such as crops grown in soil contaminated from prior use of leaded pesticides. Cocoa liquor is the principle source of lead in chocolate. As a consequence, lead levels in finished chocolate products tend to be higher in dark than milk chocolates, due to their higher liquor content. However, the US FDA believes that lead levels in finished dark chocolate products should not normally exceed 0.1 mg/kg if raw materials are sourced appropriately (US Department of Health and Human Services, 2005).

23.5.1.2 Mycotoxins

Mycotoxins are toxic substances produced by specific fungal moulds. Toxigenic fungi occur regularly in food supplies worldwide due to mould infestation of susceptible agricultural product such as grains, nuts and fruits (Murphy *et al.*, 2006). Ochratoxin A (OTA) is the major mycotoxin that threatens cocoa. OTA is produced by several species of *Aspergillus* and *Penicillium* and has been found to occur essentially during the post-harvest period, during the initial stages of sun drying of cocoa beans (Bonvehi, 2004), and under warm, humid transport or storage conditions. Good post-harvest practises are the only means to prevent mould development and OTA contamination. Ochratoxin A can have serious health consequences, including kidney failure, and is classified as a probable human carcinogen by the International Agency for Research on Cancer (IARC). Research on Ochratoxin A levels in cocoa products showed the highest levels concentrated in the shell – mean levels in roasted cocoa shell were found to be 11 µg/kg – and cocoa cake (mean 2.79 µg/kg), reducing to much lower levels in other cocoa products and finished chocolate products (Bonvehi, 2004; Amezqueta *et al.*, 2005). The lowest levels are found in the fat fraction of cocoa products.

Aflatoxins are also generated by a number of species of *Aspergillus* and *Penicillium.* They are carcinogenic and toxic to the liver (Engel *et al.*, 2001). Although most commonly associated with nuts, cereals, rice and dried fruits, Aflatoxin B1 has occasionally been identified in batches of cocoa beans (Doncheva and Dikova, 1992). This research showed levels tending to decrease with each cocoa bean processing step, until they were undetectable in cocoa butter.

23.5.1.3 Pesticides

Pesticides are a group of substances designed to kill pests and weeds and to protect crops and stored products. Some pesticides can accumulate in the environment and become increasingly concentrated as they move up the food chain (Engel *et al.*, 2001). The type of pesticide used varies by growing region of the cocoa bean. Consignments of West African cocoa have been known to have been rejected due to residues of Lindane that was traditionally used to control mirids (sap sucking insects) (Mabbett, 2002).

Methyl bromide has for many years been used to fumigate cocoa beans in storage, particularly as a defence against the cocoa moth, which is a main agent of destruction of stored beans in countries of tropical origin. However, the use of this chemical is being phased out for environmental reasons and alternative methods are in use or being developed.

23.5.1.4 Mineral oils

Cocoa beans are traditionally shipped in bags or sacks, made of woven natural fibres, commonly jute. Jute has previously been impregnated with mineral hydrocarbons, which may subsequently contaminate the cocoa beans. As a consequence, the International Jute Organisation has put a ceiling of 1250 mg/kg unsaponifiable matter present in jute bags, approved by the International Cocoa Organisation (ICCO, 2006). This problem can be avoided by the use of non-toxic vegetable oils for this purpose (Mabbett, 2002).

In addition to the hazards described above, relating to cocoa products, chemical hazards in other chocolate-making ingredients must also be considered, as these may all end up in the finished product. Other agricultural crops such as those used to produce vegetable oils, sugar, or lecithin, may be similarly exposed to environmental contaminants such as heavy metals or to pesticide residues. Milk products can be derived from raw milk that may contain traces of antibiotics, pesticides and hormones, heavy metals or aflatoxin M1 (Fischer *et al.*, 2003).

To evaluate the likelihood of occurrence of chemical contaminants in incoming ingredients, knowledge on the origin of raw material is important, for example country of origin, soil type and local climate where relevant as well as the existence and enforcement of regulatory measures. Moreover, information on storage conditions at farm and at supplier level, availability and price of agrochemicals used for ingredients of agricultural origin, as well as the supplier history and confidence level, are all key factors to be analysed when determining which contaminants might occur and at what level.

23.5.2 Chemical hazards occurring during processing

Contamination of chocolate with chemicals can also occur during manufacture and processing. Cross contamination linked to the use of chemicals for cleaning confectionery equipment can easily happen. An example is sodium hydroxide solution, which is used to clean equipment such as caramel cookers – to avoid causing contamination, it must be used in the correct concentrations, effectively rinsed off afterwards, and properly segregated or stored. Other chemicals, used for treatment of water in heating and cooling systems, or for boiler treatment, may also potentially contaminate the product through inadvertent leakage.

Oils and greases, which are necessary to many items of processing equipment, may potentially cross-contaminate confectionery products. Therefore it is essential that food grade oils and greases be used where there is any possibility that they may come into contact with food materials.

Other chemicals required for maintenance and upkeep of the production environment, such as paints and sealants, must be of food safe composition when they may come into contact with food. They should be correctly stored and adequate precautions should be taken when using them, including the protection of production lines and ensuring good ventilation.

23.6 Microbiological hazards

23.6.1 *Salmonella*

The key microbiological hazard during chocolate manufacture and use is *Salmonella*. Although chocolate is a relatively dry product, with a low water activity typically around 0.4–0.5, it is proven that, although it cannot grow in these conditions, *Salmonella* can survive in chocolate products for longer periods of time than in other food matrices; in fact periods of several years have been reported (Cordier, 1994).

There have been a number of food poisoning outbreaks that have been associated with the presence of *Salmonella* in chocolate, often caused by a surprisingly low number of cells. It is hypothesized that the fatty matrix of chocolate actually protects the *Salmonella* cells from the acidic environment of the stomach, allowing them to colonize the lower gastrointestinal tract, producing clinical symptoms (D'Aoust, 1977).

The outbreaks shown in Table 23.1 demonstrate the small number of *Salmonella* that may be sufficient to cause illness in a large number of people, often children. With exporting of chocolate products to other countries now being commonplace, outbreaks could become very widespread in nature.

Symptoms of Salmonellosis are diarrhoea, vomiting, fever and abdominal pain, lasting up to seven days. Although rarely so, it can be fatal, with higher mortality rates amongst 'high risk' groups – the very young, elderly, and those who are ill, convalescing or with a weakened immune system (Engel, 2001).

Salmonella may be introduced into the chocolate process through incoming raw materials, or through inadequate hygiene practices at the factory.

23.6.2 *Salmonella* in raw materials

The primary origin of *Salmonella* is the intestinal tracts and faeces of humans or animals (Engel, 2001); therefore, the raw materials that are most likely to become contaminated are those of an agricultural origin that may have been exposed to such conditions.

23.6.2.1 Cocoa beans

Cocoa beans are a known potential source of *Salmonella*, due to poor hygiene conditions during bean harvesting, fermenting and drying. The pulp and beans are contaminated during and after breaking of the pod by many sources, including hands and tools of harvesters, soil, leaves, re-used wooden containers, insects and animals (Lund *et al.*, 2000).

After harvesting, beans undergo a fermentation process, during which a succession of different micro-organisms can be identified. At the start, yeasts are predominant, declining by around the third day in favour of lactic acid bacteria, and acetic acid bacteria (see Chapters 2 and 8). The last phase of fermentation favours the development of thermophilic spore-forming bacteria, and the microflora of fermented beans predominantly consists of members of the genus *Bacillus* (Barrile *et al.*, 1971). After fermenting, beans are dried, commonly in the sun. During the drying process there may be little environmental control and further microbial contaminants can access the beans. As a consequence of the fermentation and drying processes, raw cocoa beans have high microbial levels and the presence of *Salmonella* is a well-recognized hazard (Bell and Kyriakides, 2002).

Table 23.1 Summary of published chocolate outbreaks due to *Salmonella* contamination. Reproduced from Werber, D., *et al.* (2005), with permission of Dr D. Werber.

Year	**Country**	**Serovar**	**Vehicle**	**Source of contamination**	**cfu/g**	**No. of affected persons**	**Age of cases (years)**
1970	Sweden	*S. durham*	Chocolate products	Cocoa powder	/	110	53% ≤15
1973–1974	USA, Canada	*S. eastbourne*	Chocolate balls from Canada	Cocoa beans	2.5	200	3 (median)
1982	England, Wales	*S. napoli*	Chocolate bars from Italy	Unknown	2–23	272	58% ≤15
1985–1986	Canada	*S. nima*	Chocolate coins from Belgium	Unknown	/	/	?
1987	Norway, Finland	*S. typhimurium*	Chocolate products from Norway	Avian contamination speculated	≤1	349	6 (median)
2001–2002	Germany, other European countries	*S. orianenburg*	Two chocolate brands from Germany	Unknown	1.1–2.8	439	15 years (median)

Roasting of beans or nibs is an essential step in the destruction of *Salmonella* and other vegetative bacteria. It is therefore very important that appropriate controls are applied at the roasting step to ensure that sufficient temperatures and roasting times are achieved and that no under-roasted material can pass into the subsequent process. It is considered that the traditional roasting process (typically temperatures of 105–150°C (120–300°F) for 15 min to 2 h) is sufficient to destroy vegetative microorganisms, including pathogens such as *Salmonella* (ICMSF, 2000). The most effective process in reducing microbial levels is one that combines a steam pre-treatment, or 'debacterization' step; lower thermal death rates can be expected from a dry roasting process. Alternative roasting processes should be validated to ensure that they are capable of inactivating expected levels of *Salmonella.*

After the roasting step, there are no further processing stages in the manufacture of chocolate products that will effectively destroy *Salmonella*, as the low water activity and high fat content lead to significantly increased heat resistance of *Salmonella* in the chocolate matrix (Cordier, 1994). Temperatures of 70–80°C (158–176°F) attained during milling, refining or conching are not sufficient to destroy small numbers of *Salmonella* (Lund *et al.*, 2000). Therefore, hygienic processes and working practices are essential as preventive measures to avoid *Salmonella* cross contamination.

Correct hygienic zoning of the cocoa bean process is required to ensure that there is no possibility of cross contamination from the raw beans to subsequent, post-roasting steps. Raw bean storage and handling areas must be well segregated. Personnel and equipment should be dedicated to these areas and movement between the raw bean and post-roasting departments must be minimized. Hygiene barriers between these areas must be robust, incorporating shoe and overall changing for workers, and complete separation of the buildings and equipment. The airflow as well as personnel and vehicle movement must be designed to prevent any chance of the ingress of raw cocoa bean dust into the post-roasting process. Air, including that used for cooling the beans after roasting, must not be drawn from the environment in which raw beans are present (Bell and Kyriakides, 2002). All air introduced directly into products or in an exposed product environment should be suitably filtered (IOCCC, 1991).

23.6.2.2 Other raw materials

The hazard of *Salmonella* must also be controlled during the production processes of other sensitive chocolate ingredients. Milk powder has been implicated in a large number of salmonellosis outbreaks (Bell and Kyriakides, 2002) and heat treatment and cross contamination controls in the milk powder manufacturing process must be strictly followed. Similarly to cocoa beans, raw nuts may become contaminated with *Salmonella* if they are exposed to poor hygiene conditions and once again the roasting step is an essential control. The presence of *Salmonella* has also been linked to other common confectionery raw materials, including egg products, flours and starches, lecithin and coconut (Cordier, 1994).

Although *Salmonella* is the main organism of concern for chocolate manufacturers, it is also important that all raw materials are assessed during HACCP studies for other microbiological hazards – for example freeze-dried fruits used as inclusions in chocolate products could be at risk of contamination by viruses or other enteric pathogens.

Careful supplier selection and auditing is important to ensure that incoming ingredients will be microbiologically safe for use in the chocolate-making process, particularly because the microbiological safety of the chocolate products relies entirely on the use of safe ingredients and the control of cross contamination during processing and packing. Regular risk-based microbiological monitoring of incoming raw materials should be carried out. Ingredients should be inspected on arrival to ensure they are in good condition, with no damage, or signs of pest activity.

23.6.3 Prevention of microbiological contamination during processing

In addition to the incoming cocoa beans and other raw materials, it is important to consider the other possible sources of microbiological contamination, including *Salmonella*, in the chocolate process.

Once again, good manufacturing practices are imperative in the prevention of *Salmonella.* All employees, visitors and contractors should strictly follow basic personal hygiene rules. These must include thorough hand washing and drying, removal of jewellery, prevention of hand to mouth contact (e.g. prohibition of eating in the production room), provision of appropriate work wear, pre-employment medical screening of food handlers who may be carriers of microorganisms capable of causing food-borne diseases, and reporting of cases of sickness and diarrhoea by workers, with exclusion from food handling duties until clearance is given.

Pest management is important to prevent potential pathogen-carrying pests such as birds, insects and rodents from entering the food production area. This includes ensuring that buildings are pest proofed with no unscreened windows or gaps below doors, keeping the interior and exterior of the premises tidy and clear of waste and spillages that will attract pests, and employing an effective pest control system of baits and traps for early detection.

Rework must be hygienically collected, carefully stored in clean, dry, covered containers or closed bags, and kept in suitable storage areas. Its condition should be assessed before use to ensure there has been no possibility of contamination.

23.6.4 Water control and cleaning practices

A key element in the prevention of *Salmonella* in chocolate processes is the minimization and control of water.

Cleaning procedures used in chocolate manufacturing and processing are normally focussed towards dry cleaning wherever possible. Dry cleaning procedures include manual scraping, brushing, and vacuum cleaning. Use of water should be minimized, but where it is absolutely necessary, equipment must be designed for this purpose, with surfaces that can be easily and quickly dried, and visual inspection possible after cleaning. Cleaning tools should be dedicated for food contact surfaces – normally through a clear colour coding system – to ensure that equipment used to clean the floor does not come into contact with that used to clean the production line.

Linked to this, hygienic design of equipment is an important factor – ensuring that the 'cleanability' of processing equipment is considered during its design, minimizing complex surfaces, avoiding hollow bodies, allowing full access for people and tools during cleaning and easy dismantling and reassembling of the equipment where necessary. Walls and floors should be well constructed, smooth and impervious, and capable of being easily cleaned. Storage tanks and hoppers should be covered, and plant layout should be carefully assessed, ensuring that pipes, cables or other installations that may collect dirt, leak, cause condensation or otherwise contaminate the product are not located above uncovered product flow. Condensates from cold water pipes, refrigerator coils and cooling tunnels can introduce water into an otherwise dry environment. Cool surfaces in warm areas should be insulated and the temperature of coolers should be correctly set for the throughput of the production line and thereby minimize risk of condensation (IOCCC, 1993).

Water leaks are also a potential source of contamination. Much of the equipment used during chocolate processing is kept warm by water jacket systems, for example to maintain pipeline temperatures, tempering zones and storage tank jacket temperatures. This can lead to the risk of corrosion and micro leaks, especially in older installations. The water circulates through the system, often with relatively slow flow and only low levels of replenishment with fresh water. This can be compounded in older processing facilities where changes to production lines and water circuits over the years can lead to complex circuitry and the possibility of dead-ends containing stagnant water.

The growth of pathogens, particularly in association with biofilms inside the pipework, is a possibility and should be controlled. Biofilms containing sulphite-reducing bacteria may also lead to the development of leaks, which could allow water to contact the products. Systems should be closed to prevent ingress of nutrients into the water. Circuit diagrams of water systems should be available, and any dead legs eliminated. Suitable sampling points should be installed, with regular testing of microbiological water quality, and prompt action in the event of abnormal results. Action can include heating up the water in the system; treatment with appropriate biocides, although great care should be taken to avoid inducing corrosion; draining and flushing out of the water system; and, in the worst case, replacement of sections of pipe work.

Water used as an ingredient or for cleaning must be of potable quality. Steam in contact with food or food surfaces must be food-grade quality (IOCCC, 1991).

23.6.5 Microbiological monitoring

A well designed monitoring programme for the environment and product is essential to verify the effectiveness of microbiological controls and to serve as an early warning system in the event of contamination.

A sampling plan must be devised to regularly test for both *Salmonella* and for suitable hygiene indicators, such as Enterobacteriaceae. It is important that sampling programmes include vulnerable points on the line, such as processes with high levels of human handling, areas of recent building work or maintenance, rework, and equipment where wet cleaning is necessary. Samples should not only be taken of 'clean' finished product, more meaningful samples are where residue accumulates on and around the production line. Examples include inside the walls of vessels, build-up on sieve meshes, on catch trays and ledges of the plant, on rollers that drive conveyor belts, on food contact cleaning tools, and from debris collected inside food-contact vacuum cleaners. Samples should not only be taken according to a regular plan, but should include investigative samples taken according to the condition of the production line on the day, or taken during cleaning when the line is open and more exposed for effective sampling. Management of data and evaluation of trends over time can help to identify the development of problems before they can influence product safety.

23.7 Allergen hazards

A food allergy is a food hypersensitivity involving the immunological mechanism. Food allergy is known to affect 4–6% of children, reducing to 1–3% of adults. Coeliac disease, another important food hypersensitivity to gluten-containing cereals such as wheat or barley, is estimated to affect up to 1% of the population. The clinical symptoms of food allergies, which can be triggered by very small quantities of the offending food, range from mild discomfort to severe or life-threatening reactions, requiring immediate medical treatment. Common symptoms affect the skin, gastrointestinal tract, respiratory tract, eyes and/or central nervous system (INFOSAN, 2006).

The presence of unlabelled/hidden allergenic foods is therefore a major food safety hazard faced by the confectionery industry. There have been a number of recalls of confectionery products in recent years due to the presence of inadequately labelled allergens in the product. With food allergen labelling legislation with regards to ingredients now in force in many parts of the world, the thorough management of allergenic ingredients and prevention of cross-contact in chocolate processes is essential.

The majority of allergic reactions and cases of food hypersensitivity are triggered by the following foods and ingredients, as defined by the Codex Alimentarius Commission Committee on Food Labelling (INFOSAN, 2006).

- Peanuts and peanut products
- Tree-nuts and nut products (Hazelnut, Almond, Walnut, Cashew, Pecan nut, Brazil nut, Pistachio nut, Macademia nut and Queensland nut)
- Milk and milk products (including lactose)
- Eggs and egg products
- Soya and products of these
- Cereals containing gluten; i.e. wheat, rye, barley, oats, spelt or their hybridized strains and products of these
- Fish and fish products
- Crustacea and products of these
- Sulphite in concentrations of 10 mg/kg or more.

In some countries, there are additional allergens that are particularly prevalent amongst their population, such as celery in Switzerland, Germany, etc. After evaluation by the European Food Safety Authority (EFSA), the EU have added celery, mustard, sesame seeds, lupin, molluscs and products thereof to the list of allergens that must appear on food labels (EC Directive, 2006).

The confectionery industry faces challenges with allergen management, as the first six types of allergen in the above list are commonly used in the manufacture of confectionery products.

When determining allergen management programmes in confectionery factories, it is important to consider the various routes by which allergens may be present in the finished product. Table 23.2 shows the potential sources of allergens into the production process.

23.7.1 Allergens as ingredients

These are the easiest to consider, as they are primary ingredients of the product and should be well known, such as milk used in the manufacture of milk chocolate, lecithin if derived from soya, peanuts or tree-nuts used as inclusions for example in moulded tablets and wheat gluten found in wafers or biscuit inclusions. However, it is fundamentally important to find out information about the ingredient's composition and the supplier's process, as there may be minor components of an ingredient that may contain a major allergen, or cross contact due to shared production lines, equipment or transport used by the supplier. This information needs to be carefully assessed, to understand the hazard it presents to the finished product – will it require labelling, or is it possible for the supplier to apply further controls to exclude the allergen.

Table 23.2 Potential sources of allergens into the production process.

Potential direct source of allergens into a product	Potential indirect sources of allergens into a product (cross contact)		
Materials used to make the product	**Equipment used to make the product**	**Raw material storage and handling**	**Other shared resources**
Ingredients	Shared production line	Storage areas	People
Rework	Shared process equipment e.g. mixers	Transport	Cleaning equipment
Processing aids	Pipelines and storage tanks	Ingredient handling e.g. scoops	Maintenance tools
Packaging	Shared wrapping machinery	Rework and semi finished product containers	Air handling

Another important consideration is rework – it has to be considered as an ingredient of the finished product, and all sources of rework, and potential allergens contained within it, must be known. Rework should ideally be reused back into the same product (Chapter 18). If this is not feasible, it must not contribute additional unlabelled ingredients, especially unlabelled major allergenic foods from ingredients, additives or processing aids into the product in which it is used.

23.7.2 Allergens from cross contacts at the factory

Owing to the diverse range of confectionery products manufactured, their frequency of change and new product development, coupled with the economic necessity for flexible production lines, it is quite common for a production line to manufacture a number of different products. Compounding this problem is the difficulty in thoroughly cleaning confectionery lines – in fact, as already discussed, dry cleaning is the normal method to minimize microbiological risk, but this naturally leads to some levels of residue remaining on the line. All this leads to the necessity to very carefully consider the allergen hazards across the full portfolio of products made on the same production line, as residues can easily remain in the equipment on changeover from one product to another. This is particularly the case for ingredients of a particulate nature, such as peanuts and tree-nuts, where particles or dust of the ingredient are not homogeneously distributed and may collect and later dislodge from hidden areas of the process.

Additional allergen cross contacts must also be considered within the factory environment as a whole – if an allergenic ingredient is used on a production line in only one part of the factory, there may be a possibility that cross contact can occur through the use of shared materials and tools. Examples of this include plastic containers use to store or transport rework or semi-finished products, cleaning tools and materials used for food contact such as ingredient scoops, or maintenance tools. Also cross contacts must be considered for shared items of processing equipment – for example mixers that may be used for different products or processes.

Allergen assessment in the factory must be extremely thorough and systematic to ensure that the full range of ingredients, products, processes and procedures are considered in the factory, and all possible allergen sources are identified.

23.7.3 Control measures

For each allergen hazard identified, it is essential that an effective control measure is in place. For allergens present as an ingredient, the control is the clear labelling of the ingredient on the packaging. For minor ingredients that contain an allergen that otherwise would not be present in the ingredients list, it is good practice to consider whether it is feasible to replace the ingredient with one that has similar functionality, but that does not present an allergen hazard.

For allergens present as potential traces in the finished product due to cross contact, precautionary labelling of the finished product should be the last resort, in order to offer the allergic consumer the widest possible choice of available products. Firstly, other means of controls should be evaluated, for example using dedicated processing equipment, or a dedicated colour coding system for storage containers to segregate products that contain allergens. Any such system must be thoroughly implemented through careful training to ensure full understanding and compliance and be regularly checked to ensure it is being adhered to.

For shared lines and equipment, cleaning is a possibility, but it must be ensured that cleaning is fully effective and validated, can be consistently performed to the same standard, will not leave levels of residues that will present an allergen hazard in the subsequent product and can be fully visually inspected after the clean is complete. For many complex confectionery processes, especially those that are dry cleaned, this can be very difficult to achieve.

Sequencing of production runs is another option, so that there is follow on of the allergen-containing products, hence reducing the number of major allergen cleans required.

Where labelling of the allergen as an ingredient or via a precautionary warning is necessary, it is imperative that the labelling is done clearly and legibly on the wrapper. This can be a challenge for confectionery, especially for small products where there is minimal room on the wrapper, or where the information may need to be presented in a number of languages. The packaging needs to be carefully designed to ensure that the consumer can easily find this critical food safety information. When the wrapping material is being changed it is of great importance to ensure that the allergen information is thoroughly checked and is verified to be correct before use on finished product. Also, systems must be in place in the factory for product changeovers, to ensure that the correct packaging material with its correct labelling is always in use.

Conclusions

This chapter has presented an outline of the different categories of food safety hazards that must be considered during the manufacture and processing of chocolate. It is hoped that this has given the reader a general overview of the different hazards, and their potential sources, that must be considered, and also some ideas on control measures.

All food safety hazards should be carefully evaluated for each product and manufacturing process through the HACCP approach, including good manufacturing practice programmes, to ensure that such hazards are effectively controlled, enabling the confectionery industry to continue to produce safe and pleasurable products.

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Chapter 24

PACKAGING

C.E. Jones

24.1 Introduction

This chapter starts by looking at the different types of chocolate products and how they are packaged. Flow-wrapping is used for a large proportion of confectionery products so this is then described in some detail together with different methods of sealing the wrappers themselves. Finally, the various packaging materials are reviewed as to their particular beneficial properties and to where they should or should not be used.

24.2 Confectionery types

24.2.1 Moulded chocolate tablets and bars

For many years moulded chocolate bars have remained relatively unchanged, and minimal barrier protection has been required. However, with the introduction of 'inclusions' such as cereals and nuts (e.g. rice crispies, hazelnuts) the protection required from the packaging has increased.

Traditional chocolate bars utilized tinfoil and paper-band over-wrap packaging; today, aluminium foil has replaced tinfoil (Figure 24.1) with some formats employing a full cover paper or paperboard envelope style over-wrap. The typical thickness of aluminium foil for bars without inclusions is 10 μm (0.4×10^{-3} in.), whereas, bars with inclusions that may damage the foil should be thicker (12–14 μm (0.5×10^{-3}–0.6×10^{-3} in.)). Improved barrier protection against such things as infestation, gases and water vapour can be provided by the application of heat-sealable coatings or polyethylene (PE) linings.

In the UK and some other countries around the world, flow-wrap packaging for tablets has largely replaced foil and paper packaging (Figure 24.2). Faster wrapping speeds and lower cost packaging materials have encouraged the use of flow-wrap formats. For fragile tablets cardboard is often placed below the chocolate to prevent tablet breakage and/or keep the tablet stable if the tablet should be broken.

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Figure 24.1 Typical foil and band tablet packaging. See Plate 20 for the colour image.

Figure 24.2 Flow-wrapped countlines. See Plate 21 for the colour image.

Twelve to 36 tablets are typically packed into a box known as an outer (in some countries called an inner) or display box (Figure 24.3). These outers are placed into a corrugate case for transportation. Microflute corrugated outers and display boxes have become very common in West European countries in recent years. Fully printed boxes, made with E, F and N flute (see Section 24.4.2) provide additional strength and in many circumstances

Figure 24.3 Display box. See Plate 22 for the colour image.

eliminate the need for corrugated shipping cases. Where the boxes are used for display the tablets are often packed horizontally, but where the box is used only for transport purposes, the tablets are often laid on edge to provide a stronger configuration. This means that lower strength boxes and/or shipping cases are required.

24.2.2 Chocolate countlines

The 'countline' is the core of the large-scale chocolate business in many countries. It is typically an enrobed irregular shaped product in contrast to the uniform shape of a tablet. Flow-wrap packaging formats dominate the countline market, although foil and paper packaging formats are still found for some products.

The flow-wrap can provide barrier protection for the product or hold a number of pre-wrapped products (multi-pack). Varying the structure of the film can modify the barrier properties of the package to exclude ingress of moisture vapour, gases, odours and light, or to prevent the loss of flavour.

White chocolate does not contain the anti-oxidants present in milk and dark chocolate (Chapter 27) and therefore requires packaging with light barrier properties such as metallized films to prevent light-induced oxidative rancidity. In addition, countlines containing nuts can find shelf life extended by light excluding packaging.

The outer packaging and shipping case packaging for countlines is essentially the same as that for moulded tablets; however, in most cases countlines are laid flat in the box and are very often in display boxes. Because flow-wrap countlines have extended end seals and tend to have large amounts of trapped air within the wrapper, more free-space is required inside the outer box compared to moulded tablets. This means that distribution costs can be relatively higher. However, modern high-speed flow-wrap equipment can be fitted with air reduction systems to minimize the size of the outer box.

24.2.3 Bulk chocolate

Although most bulk chocolate is now transported in liquid tankers, an appreciable market still exists for block or pelleted chocolate. In both cases the preferred packaging method is polyethylene-lined multiply paper sacks containing, say, 5 × 5 kg (11 lb) blocks or an equivalent weight of pellets, flakes, etc. To maintain stability it is advisable to ensure that the outer paper ply is treated to prevent it slipping. It is advisable to place a polyethylene sheet between the transportation pallet and the sacks to reduce any possibility of moisture or taint from the wood affecting the product. Liquid chocolate can be poured into a case, generally corrugated board, lined with a polyethylene bag. When the chocolate has set, the bag and chocolate can easily be removed and is very stable for transportation.

24.2.4 Boxed chocolates

The variety of containers for boxed chocolates appears to be almost infinite, ranging from rigid hand-made boxes with plinth bases, metal feet and tasselled lids to machine erected single-walled or double-walled cartons. In markets where the cost of labour is low, hand-erected pre-glued cartons are often used either in single or double-wall format. Hand-erected cartons offer greater flexibility in box format compared to machine-erected cartons (multiple change-parts for the erecting machine are not required), in addition, machine-downtime for size changes are avoided. The materials used range from flock paper or chipboard to metallized or film-laminated cartonboard; UV varnishes and inks can also add a high gloss surface. Rigid injection moulded transparent plastic can be used to give a clear container that shows off brightly foiled sweets to best advantage (Figure 24.4). Alternatively, thin film in the form of a window can be combined with cartonboard to give the same effect.

In contrast to the multitude of the outer container forms, the inner fitments of chocolate boxes vary relatively little from box to box. Plastic thermoformed trays have almost completely replaced heat-formed glassine cups, once universally used to hold individual sweets, although biopolymer trays are finding their way into some markets. Plastic and biopolymer trays are produced by heating the plastic or biopolymer to soften the sheet, which is then drawn by vacuum into a metal mould of the desired shape, with an individual cavity for each sweet. Plastic trays can be made from one of several different polymers in a variety of colours ranging from crystal clear to silver or metallized gold. They can be made to reproduce the appearance of a layer of paper cups or designed to give extra protection to particularly vulnerable centres. They can also be built up below the flatter

Figure 24.4 Rigid plastic containers. See Plate 23 for the colour image.

sweets by the inclusion of a ‘step’ so that the whole layer appears to be of uniform height.

Other items that may be incorporated in the internal packaging of a box of chocolates are wave-embossed or corrugated glassine or a greaseproof sheet to provide cushioning and prevent crushing of the sweets and keep the sweets safely in-place during transportation. Glassine-lined cellulose wadding can perform a similar function, perhaps more attractively, although more expensively. Corrugated glassine pads are commonly found in chocolate boxes, with corrugated plastic sheets providing a cheaper alternative.

Some nutty sweets, such as pralines or coconut clusters, exude fat to such an extent that this can permeate glassine or cellulose layers. These may therefore require a sheet of impermeable film to prevent staining of the box itself. An alternative, more unusual, method of restraining fat exudation is however to foil wrap these individual sweets. In addition to protecting the packaging from the sweet and, in some markets with particular extreme climates, providing a last protective barrier to the sweet, foil is frequently used on individual sweets purely for decorative purposes.

Great care must be taken when using printed inserts such as corrugated glassine cushioning layers in chocolate boxes that the inks and varnishes used do not contaminant the chocolate. Print should never be in direct contact with the product; even so, the headspace within the box can become contaminated from the inks and varnishes that in turn can produce off-flavours in the chocolate.

The principle means of protecting boxed chocolates from the atmosphere, and incidentally the box itself from scuffing and marking, is a film overwrap. This can take the form of cellulose or plastic film (predominately oriented polypropylene), although polypropylene has largely replaced cellulose due to the limited numbers of suppliers and high cost of cellulose. This overwrap format employs a heat-sealed overlap along the base and heat-sealed envelope folds at the ends (Figure 24.5). While offering good protection to the sweets inside, envelop-sealed overwrap formats rarely provide a 100% seal due to the number of folds in the ends. To offer easy opening of the overwrap, self-adhesive tear tape is normally applied to the film on the wrapping machine.

Heat-induced shrink-wrap film using either PVC or polyethylene film provide an alternative to the envelope overwrap. These films produce a smooth flat surface whereas the polypropylene and cellulose envelope style can leave gentle undulations and ripples in the film surface. In recent years, an intermediate system has been developed using 'blown' oriented polypropylene film in an envelope overwrap format. This film offers a limited shrink range when heated and produces a tighter fitting smooth surface wrap and therefore improved appearance and atmosphere protection compared to standard envelope overwrap films.

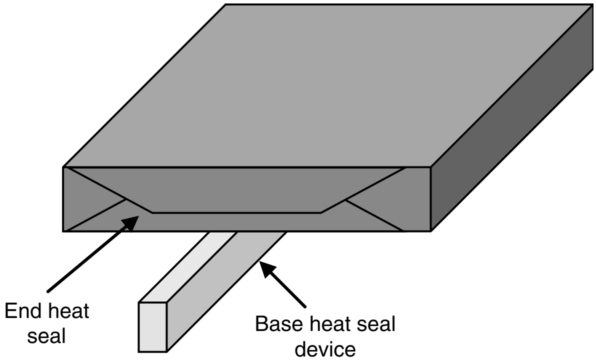


Figure 24.5 Envelope over-wrap format.

Standard cartons of chocolate can be converted into seasonal use by the addition of a printed paper or film band with a seasonal theme, which can be removed from unsold stock after the festival. The same objective can be achieved by the use of self-adhesive stickers, e.g. heart-shaped for St. Valentine's Day. Such stickers can be made of a wide variety of materials, ranging from high-gloss paper to crystal-clear polyester and polypropylene.

When boxes of chocolates are combined together in an outer, a conscious decision needs to be taken as to whether they should travel flat or on edge. If there is any likelihood of a large soft-centred sweet coming under pressure, it is often better to pack the carton on edge so that the thermoformed tray can relieve the pressure, provided it is made sufficiently strong to do so. In addition, in a double-layer box (common in the UK) the tray should be designed so that the upper layer can be turned round to place a small sweet over a large one in the bottom layer. In other respects, the construction of the outers and cases is similar to bars or countlines.

24.2.5 Twist wrapping (Figures 24.6 and 24.7)

Gaily wrapped twist-wrapped chocolates have been a major part of the confectionery scene for many years. The basic materials used have become rather sophisticated and the machinery faster, but fundamentally there has been little change. The materials used are still aluminium foil, backed or unbacked, plain silver or coloured and film, tinted, clear or printed. The foil can be applied separately as an under-strip or it can be laminated to the film (this can cause problems because the centre of the reel of material builds up due to its double thickness compared with single thickness at the edges). The foil also allows films that do not retain their shape to remain twisted following wrapping. Although regenerated cellulose film (RCF) can still be

Figure 24.6 Double-ended twist wrapped sweets. See Plate 24 for the colour image.

Figure 24.7 Single-ended twist wrapped sweets. See Plate 25 for the colour image.

found in twist wrap applications, it has become less and less common due to the high cost and reduction in producers of RCF. However, to date, no other film has been able to offer the feel, clarity and sparkle of RCF especially when the film is tinted in the master batch (coloured film is used as opposed to film where the surface is printed to produce a solid colour). Twist-grade metallized paper and metallized films such as PVC and polypropylene are increasingly being used to add an extra dimension to the variety of wraps in an assortment. The addition of pattern applied cold seal adhesive in the twist area has become more common in recent years to enable films to be used that would not normally retain a twist. In addition, cold seal can also be applied to create a fin-seal closure along the base of the sweet. This increases the barrier protection properties especially when used in combination with cold seal in the twist areas. New biomaterials such as PLA (produced from cereal starch) have also been trialled for twist-wrap applications as this book went to press.

The most common form of twist wrap is the 'double-end fantail' known as a double twist (Figure 24.6). A popular alternative is a combination of twist at one end and folds at the other, giving a sachet style wrap (Figure 24.7). This is particularly effective with fruit designs, for instance for strawberry creams, where the body represents the sweet and the fantail the leaves.

Because the attraction of a twist-wrapped assortment lies in its bright, glossy and colourful packaging, the container in or from which it is sold, usually tends to be transparent or at least have a clear window. For many years twist-wrapped chocolates were sold from screw-topped returnable glass jars, but in line with the modern trend to non-returnability, these have generally been replaced by clear polyvinylchloride (PVC), polypropylene (PP) or polyethylene terephalate (PET) containers. The glass jar in recent years has found itself supplanted by PET due to PETs glass-like visual clarity and ability to be moulded into a variety of shapes resulting in the jar often finding a secondary usage in the home.

Brightly printed round tins also have been used traditionally as both consumer and weigh-out retailer packages, with the finish and quality of print and design making up for the loss of visibility. Tinplate, however, is expensive and therefore in many applications has been replaced with metallized materials, such as cartonboard laminated with metallized film or metallized plastic containers.

Twist-wrapped chocolate sweets also lend themselves to packaging in printed film bags, generally with display windows, produced on vertical form-fill-seal machines. The variety of films that can be used to make the bags is very wide, but Bi-oriented polypropylene (BOPP), polyethylene (PE) or polyethylene terephthalate (PET) usually in laminated forms are the most commonly found formats.

24.2.6 Easter eggs and other seasonal chocolate novelties (Figure 24.8)

Traditionally, Easter eggs and other seasonal novelties, such as Easter Rabbits, Father Christmas, chocolate bells etc., have been foil wrapped, taking advantage of the ability of foil to follow irregular contours and to be smoothed into shape, as well as its decorative appeal when printed.

Foiling Easter eggs is relatively simple, either by hand or by machine, but the designing of a piece of foil to go round a Father Christmas requires the skill of a specialist to ensure that all the features on the foil match up with those of the chocolate figure. This can be achieved by using the printed foil to line the mould. However, the usual method is to produce the figure first and then foil it, relying on the skill of the foiler to apply the properly designed foil accurately. Machinery is available to foil simple shapes and, where appropriate, to attach cords for hanging from Christmas trees.

Where there is a short shelf-life and good storage conditions, unfoiled novelties may be wrapped in clear or part-printed film to show off the quality of the product. Care must be taken to ensure that the film used is impervious to moisture and that conditions conducive to chocolate bloom are avoided. Strip-metallized films are frequently used for this purpose as they are good barriers and highly decorative. They make good bags, but of course cannot be used to 'foil', as they have no dead-fold characteristics (i.e. cannot retain their folded shape).

A wide variety of containers is available for presentation of foiled eggs and figures. The most usual are either some form of open windowed carton or clear plastic vacuum formed 'clam-shell' type containers within a carton frame. Eggs were traditionally sold in eggcups, printed beakers, wicker or

Figure 24.8 Seasonal chocolate novelties. See Plate 26 for the colour image.

plastic nests and baskets, however, in recent years, price sensitivity have seen the reduced usage of this type of container in many markets.

There is no doubt that the likely cause of damage to Easter eggs and novelties is poorly designed packaging. The most attractive cartons are useless if they cannot protect their contents from the rigours of the distribution chain, and it is often necessary to affect a compromise between design and strength. High-quality boards and board laminates can enable designs that were formerly impracticable to be used, but at a cost.

It is always advisable to carry out carriage tests on new packaging materials and/or formats. The tests must be designed as far as possible to reproduce the normal hazards of distribution, but with Easter eggs and novelties this becomes essential. It is also critical that such tests are carried out using exactly the materials that will be used in bulk manufacture and that these materials are clearly specified and checked. There have been many cases where cartons have been made of different boards when printed for the final product, compared with the plain form supplied for testing.

24.2.7 Shelf ready/retail ready packaging

Recent developments have seen the growing demand from retailers for ‘shelf ready’ or ‘retail ready’ packaging, i.e. packaging that will go from transit to shelf with the minimum amount of labour and time. Therefore, transit cases are becoming more expensive in order to decorate the case more elaborately, to enable the contents to be placed on the retail shelf with minimum effort (Figure 24.3). Corrugated (including micro-flute) and cartonboard cases are becoming more complex with tear-off lids and/or multiple-piece construction allowing a lid or hood to be removed easily without the aid of cutting blades. Usually this leaves a tray holding the contents, which can easily be placed on the shelf, thereby significantly reducing the labour time required to fill the shelf.

Although shelf ready/retail ready packaging is an added cost for the manufacturer of the goods (increased decoration, complexity and materials that are more robust), it also should be recognized that these transit formats offer increased potential to display the brand image to its best advantage on the retail shelf. In addition, transit cases are becoming more easily identifiable in the back of store; therefore, shelf out-of-stock situations can be reduced.

24.3 Flow-wrap machinery and sealing (Figure 24.9)

The flow-wrap is carried out as follows: A horizontal form-fill-seal machine (flow-wrap machine) forms a continuous tube of packaging film by producing a longitudinal seal (often referred to as a fin-seal) along the base of the pack (Figure 24.10); the product is pushed into the tube for a set distance. The tube containing the product is sealed (end-seals) by rotating predominately metal jaws and cut to a predetermined length. Alternative sealing surface materials can also be used for cold seal applications such as Kevlar and rubber. The softer surfaces of these materials even-out irregularities in the film to produce improved seal integrity.

Sealing of flow-wrap packaging is performed by the application of pressure, heat and dwell time or by pressure and dwell time alone when cold seal adhesive is employed. For heat sealing the main wrapper typically consists of several layers of polypropylene co-polymers extruded together

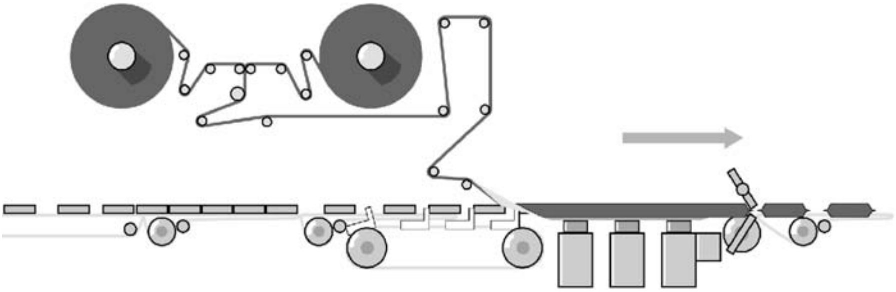


Figure 24.9 Schematic illustration of flow-wrap packing line.

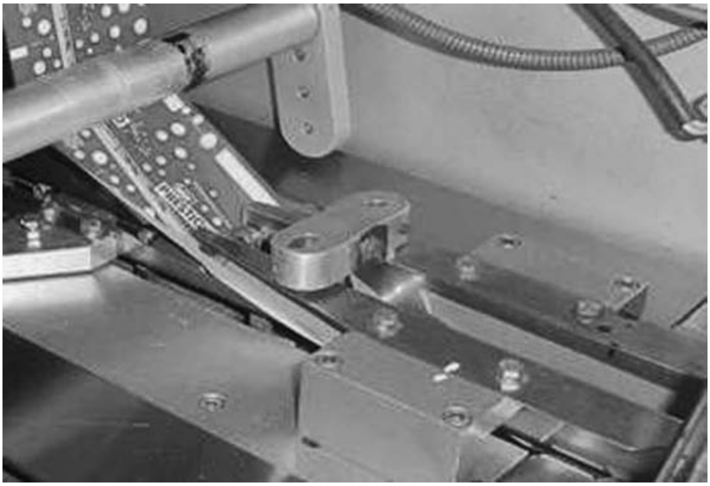


Figure 24.10 Folding box to produce the tube for horizontal flow wrapping. See Plate 27 for the colour image.

(co-extrusion) to form a mono-web film. Heat sealing can be achieved either by the application of coatings such as PVdC (polyvinylidene chloride), acrylic etc. or by the inner layer in the co-extrusion (the sealing surfaces) having a lower melting point than the outer surface.

Where higher barriers are required (e.g. to oxygen or moisture ingress/loss), or, high visual impact, several layers of different films can be laminated together with adhesive (usually done by the printer). A typical structure for high-quality impact could be cast polypropylene (CPP)/adhesive/polyester terephthalate (PET) whereby the print is sandwiched between the adhesive and PET giving a high gloss surface. In this structure the heat seal is provided by the internal layer of CPP that has a lower melting point than the external layer of PET. In addition, a thicker sealing layer is used compared to a coated film to guarantee maximum seal integrity and high sealing bond strength.

Heat seal coatings (e.g. acrylic) are typically 1–3 μm ($0.04 – 0.1 \times 10^{-3}$ in.) in thickness, whereas laminations typically employ 30–50 μm ($1.2–2.0 \times 10^{-3}$ in.) sealing layers. On horizontal flow-wrap machines standard heat seal films run at up to 30 m/min (90 ft/min), but low temperature sealing (LTS)/broad sealing range (BSR) films are proven to run at 70–80 m/min (210–240 ft/min), however, some suppliers state their films run at up to 100 m/min (300 ft/min). LTS/BSR films attract a premium price and have therefore found limited use compared with cold seal adhesive films. LTS/BRS films are not recommended for vertical pillow pack machines due to their initial weak bond strength (seal required to carry a load immediately after sealing and before the seal has cooled).

Cold seal films work by applying a pattern-applied layer of natural rubber latex-based adhesive onto the internal edges of the film to be sealed;

these are then pressed together on the wrapping machine at high speed (see Section 24.4.5). Cold seal films are typically used for horizontal flow-wrap operations where high-speed wrapping is required. Vertical pillow-pack operations rarely use cold seal films due to the low speed and the premium price incurred by cold seal.

24.4 Materials

24.4.1 Aluminium foil

Aluminium foil provides the best barrier to water vapour, gas transmission and odour available in a flexible format. Aluminium is generally defined as fully annealed, soft temper metal of 99–99.5% purity, the remaining percentage being made up of silicon and iron with traces of other elements. Recent developments have reduced the percentage of aluminium by incorporating manganese to give added strength (the so-called 'special alloys').

The thickness can be from 5 μm to 20 μm (0.2×10^{-3}–0.8×10^{-3} in.), but generally range from 6.5 μm to 17 μm (0.3×10^{-3}–0.7×10^{-3} in.) for confectionery purposes. Cost reduction has resulted in special alloys, rolled thinner on more efficient modern plant so that, for example 8 μm (0.3×10^{-3} in.) foil can be obtained that is stronger than the old 9–10 μm (0.4×10^{-3} in.) foil, and, in some cases, than the traditional 12 μm (0.5×10^{-3} in.). Thinner gauges of foil are rolled double, giving the characteristic shiny and matt sides that appeal to artists and designers in different ways – some prefer the bright side for display value, whereas others regard the matt face as conveying discreet quality.

For bar and tablet wrapping, foil can be specified in several forms, plain un-backed with or without embossing, backed with or without embossing or coated with or without embossing. In most cases, un-backed foil is used with the embossed versions providing additional decoration along with a slight increase in rigidity for transport through the wrapping machine. When added strength and crease resistance are required e.g. when nuts protrude from the back of a bar, it may be necessary to laminate the foil to other materials.

The most popular backing material is paper because it is strong, easily printed and relatively inexpensive. Depending on the end use, and whether it is laminated to the outside or inside of the foil, there is a wide choice of paper forms available, for example sulphite tissue, kraft (usually bleached) and glassine, with an equally wide range of adhesives, such as dextrin, polyethylene, wax and hot melt. A widely used combination is, for example, 7 μm (0.3×10^{-3} in.) foil/3 gsm wax/20 gsm tissue paper (gsm = grams per square metre).

In addition to adding strength to the foil, lamination, for example to 20 gsm tissue paper, can provide a cost reduction in material when compared to using higher gauge foils such as 17 μm (0.7×10^{-3} in.).

Plastic films are used where extra barrier properties and puncture resistance are required and occasionally to provide a high gloss finish. In this instance, it is important to balance the relative gauges of material so that the ‘spring’ of the film does not overcome the desirable dead fold properties of the foil. An example of such a structure is 9 μm (0.4×10^{-3} in.) foil laminated to 12 μm (0.5×10^{-3} in.) bi-oriented polypropylene (BOPP).

In general, the thinner the gauge of foil the more minute pinholes can be expected per square metre, for example, 7 μm (0.3×10^{-3} in.) foil will have more pinholes than 20 μm (0.8×10^{-3} in.) foil. When foil is coated, usually with vinyl or polyethylene in order to make it heat sealable, this has the additional effect of filling in the pinholes. Although research has shown that most pinholes have very little effect on the barrier properties of foil, such filling can only be beneficial.

Pattern applied cold seal coatings are generally used with paper foil laminates rather than with unsupported foil.

Provided all traces of residual rolling oil (which could go rancid under certain conditions) is removed, unconverted foil is perhaps the material least likely to taint a sensitive product such as chocolate. Converted foil (i.e. foil converted by printing, coating or laminating) can create odour problems because of the coatings and adhesives as well as from printing inks; therefore, it is important that full taint and residual solvent tests be carried out before such material is used.

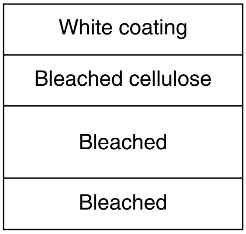
Foil is most attractive when printed. All major printing processes, particularly gravure and flexography, can do this and foil is frequently over-lacquered with transparent colours to make full use of its metallic visual properties.

In its unconverted form, aluminium foil has a wide converting area, ranging from 46 m^2/kg (225 ft^2/lb) for 8 μm (0.3×10^{-3} in.) to 31 m^2/kg (153 ft^2/lb) for 12 μm (0.5×10^{-3} in.) foil, but coating and laminating, in particular, will drastically reduce this.

24.4.2 Paper and board

These are materials produced from the natural cellulose fibres found in trees. The production process broadly consists of taking the wood apart by pulping and subsequently rejoining the fibres, without their own binding materials, as an engineered matrix designed to perform a specific function. This pulping can be done either chemically whereby the organic binding material holding the fibres together is dissolved away (e.g. solid bleached sulphite with all layers being chemical pulp, see Figure 24.11), or physically whereby the wood is ‘mechanically’ broken up and the binding material washed away by water (e.g. coated chromoboard with a centre layer of mechanical pulp, see Figure 24.12). The former method produces strong, expensive paper or board with minimal odour and taint potential and ideal for direct chocolate contact, the latter relatively weak, cheaper

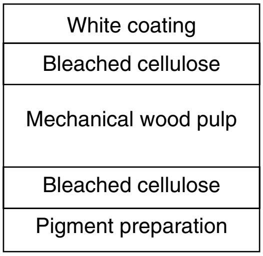
(**SBS** = solid bleached sulphate)



Proportion in g/m^2	% proportion
20 g/m^2 coating	6.7%
40 g/m^2 white covering	13.3%
200 g/m^2 white middle	66.7%
40 g/m^2 white back	13.3%
300 g/m^2	**100%**

Figure 24.11 Structure of solid bleached sulphate paper.

(**GC** = coated chromoboard)



Proportion in g/m^2	% proportion
20 g/m^2 coating	5.0%
60 g/m^2 white covering	15.0%
260 g/m^2 middle layer cream	65.0%
55 g/m^2 white back	13.8%
5 g/m^2 pigmentation	1.2%
400 g/m^2	100%

Figure 24.12 Structure of coated chromoboard.

material, which is, however, perfectly adequate for many purposes, such as newsprint, but can also produce tainting of chocolate due to the production of hexanal over time.

The finished slurry is dried out in sheet form and passed through rollers to make paper or built up in layers to make board. The layers can be of different qualities, making a multilayer sandwich by including different materials such as reclaimed waste paper and pure fibres. If the board or paper is to be printed, it normally has a top layer of good-quality bleached fibres plus a coating of china-clay-containing pigment such as titanium dioxide and possibly an optical brightening agent. This is known as coated paper or board, and many different types and qualities are available.

Care should be taken to avoid the use of recycled fibres in direct contact or even in-direct contact where no functional barrier exists between chocolate and board. Contaminants may be present in the recycled board that can migrate to the chocolate either directly or via a headspace creating an off-flavour or indeed a food safety issue.

Different chemical techniques can produce glassine, in which the fibres are completely destroyed, giving a very high degree of resistance to oil and grease in the final product, but making the paper relatively weak. Glassine can be formed into rudimentary shapes by heat and pressure, producing, for example, paper cups into which chocolates can be placed or very fatty product such as noisette can be directly deposited. Glassine is frequently used laminated to board, in order to protect it from fat penetration and staining. It can also be incorporated in a non-heat-sealed wrap to stop fat migration from chocolate bars in hot climates. Glassine in corrugated form is also in widespread use, ranging from sincor (wave-embossed) to single- and double-faced fluted material to provide cushioning inside boxed chocolates.

Similar cushioning, but of rather coarser quality, can be achieved by using corrugate made from greaseproof or vegetable parchment. The latter is produced by the action of concentrated sulphuric acid on wood pulp, giving greater strength along with grease resistance.

In many instances cartonboard outers are packed into shipping cases for distribution, particularly where rail or sea transportation is involved, and here corrugated board is used. No other material offers corrugated board's unique combination of product protection, stacking strength, printability, light weight and relatively low cost.

In general, corrugate board is made of two plies of liner material separated by a layer of fluting or corrugating medium. Both liners and fluting can be treated to give wet strength, flame resistance, etc. The fluting is formed from the flat material by huge meshed rollers: glue is applied to the tips of the fluting and the liners are then stuck on. Usually this is done on one long machine, which also prints the finished material and cuts it into the appropriate shape for the finished case. The type of corrugate is described by the number of flutes per cm or foot. The most widely used version is B-flute, which has some 1.7 flutes per cm (51 flutes per foot). For smaller boxes where a finer material and more decorative surface are required, E-flute, with 3.2 flutes per cm (96 flutes per foot), is often used; even finer 'microflute' such as F and N flute are now also available.

Depending on the use to which the finished box is put, many different qualities of material can be used for the liners, ranging from heavy-duty kraft down to glassine or greaseproof.

The traditional method of printing as an integral part of the process of corrugate manufacture, followed by creasing and slotting, results in a poor quality of reproduction by modern standards. There is therefore an increasing tendency to preprint the outer liner before it being formed into corrugate. This enables more sophisticated printing methods to be used, giving much better decoration, and illustrations can be achieved by the use of halftones. However, one advantage of micro-flute is that it can be printed directly to give high-quality graphics. Changeable information can be applied at the last moment using the actual corrugating equipment. (*Note:* High-quality print methods such as gravure or litho can be applied to single-web paper or board, but not to formed corrugate because they would break down its structure unless micro-flute is being used.)

24.4.3 Regenerated cellulose film

Until the late 1970s and 1980s regenerated cellulose film (RCF) dominated the flexible packaging field. Like paper and board it is made from wood pulp, although generally of a higher quality: a high proportion comes from eucalyptus grown especially for the purpose. A chemical process is used in which, as in paper making, individual fibres are put into solution. Instead of being spread out in layers, they are then chemically regenerated and passed through a slot to form a transparent film. Glycerol and various glycols are used as plasticizers and to add flexibility to the film.

In its natural state RCF has few characteristic properties other than transparency, flexibility, dead-fold and the ability to form a barrier to oxygen, provided it is dry. It cannot be sealed and it is very susceptible to moisture, expanding or contracting with changes in atmospheric humidity. This property was taken advantage of in wrapping fancy boxes before the advent of custom-designed shrink films and bi-oriented polypropylene over-wrap film and blown OPP film with limited shrink wrap capabilities. Plain RCF would be dampened and placed over the box so that when it dried out it gave a very tight, sparkling wrap. Unfortunately its shrinkage was uncontrolled, so either the film would split or the box crush, depending on which was the stronger. In order to make RCF a practicable proposition, therefore, it has to be coated. Initially it was made heat sealable and given some barrier properties by the application of a nitrocellulose coating. This material (MS) is perfectly adequate for most confectionery purposes. Where extra protection is required, a polyvinylidene chloride (PVdC) coating is used and the film is then characterized as MXXT, with the suffix ‘S’ for solvent applied or ‘A’ for aqueous dispersion coated. Although it is more effective and avoids the problem of disposal of residual solvents, the reactivity of RCF to moisture makes the aqueous method of coating much more difficult. MXXT films generally have more sparkle than MS and more resistance to abrasion.

Other coatings or treatments can be used to make RCF permeable to some gases and not to others. This enables the atmosphere inside to be controlled to a certain extent for the benefit of some products. It can also be made extra flexible (PF) for twist wrapping, supplied uncoated where moisture pick-up is not a problem, e.g. most chocolate-covered sweets, and can be coloured either intrinsically or in the coating.

Coated RCF is an ideal film for automatic packaging because it is not subject to structural alteration as a result of temperature; however, it cannot be thermoformed. It offers a combination of rigidity with elasticity – it will stretch before it breaks – and it avoids problems associated with static electricity (such as attracting dirt and upsetting wrapping machines). Its tensile and burst strengths are good; a tear, once made, propagates easily, but this is actually an advantage when a tear strip is required. The heat-seal temperature is not critical, as coated film has a relatively wide sealing range. It can be obtained in various thicknesses, and in general the thicker the film, the stronger it is; barrier properties, however, do not vary with overall thickness since the coating weight (expressed in gsm equivalent units) remains the same. RCF, unlike most plastic films, is biodegradable so it appeals to environmentalists.

On the debit side, RCF, even when coated, does not have the shelf-life of plastic materials. It requires carefully controlled storage conditions, but even so will deteriorate with time. As with paper and board packaging it is essential to place the RCF in the packaging hall at least 24 h before use, to allow the material to equilibrate with the atmosphere in the room.

Although banned in the USA, monoethylene glycol (MEG) and diethylene glycol (DEG) have until recently been in widespread use in Europe as softeners in RCF. Severe restrictions on the amount of these additives migrating into foods have now been introduced throughout the EU.

In recent years, RCF production has been deemed environmentally unfriendly due to some of the chemicals used in its manufacture. Therefore, the number of producers of RCF is now very limited, which has in turn led to the film becoming expensive in comparison to plastic films.

24.4.4 Plastic films

Despite all its properties, RCF has largely been supplanted by plastic films for flexible packaging. PVdC, used to coat RCF, is itself a plastic and can be obtained in film form, as well as in coating form. The range of plastic materials available for packaging is very wide and increasing, but this chapter is confined to those that play a significant part in the packaging of chocolate products.

24.4.4.1 Polyethylene

Polyethylene was the first major synthetic material to find a place in packaging and it is still the most widely used. The most outstanding characteristics of its commonest low-density form are low cost, flexibility, moisture protection, heat sealability and versatility. It can be made with a 'memory' so that it can be induced to shrink or stretch and remain shrunk or stretched or revert to its original form. It can be used as a coating, as a film, as an adhesive or in solid form.

On the other hand, polyethylene is not a good barrier to gas or taint and it is not easy to seal on its own. Its surface is non-polar, so treatment with flame or corona discharge is necessary before it can be printed or induced to accept adhesive. Care must also be taken to ensure that polyethylene coatings or laminates are odour free.

As a film, its principal uses are where toughness rather than clarity is required for example as a stretch film for pallets or trays of heavy items. It can also be used as a barrier film on pallets. As a coating, it adds toughness, a moisture barrier and heat sealability to other materials such as paper and aluminium foil. In its opaque white form, it can be used to coat poor-quality grey board (partially derived from reconstituted waste paper and board) and give it a high-quality finish. As an adhesive, it can be used to laminate disparate materials and additionally provide a moisture and fat barrier where these materials are deficient in such properties.

24.4.4.2 Polyvinyl chloride

Polyvinyl chloride (PVC) is most commonly used where clarity and sparkle are required in a film, rather than strength, e.g. for shrink-wrapping fancy boxes. It has good resistance to oils and fats, but its water-vapour permeability is relatively high. Where protection against moisture is important, for example if a chocolate box to be over-wrapped contains wafer-based sweets, a form of polypropylene shrink film would be preferable. PVC for use with food should be un-plasticized to minimize the possibility of taint or migration from the packaging into the product.

Much thicker PVC is used in thermoformed trays for packing chocolate assortments in some countries. As with RCF, PVC in recent years has suffered from constant criticism because of its chlorine content, which is seen as being environmentally unfriendly. Other concerns have also been raised with regard to vinyl chloride monomer and the type of plasticizers and stabilizers used.

In some parts of the world the old glassine cups are again being used. There is little doubt that the great saving in labour resulting from the use of thermoformed trays to locate and protect sweets in predetermined formation will ensure most manufacturers continue using trays. In the USA, *polystyrene* (PS) is widely used for the manufacture of these trays. However, residual styrene monomer in the tray can lead to tainting of the chocolate leaving the consumer with an acrid taste.

24.4.4.3 Polypropylene

The plastic that has had perhaps the greatest impact on the packaging of confectionery is *polypropylene* (PP) although in most applications this is bi-axially oriented polypropylene (BOPP) whereby the extruded film is stretched in both the transverse and machine direction. This is a close cousin of polyethylene; both are polyolefins derived from petrochemicals, but PP has an even wider range of applications. As a film it can be made very thin, down to 12 µm (0.5×10^{-3} in.), and it is the least dense commonly used plastic material, so it is very light; the combination of these characteristics gives very high yields. (Yield is the area of material contained in a given weight, generally expressed as m^2/kg or $in.^2/lb.$) It can be coated with other materials or co-extruded with them to give any combination of properties required in a package. It runs well on automatic packaging lines, having a low coefficient of friction with metal, and it has a wider sealing range than its competitors, provided the machinery has adequate heater controls where heat sealing is employed.

In its clear form, PP has largely captured the boxed chocolate market, and most confectionery bags are now made from BOPP or laminates incorporating BOPP or cast polypropylene (CPP). PP can be used to make thermoformed trays, although these are more difficult to form, more rigid and less user friendly then the un-plasticized PVC version. On the other hand, blown PP shrink film, although rather more difficult to handle, gives more protection than PVC.

The material whose use has shown the most rapid growth world-wide is white opaque or pearlized polypropylene (also known as cavitated) whereby the core layer of a co-extruded film (typically 3–7 layers) contains air pockets. As well as being light, thus giving a high yield, it is relatively rigid and crisp, and it can be made either with high or low sheen to look like paper. Perhaps its biggest advantage for use with chocolate-coated products is that it eliminates optical staining (when wet or greasy marks show through), a constant problem with paper, glassine and transparent film.

The film can be white with a pearl-like colour where the outer layers are transparent, or, 'super white' where the outer layers are coloured white providing a deep white and glossy surface for printing. Development work is continuing and several manufacturers have reduced density even further while increasing opacity and stiffness, without impairing the barrier properties of pearlized material. These can, however, easily be provided, albeit at a cost, by coating it with PVdC.

Other structures used include solid white BOPP for a more rigid feel, metallized transparent BOPP for added moisture, oxygen and light barrier and laminated films such as metallized BOPP/PET for high barrier and quality feel. In recent years metallized cavitated OPP has become available due to its higher yield over transparent solid metallized film and therefore potential lower cost per metre^2. Metallized films are often used for their ability to retard light-induced rancidity, for example with white chocolate, thus extending shelf-life, and minimizing optical staining or 'show through'. In many ways metallized films are superior to aluminium foil, which they closely resemble, but none has the same dead-fold properties, so they are primarily used on horizontal and vertical form-fill-seal equipment to create pillow packs.

24.4.4.4 Polyester

The other plastic film that has achieved relatively widespread acceptance in confectionery packaging is *polyeste*r (polyethylene terephthalate), which is very strong and clear. It does not seal in its natural form, but this problem can be overcome by co-extrusion or lamination to polythene, for example. It does not tear easily, and is resistant to abrasion as well as to oils and fats. It is a fairly good barrier to moisture vapour and gas, and thus to taints.

Although it can be obtained commercially down to 12 µm (0.5×10^{-3} in.) in thickness, polyester is still an expensive material, largely because of its other uses: recording tapes and in the electronics industry. As a packaging material, it is probably most widely used in its metallized form, which greatly enhances not only its appearance but also its barrier properties against moisture, gas and ultraviolet light. In addition, because it can readily be printed at 12 µm (0.5×10^{-3} in.) it is often used as the reverse printed surface layer in bag laminations to give high gloss and sparkle.

24.4.5 Cold seal

Although the above films are capable of being heat sealed by means of co-extrusion, other coating methods or lamination, there is no doubt that a revolution in packaging has come about through combining films with special properties and cold-seal coating, based on natural rubber latex combined with resins.

The great advantage of cold seal is that all three parameters governing the sealing process (pressure, dwell time and temperature) are reduced, with heat not being required at all. Without the necessity to control temperature, which can be particularly critical with plastic films, there are no restraints, other than mechanical ones, on the wrapping speeds that can be achieved. In addition, as heat is not required, the possibility of damage to chocolate products during machine stoppages is eliminated. Other benefits are reduced energy usage and reduced wear on the sealing mechanism.

Cold seal adhesive should always be applied in a pattern on the inner surface of the film whether the film is a surface-printed mono-web film or a sandwich-printed laminate film (print between two layers of film). Chocolate is capable of picking cold seal off the film when in contact with the cold seal, therefore, the pattern of cold seal must allow for the minimum possible contact between chocolate and cold seal adhesive.

Surface-printed cold seal films employ a ‘release lacquer’ over the whole surface of the printed film to prevent the inner layer of the film adhering to the outer layer of the film in the reel (known as blocking). Such lacquers are based on polyamide or nitrocellulose-modified polyamide, and may under certain circumstances be incorporated in the ink provided the ink covers the whole surface of the film.

Sandwich-printed laminated cold seal films can utilize a release laminate layer where the outer surface of the external layer of the film is not receptive to the cold seal adhesive on the internal layer of the film.

Cold seal adhesive films must be considered as a complete system where the substrate, ink, cold seal and release lacquer must be compatible. Cold seal adhesive films theoretically have unlimited running speeds with countlines typically running 300–600 packs/min although speeds up to 800 packs/min are known for smaller size countlines.

Typical dry coating weight of cold seal adhesive is 3.5–5 gsm. Synthetic cold seal adhesives are now available that avoid the use of natural rubber latex and avoid potential odour and performance issues and require a lower coating weight typically 2–3 gsm. At the time of printing synthetic cold seal adhesive was not widely used due to the limited formulations available and significant on-cost compared to latex cold seal.

It is important to ensure that any inks used for overprinting or in-line marking (e.g. of 'best before' information) can be applied over the release lacquer or release laminate.

Cold seal adhesive can be difficult to see, especially on white film; this can lead to difficulties in setting-up the wrapping machine, or in checking the presence and correct positioning of the cold seal in the sealing areas. Adding colour (generally light pink or blue) to the adhesive can overcome this problem.

Tough plastic materials and cold seal have developed in parallel with the growing sophistication and availability of microprocessor controls. Together they have, in effect, removed the bottleneck frequently caused by the packaging element in an integrated production line and at the same time have reduced operator supervision. The use of cold seal means that wrapping machines can speed up or slow down, giving an instant response to availability of product. This applies whether they are wrapping naked bars straight from an enrober or moulding plant, or collations of wrapped bars from a number of primary wrapping machines. At speeds of about 600 or so per minute, automatic feed systems and automatic boxing are essential, as is the automatic splicing when changing to a new reel of film. This avoids the need to stop the wrapping machine to renew the wrapping material.

24.4.6 Bio-polymers

In recent years, both industry and consumers have become increasingly aware of the need for sustainability in many aspects of life including the use of packaging materials. Conventional plastics are made from oil and gas feedstock, which are both finite resources and subject to many price fluctuations. Plastics produced from oil and gas can take many years to breakdown once their useful life has finished. In addition, the availability and use of landfill waste sites has become less acceptable. Therefore, recent years have seen the development and commercialization of a wide variety of renewable biopolymers for packaging.

Renewable resources for packaging can be broken down into four main categories; (see Table 24.1).

In addition to cellulose film (see Section 24.4.3), two of the main renewable packaging materials used for chocolate are PLA and Plantic.

24.4.6.1 Poly lactic acid (PLA)

Poly lactic acid (PLA) is produced from cereal starch. PLA 'NatureWorks', as produced by Cargill, uses cornstarch to manufacture aliphatic polyesters, which can be used for flexible films and rigid packaging. At the time of writing, various trials were being performed using PLA NatureWorks for twist-wrap applications with chocolate confectionery.

Table 24.1 Renewable resources for packaging.

Starch-based	Polyhydroxy(alkanoates/butyrates)/Polyesters
Plantic Technologies Ltd.	Biopol, PHA (Metabolix)
Biopar (Biop)	Nodax, PHA (P&G / Kaneka)
MaterBi (Novamont)	Sorona, Poly trimethylene terephthalate (DuPont)
Bioplast (Biotec)	
IBEK Verpackungs GmbH	
Polylactic acid (PLA)	Cellulose-based
NatureWorks	NatureFlex (Innovia Films)
Hycail	Biograde (FKuR/IBEK Verpackungs GmbH)

Properties of PLA include high stiffness, high transparency and gloss, good dead-fold and twistability and low water vapour barrier. The rigidity of the film gives it a metallic sound similar to polystyrene when manipulated.

24.4.6.2 Plantic

Plantic is also produced from cornstarch, where the cornstarch is modified with the inclusion of ingredients such as plasticizers and processing aids and extruded. At the time of writing this chapter, Plantic vacuum formed trays were being used in limited applications for chocolate assortment boxes. In addition, flexible films were also under development.

Properties of Plantic material in VFT format include rigid feel, static resistance, easily heat formable and dissolves completely in warm/hot water. Moisture content control and vacuum forming process control are critical in producing VFTs. In addition, storage conditions of the finished product are important, as the material will pick-up and lose moisture as the ambient climate changes, which can lead to the material becoming brittle.

When dealing with these forms of packaging it is important to distinguish between the following two definitions:

Renewable materials – regenerated within a human lifetime.
Biodegradable – can be assimilated by micro-organisms, and reintroduced into the natural cycles under controlled conditions as defined by standards (EN 13432).

24.5 Quality control and environmental criteria

24.5.1 Quality control

The integration of production lines, such as those described above, would not be possible without full electronic control of what is basically a series of mechanical operations. It also depends heavily on the quality of the packaging materials and here such factors as print and sealant registration, particularly where the photoelectric cell (PEC) register mark is concerned, stretch, slip and accuracy of slitting must be controlled to a much higher degree than before and monitored by the end user. This control of quality can involve a multiplicity of tests to be carried out before materials reach the production line. If agreement on standards can be reached with suppliers, it should be possible for the supplier to carry out the bulk of the testing, with only spot checks being carried out by the user – 'Certificates of Compliance' should be provided by the supplier. Nevertheless, a well-equipped packaging laboratory should be capable of carrying out at least the following tests:

- seal strength, tensile strength, burst strength;
- coefficient of friction;
- moisture vapour resistance (MVR);
- detection of residual solvents, e.g. by gas liquid chromatography (GLC);
- taint, using a panel of tasters;
- print stability and resistance to abrasion;
- scannability of bar codes.

Chocolate is particularly sensitive to external taint and it is essential that every precaution be taken to exclude it. Most modern flexible materials are at least fairly good barriers to taint and can be made much better by coating with PVdC or acrylic, laminating or metallizing. The quality of seal is important: where the package is not sealed, external taint sources must be eliminated.

While it is appreciated that after the product has left the manufacturing plant the manufacturer has little control over the environment in which it may be kept and sold, there are many potential sources of taint during manufacturing operations. These include residual solvents, or other likely contaminants in wrapping materials, resulting from incomplete drying or oxidation of printing inks and varnishes, including sealants. Print can 'offset' on to the inside of reeled, or indeed any printed materials and come into direct contact with chocolate. Incorrectly applied coatings or laminates, such as polythene, can also be the cause of taint.

In addition to its role in protecting its contents from the hazards of climate and distribution, packaging is also instrumental in persuading the consumer to buy. It is therefore well worth taking pains to get it right.

24.5.2 Environmental issues

All packaging must now take into account environmental criteria. Fundamentally, this means using the minimum amount of material consistent with the requirements of the product, but in some markets there are prejudices against specific materials, which must also be taken into account. Such materials include PVC, primarily because it is perceived as contributing towards acid rain and releasing dioxin when burned, and aluminium because of environmental damage allegedly caused during its manufacture and the original extraction of bauxite.

Although there are few legal restrictions on the use of such materials, consumer objections expressed through the retail trade may necessitate the use of alternative materials, such as polyester and polypropylene, for vacuum-formed trays or wrapping chocolate blocks. Where laminates are concerned it is wise to ensure that the different layers can be recycled together, or easily separated for recycling, but the use of mono-materials is generally to be recommended from an environmental standpoint.

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Chapter 25

LEGAL ASPECTS OF CHOCOLATE MANUFACTURE

A. Martinez-Inchausti

25.1 Introduction

Chocolate is taken very seriously by its consumers and its perceived quality is deemed to be particularly important. Chocolate products are normally controlled by specific regulations in addition to general quality and safety criteria, such as described in the provisions of the European Community (EC) General Food Law – Regulation (EC) No. 178/2002. It is appropriate therefore, to look at the specific requirements for chocolate products under EU Law, as well as the regulations in a number of other major countries.

25.2 Compositional issues for chocolate – the EU picture

Chocolate products are one of the few specific sectors whose composition is currently controlled at EC level. The first Community Directive establishing standards of composition and labelling of chocolate and chocolate products was published in 1973 (Council Directive 73/241/EEC (1973)). After having been amended a number of times, this Directive was revoked and repealed in 2000 by European Parliament and Council Directive 2000/36/EC (2003).

The objective of the publication of this legislation was to simplify the Community provisions on the composition, manufacture and labelling of cocoa and chocolate products in order to guarantee their free movement in the Community, taking into account technological progress and changes in consumer taste, and general Community legislation on foodstuffs.

For those less familiar with food law, it is first of all necessary to define the scope of this Directive. It in fact only applies to products that are sold using the specific names of cocoa and chocolate, for example to milk chocolate, chocolate, white chocolate, 'chocolate a la taza', when sold *per se*. Food products such as chocolate confectionery, fine bakery products, biscuits or desserts, which contain chocolate as an ingredient, fall outside the scope

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of this Directive. Compositional requirements for these are in many cases covered under national Member States' legislation.

The key compositional requirements for chocolate products define the minimum percentage contents for dry cocoa solids, dry non-fat cocoa solids and for cocoa butter. In addition, for products containing dairy ingredients such as milk chocolate or chocolate praline, the total milk solids content obtained from named dairy ingredients is specified. One compositional issue that has been the source of interest over the years is the addition of dairy ingredients, which do not contain all the components of cow's milk; such as the addition of whey powder to milk chocolate. Essentially, provided the minimum required amount of milk solids is met by milk constituents in the natural proportions as found in milk, additional dairy ingredients above this are considered acceptable. Chocolate manufacturers should check the acceptability of whey powder in other countries since, for example, it would not be acceptable for use in chocolate for sale in the United States.

The minimum contents of the individual ingredients within a product are calculated either after deduction of flavourings, additional edible matter and/or filling, or according to the total weight of the finished product, as appropriate.

Unlike in Directive 73/241/EEC, Council Directive 2000/36/EC harmonised the provisions on the addition to chocolate of vegetable fats. Before the publication of the current legislation Member States were allowed to use their own national legislation to permit or prohibit the addition of vegetable fats other than cocoa butter to chocolate. The current Directive specifies that (plain) chocolate, milk chocolate, white chocolate, as well as 'chocolate a la taza', may contain up to 5% vegetable fat other than cocoa butter. These vegetable fats can be illipe, palm oil, sal, shea, kokum gurgi, mango kernels, used singly or in combination, and are all cocoa butter equivalents. They are thus non-lauric, miscible in any proportion with cocoa butter and compatible with its physical properties, and have to be obtained by processes of refinement and/or fractionation.

The addition of other edible substances is also allowed up to 40% of the total weight of the finished product. This can be pieces of fruits, nuts, coffee, biscuits, etc., however, it excludes animal fats and preparations not exclusively derived from milk, as well as flour or starch (except for 'chocolate a la taza'). The additional of flavourings, except flavouring preparations that imitate the natural flavour of chocolate or of milk fat, is acceptable in stated chocolate products, as well as in cocoas and powdered chocolates. Vanillin and ethyl vanillin are some of the most frequently used flavourings.

For products called 'pralines' or 'chocolates' (single-mouthful size), the chocolate proportion must comprise a minimum of 25% by weight of the total weight of the product. It is commonly erroneously thought that the compositional rules for chocolates and filled chocolates apply to the filling, in addition to the chocolate portion. This is not the case and the filling portion of the product can contain any edible ingredient, including those fats excluded by the Directive.

25.2.1 Sales names and definitions under European Parliament and Council Directive 2000/36/EC (2000)

25.2.1.1 Cocoa butter

The fat obtained from cocoa beans or parts of cocoa beans with the following characteristics:

- free fatty acid content (expressed as oleic acid): not more than 1.75%
- unsaponifiable matter (determined using petroleum ether): not more than 0.5%, except in the case of press cocoa butter, where it shall not be more than 0.35%.

25.2.1.2 Cocoa powder, cocoa

The product obtained by converting into powder cocoa beans which have been cleaned, shelled and roasted and which contains not less than 20% cocoa butter, calculated according to the weight of the dry matter, and not more than 9% water.

25.2.1.3 Fat-reduced cocoa, fat-reduced cocoa powder

Cocoa powder containing less than 20% cocoa butter, calculated according to the weight of the dry matter.

25.2.1.4 Powdered chocolate, chocolate in powder

The product consisting of a mixture of cocoa powder and sugars, containing not less than 32% cocoa powder.

25.2.1.5 Drinking chocolate, sweetened cocoa, sweetened cocoa powder

The product consisting of a mixture of cocoa powder and sugars, containing not less than 25% cocoa powder; these names shall be accompanied by the term ‘fat-reduced’ in the case where the product is fat-reduced as defined above.

25.2.1.6 Chocolate

The product obtained from cocoa products and sugars which contains not less than 35% total dry cocoa solids, including not less than 18% cocoa butter and not less than 14% of dry non-fat cocoa solids; however, where this name is supplemented by the words:

- ‘vermicelli’ or ‘flakes’: the product presented in the form of granules or flakes must contain not less than 32% total dry cocoa solids, including not less than 12% cocoa butter and not less than 14% of dry non-fat cocoa solids;
- ‘couverture’: the product must contain not less than 35% total dry cocoa solids, including not less than 31% cocoa butter and not less than 2.5% of dry non-fat cocoa solids;

- 'Gianduja' (or one of the derivatives of the word 'gianduja') nut chocolate: the product must be obtained firstly from chocolate having a minimum total dry cocoa solids content of 32% including minimum dry non-fat cocoa solids content of 8%, and secondly from finely ground hazelnuts in such quantities that 100 g of the product contain not less than 20 g and not more than 40 g of hazelnuts. The following may be added:

(1) milk and/or dry milk solids obtained by evaporation, in such proportion that the finished product does not contain more than 5% dry milk solids;
(2) almonds, hazelnuts and other nut varieties, either whole or broken, in such quantities that, together with the ground hazelnuts, they do not exceed 60% of the total weight of the product.

25.2.1.7 Milk chocolate

The product obtained from cocoa products, sugars and milk or milk products contains:

- not less than 25% total dry cocoa solids,
- not less than 14% dry milk solids obtained by partly or wholly dehydrating whole milk, semi- or full-skimmed milk, cream, or from partly or wholly dehydrated cream, butter or milk fat,
- not less than 2.5% dry non-fat cocoa solids,
- not less than 3.5% milk fat,
- not less than 25% total fat (cocoa butter and milk fat).

However, where this name is supplemented by the words:

- 'vermicelli' or 'flakes': the product presented in the form of granules or flakes must contain not less than 20% total dry cocoa solids, not less than 12% dry milk solids obtained by partly or wholly dehydrating whole milk, semi- or full-skimmed milk, cream, or from partly or wholly dehydrated cream, butter or milk fat, and not less than 12% total fat (cocoa butter and milk fat);
- 'couverture': the product must have a minimum total fat (cocoa butter and milk fat) content of 31%;
- 'Gianduja' (or one of the derivatives of the word 'gianduja') nut milk chocolate: the product must be obtained firstly from milk chocolate having a minimum content of 10% of dry milk solids, obtained by partly or wholly dehydrating whole milk, semi- or full-skimmed milk, cream or from partly or wholly dehydrated cream, butter or milk fat and secondly from finely ground hazelnuts, in such quantities that 100 g of the product contain not less than 15 g and not more than 40 g of hazelnuts. Almonds, hazelnuts and other nut varieties may also be added, either whole or broken, in such quantities that, together with the ground hazelnuts, they do not exceed 60% of the total weight of the product.

Where in this name the word ‘milk’ is replaced by:

- ‘cream’: the product must have a minimum milk fat content of 5.5%,
- ‘skimmed milk’: the product must have a milk fat content not greater than 1%.

25.2.1.8 Family milk chocolate

The product obtained from cocoa products, sugars and milk or milk products and which contains:

- not less than 20% total dry cocoa solids,
- not less than 20% dry milk solids obtained by partly or wholly dehydrating whole milk, semi- or full skimmed milk, cream, or from partly or wholly dehydrated cream, butter or milk fat,
- not less than 2.5% dry non-fat cocoa solids,
- not less than 5% milk fat,
- not less than 25% total fat (cocoa butter and milk fat).

25.2.1.9 White chocolate

The product obtained from cocoa butter, milk or milk products and sugars, which contains not less than 20% cocoa butter and not less than 14% dry milk solids obtained by partly or wholly dehydrating whole milk, semi- or full-skimmed milk, cream, or from partly or wholly dehydrated cream, butter or milk fat, of which not less than 3.5% is milk fat.

25.2.1.10 Filled chocolate, chocolate with … filling, chocolate with … centre

A filled product, the outer part of which consists of one of the products defined as chocolate, milk chocolate, etc. This does not apply to products, the inside of which consists of bakery products, pastry, biscuit or edible ice. The outer chocolate portion of products bearing one of these names must make up more than 25% of the total weight of the product.

25.2.1.11 Chocolate a la taza

The product obtained from cocoa products, sugars, and flour or starch from wheat, rice or maize, which contains not less than 35% total dry cocoa solids, including not less than 18% cocoa butter and not less than 14% dry non-fat cocoa solids and not more than 8% flour or starch.

25.2.1.12 Chocolate familiar a la taza

The product obtained from cocoa products, sugars, and flour or starch from wheat, rice or maize, which contains not less than 30% total dry cocoa solids, including not less than 18% cocoa butter and not less than 12% dry non-fat cocoa solids and not more than 18% flour or starch.

25.2.1.13 A chocolate or a praline

Designates the product in single-mouthful size, consisting of:

- filled chocolate, or
- a single chocolate or a combination or a mixture of chocolates (as defined above) and other edible substances, provided that chocolate constitutes not less than 25% of the total weight of the product.

25.2.2 The use of additives

As part of the move towards legislation applicable to all foodstuffs ('horizontal'), additives are no longer controlled under compositional Directives, but by general European Community law on additives. Provisions on additive acceptability are covered under; Directive 94/35/EC (1994), as amended, on sweeteners, Directive 94/36/EC (1994) on colours and Directive 95/2/EC (1995), as amended, on additives other than colours and sweeteners, normally referred to as 'miscellaneous additives'. Annex II of Directive 95/2/EC (1995) includes a list of additives ordinarily permitted for general food use and that may be used in chocolate products, with maximum limits given as appropriate. For example, lecithins may be used in accordance with the principle of *quantum satis* (no maximum level is specified, however, additives shall be used in accordance with Good Manufacturing Practice, at a level not higher than is necessary to achieve the intended purpose and provided that they do not mislead the consumer). Annex IV includes limits for other additives, the use of which is restricted; such additives include ammonium phosphatides and polyglycerol polyricinoleate. Maximum limits for commonly used additives in chocolate are given in Table 25.1.

With respect to sweeteners, specific provisions are listed for cocoa-based products that are energy reduced (energy reduced by at least 30% compared with an equivalent product) or without added sugar (without any added mono- or disaccharides or any other foodstuff used for its sweetening properties). Examples of sweeteners permitted for use in chocolate products include acesulfame K in accordance with the principle of *quantum satis* and aspartame to a maximum of 2000 mg/kg in cocoa-based confectionery which is energy-reduced or with no added sugar. The addition of sweeteners to chocolate has been one of the most controversial issues

Table 25.1 Maximum limits for commonly used additives in chocolate under Directive 95/2/EC.

Lecithin (E 322)	In cocoa and chocolate products as defined under Directive 73/241/EEC (now D.2000/36/EC) Quantum satis
Ammonium phosphatides (E 442)	In cocoa and chocolate products as defined under Directive 73/241/EEC (now D.2000/36/EC) 10 g/kg In cocoa-based confectionery 10 g/kg
Polyglycerol polyricinoleate (E 476)	In cocoa-based confectionery, including chocolate 5 g/kg

surrounding the composition of chocolate. Some European Member States believed that sweeteners could be added to chocolate and the final product could still be called 'chocolate', 'white chocolate', 'milk chocolate', etc. Other Member States were of the opinion that if the product does not contain 'added sugar' (a sugar included under Directive 2001/111/EC (2001)) as specified under the definition for chocolate, the final product must be labelled in a manner that enables consumers to distinguish them from those with added sugar. Therefore, until very recently, in some Member States a product marketed as 'chocolate' could not have sweeteners in its composition. During a Standing Committee meeting in autumn 2006, Member States agreed that sweeteners may be used in accordance with the rules in Directive 94/35/EC the product generally falling within the 'cocoa-based confectionery/energy reduced or no added sugar' category. For these products additional labelling stating 'with sweetener(s)' next to the product name, would be required.

With regard to colours, Directive 94/36/EC on colours for use in food does not permit the addition of colours to cocoa products and the chocolate components of those chocolate products covered by the Directive. Gold and silver colours are nonetheless permitted for decorating chocolates.

The fillings of filled 'chocolates' or 'pralines' are not subject to the specific limitations imposed on use of additives in chocolate products by the relevant directives. Fillings must, however, comply with general restrictions as to the nature and quantity of additives used for the foods that they are contained within.

25.3 Labelling of chocolate products – the EU picture

As with additives, the move towards 'horizontal' legislation means that all the general labelling requirements applicable to foodstuffs laid down under Directive 2000/13/EC on the general labelling, presentation and advertising of foodstuffs, are applicable to cocoa, chocolate and chocolate products. Nevertheless, Directive 2000/36/EC requires some specific labelling information for these products.

The labelling requirements for chocolate and chocolate products are as follows:

25.3.2.1 Product name

Only products manufactured according to the compositional rules laid down by the Directive (see Section 25.2.2) may be marketed with the following names:

- Cocoa powder, cocoa,
- Fat-reduced cocoa powder, fat-reduced cocoa powdered chocolate, powdered drinking chocolate, sweetened cocoa, sweetened cocoa powder (possibly supplemented by the terms 'fat-reduced')

- Chocolate (possibly supplemented by the terms 'vermicelli' or 'flakes', 'couverture', and 'gianduja')
- Milk, cream or skimmed milk chocolate (possibly supplemented by the terms 'vermicelli' or 'flakes', 'couverture' and 'gianduja'); The UK and Ireland were granted a derogation which allows them to use the name 'milk chocolate' for products which match the description in the directive for 'Family milk chocolate'.
- Family milk chocolate
- White chocolate
- Filled chocolate
- Chocolate a la taza
- Chocolate familiar a la taza
- Chocolates or pralines.

In exceptional cases, these product names may be used for other products, but only where they cannot be confused with those products which do conform to the directive in the country where they are sold (e.g. chocolate cake). The sale names for chocolate, white and filled milk chocolates, and chocolates or pralines may be replaced by the sale name 'assorted chocolates' or 'assorted filled chocolates' when sold as assortments. Quality claims may be made for chocolate, milk chocolate and couverture chocolate, provided the stated compositional limits are met.

25.3.2.2 The list of ingredients

According to the general labelling legislation, the list of ingredients must include all the ingredients of the foodstuff, in descending order by weight, as recorded at the time of their use in the manufacture of the foodstuff. The name which has to be used for the ingredient is the legal name, if there is one in European or national legislation, for example 'sugar'. If no legal name exists, a name which clearly describes the ingredient should be used; one example would be 'almonds'. The additives used in the product have to be declared by their category name followed by the specific name of the additive or E number, for example: emulsifier (soya lecithin) or emulsifier (E 322 from soya). In 2003, a major amendment to the general labelling Directive was published. The aim of this amending Directive was to ensure that consumers suffering from food allergies are always informed. For that purpose the Directive also establishes the following list of ingredients which are liable to cause allergies or intolerances:

- Cereals containing gluten (i.e. wheat, rye, barley, oats, spelt, kamut or their hybridized strains) and products thereof,
- Crustaceans and products thereof,
- Eggs and products thereof,
- Fish and products thereof,
- Peanuts and products thereof,
- Soybeans and products thereof,

- Milk and products thereof (including lactose),
- Nuts i.e. almond (*Amygdalus communis* L.), hazelnut (*Corylus avellana*), walnut (*Juglans regia*), cashew (*Anacardium occidentale*), Pecan nut (*Carya illinoiesis* (Wangenh.) K. Koch), Brazil nut (*Bertholletia excelsa*), pistachio nut (*Pistacia vera*), Macadamia nut and Queensland nut (*Macadamia ternifolia*) and products thereof,
- Celery and products thereof,
- Mustard and products thereof,
- Sesame seeds and products thereof,
- Sulphur dioxide and sulphites at concentrations of more than 10 mg/kg or 10 mg/l expressed as SO_2,
- Lupin and products thereof,
- Molluscs and products thereof.

25.3.2.3 The quantity of certain ingredients or categories of ingredients ('QUID')

The amount of any of the ingredient which is declared as part of the product name, other than the chocolate, will have to be declared by the percentage of its weight in the final product, in the product name or the ingredients list. For example the amount of almonds will need to be stated in a 'white chocolate with almonds'. This indication allows the consumer to distinguish between a product which contains 7% almonds and another which contains 38% almond, both of which could be labelled as 'chocolate with almonds'.

25.3.2.4 The net quantity in grams or kilograms

The date of minimum durability, which will be included on the label preceded by the expression 'Best Before (End)'.

25.3.2.5 Any special storage conditions

Some chocolate product may have to be stored in a cool, dry place.

25.3.2.6 Name and address of the manufacturer

The name or business name and address of the manufacturer or packer, or of a seller established within the community.

25.3.2.7 Any vegetable fat content

Any given product containing any of the six vegetable fats other than cocoa butter permitted under the Directive must bear the statement 'contains vegetable fat in addition to cocoa butter'. This statement has to be in the same field of vision as the list of ingredients, clearly separated from that list, in letters at least as large and in bold with the product name nearby.

25.3.2.8 Chocolates with special descriptions

The labelling of powdered chocolate, of sweetened cocoas, as well as of chocolate, milk chocolate, family milk chocolate, chocolate a la taza and chocolate familiar a la taza must indicate the total dry cocoa solids content in the form 'cocoa solid _%' minimum. This requirement does not apply to filled 'pralines' and 'chocolates'.

25.3.2.9 Non-fat and reduced-fat cocoas and powdered chocolate

The labelling must indicate the cocoa butter content.

25.3.2.10 *Milk chocolate*

The label of any milk chocolate will need to state the amount of dry milk solids in the form 'milk solids _% minimum'.

Many labels also provide nutritional information. This information is currently only required if a claim is made. If a company decides to include nutrition information on a label, a set format must be used. This format and provisions on the information required are laid down under Directive 90/496/EEC (1990). Figure 25.1 shows the label on a typical chocolate countline product and Figure 25.2 the large amount of information provided for customers of an aerated chocolate bar.

Figure 25.1 Labelling on typical countline product. See Plate 28 for the colour image.

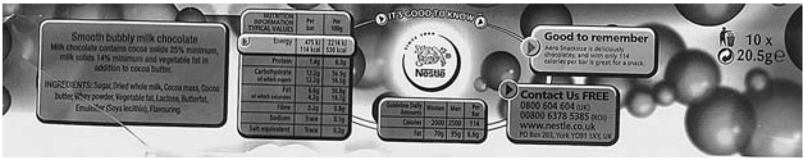

Figure 25.2 Packaging on aerated chocolate bars (UK). See Plate 29 for the colour image.

25.4 The international scene

The Codex Alimentarius (Latin for 'food code') was established by the Food and Agricultural Organisation of the United Nations in the 1960s. The standards published by Codex Alimentarius are used by many countries as the basis for determining the acceptability of foodstuffs in those countries. The majority of Latin American countries, other than Colombia, use Codex standards as their national legislation. With the reference to Codex standards increasingly being used by the World Trade Organisation, as well as being quoted in bilateral and plurilateral trade agreements, the influence of such standards has increased a lot in the last few years and is likely to increase even more. CODEX STAN 87-1981 is the current Codex standard for chocolate and chocolate products. The standard has many similarities with the Directive 2000/36/EC on the minimum content of cocoa solids, cocoa butter, etc. The Codex standard includes additional denominations such as 'sweet chocolate' and 'chocolate para mesa' (for definitions covered in the Codex standard see Section 25.4.1) and slightly different labelling requirements. Like in the EU, one of the most controversial issues within this standard was the use of vegetable fats other than cocoa butter in chocolate. Due to the Codex structure, even a minor amendment takes years to be agreed, discussion on whether vegetable fats should be allowed in chocolate went on for many years and concluded with an agreement in 2002 and the publication of an amendment to CODEX STAN 87-1981 in 2003 allowing for the use of this ingredient to a maximum level of 5%.

Standards are often established where trading blocs have been created. Outside of Europe, such trading blocs have been established in, for example, the Gulf States and Australia/New Zealand.

The Standardization and Metrology Organization for GCC (Gulf Cooperation Council) has established a standard for chocolate in the Gulf States (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and United Arab Emirates). The Gulf Standard No. 567 (1994) draws heavily from the requirements of the original Directive 73/241/EEC. The notable differences between the Gulf Standard and current European requirements are:

(a) there is no standard for 'family milk chocolate', rather all milk chocolate must contain not less than 25% cocoa solids;
(b) the product 'dark chocolate' must contain a minimum of 30% cocoa solids, which mirrors the original European Directive.

Vegetable fats (non-specified) may be used to a maximum of 5%. Spices, salt (sodium chloride), natural flavourings, vanillin and ethyl vanillin may be used to flavour the product.

There are no compositional requirements for chocolate confectionery in the Australia/New Zealand Food Code, although a definition of chocolate is laid down; chocolate is the confectionery product characterized by the presence of cocoa bean derivatives. It must contain a minimum of 200 g/kg cocoa bean derivatives and a maximum of 50 g/kg edible oils other than cocoa butter or dairy fats.

In the USA, the terms 'white chocolate', 'milk chocolate', 'sweet chocolate', 'semi-sweet chocolate' and 'bittersweet chocolate' are all terms defined by a FDA Standard of Identity (Title 21 Code of Federal Regulations Part 163, 2006). The Americans have different considerations from those established in Europe (see Section 25.4.2). The product described as 'sweet chocolate' corresponds to the European chocolate and is defined as containing a minimum of 15% by weight of chocolate liquor (mass). The total amount of emulsifying agent added is 1%. Detailed standard are also established for buttermilk chocolate, skim milk chocolate and mixed dairy product chocolates. For the last couple of years, similar discussions to those in Europe have been taking place is relation to the use of sweeteners in chocolate. It has now been clarified that the standards for white chocolate, milk chocolate, sweet chocolate, semi-sweet chocolate and bittersweet chocolate require that the product be formulated using a 'nutritive carbohydrate sweetener' such as sugar. Products formulated with other ingredients such as polyols (sorbitol, xylitol, lactitol, maltitol, etc.) do not comply with these standards and therefore cannot be called by the standardized name.

A typical wrapper showing consumer information on a chocolate bar in Mexico is shown in Figure 25.3.

Figure 25.3 Wrapper of chocolate bar from Mexico. See Plate 30 for the colour image.

25.4.1 *Codex Alimentarius* definitions for cocoa and chocolate products

25.4.1.1 Chocolate

Chocolate (in some regions also named bittersweet chocolate, semi-sweet chocolate, dark chocolate or 'chocolat fondant') shall contain, on a dry matter basis, not less than 35% total cocoa solids, of which not less than 18% shall be cocoa butter and not less than 14% fat-free cocoa solids. Chocolate a la taza is chocolate containing a maximum of 8% m/m flour and/or starch from wheat, maize or rice.

25.4.1.2 Sweet chocolate

Sweet chocolate must contain, on a dry matter basis, not less than 30% total cocoa solids, of which at least 18% shall be cocoa butter and at least 12% fat-free cocoa solids. Chocolate familiar a la taza contains a maximum of 18% m/m flour and/or starch from wheat, maize or rice.

25.4.1.3 Couverture chocolate

Couverture chocolate must contain, on a dry matter basis, not less than 35% total cocoa solids of which not less than 31% shall be cocoa butter and not less than 2.5% of fat-free cocoa solids.

25.4.1.4 Milk chocolate

Milk chocolate shall contain, on a dry matter basis, not less than 25% cocoa solids (including a minimum of 2.5% fat-free cocoa solids) and a specified minimum of milk solids between 12% and 14% (including a minimum of milk fat between 2.5% and 3.5%). The minimum content for milk solids and milk fat shall be applied by the authority having jurisdiction in accordance with applicable legislation. ‘Milk solids’ refers to the addition of milk ingredients in their natural proportions, except that milk fat may be added, or removed. Where required by the appropriate authority, a minimum content of cocoa butter plus milk fat may also be set.

25.4.1.5 Family milk chocolate

Family milk chocolate must contain, on a dry matter basis, not less than 20% cocoa solids (including a minimum of 2.5% fat-free cocoa solids) and not less than 20% milk solids (including a minimum of 5% milk fat). ‘Milk solids’ refers to the addition of milk ingredients in their natural proportions, except that milk fat may be added, or removed. Where required by the appropriate authority, a minimum content of cocoa butter plus milk fat may also be set.

25.4.1.6 Milk chocolate couverture

Milk chocolate couverture contains, on a dry matter basis, not less than 25% cocoa solids (including a minimum of 2.5% non-fat cocoa solids) and not less than 14% milk solids (including a minimum of 3.5% milk fat) and a total fat of not less than 31%.

‘Milk solids’ refer to the addition of milk ingredients in their natural proportions, except that milk fat may be added, or removed.

25.4.1.7 White chocolate

White chocolate must contain, on a dry matter basis, not less than 20% cocoa butter and not less than 14% milk solids (including a minimum milk fat in a range of 2.5–3.5% as applied by the authority having jurisdiction in accordance with applicable legislation). ‘Milk solids’ refers to the addition of milk ingredients in their natural proportions, except that milk fat may be added, or removed.

25.4.1.8 Gianduja chocolate

'Gianduja' (or one of the derivatives of the word 'Gianduja') chocolate is the product obtained, firstly, from chocolate having a minimum total dry cocoa solids content of 32%, including a minimum dry non-fat cocoa solids content of 8%, and, secondly, from finely ground hazelnuts such that the product contains not less than 20% and not more than 40% of hazelnuts.

The following may be added:

(a) milk and/or dry milk solids obtained by evaporation, in such proportion that the finished product does not contain more than 5% dry milk solids;
(b) almonds, hazelnuts and other nut varieties, either whole or broken, in such quantities that, together with the ground hazelnuts, they do not exceed 60% of the total weight of the product.

25.4.1.9 Gianduja milk chocolate

'Gianduja' (or one of the derivatives of the word 'Gianduja') milk chocolate is the product obtained, firstly, from milk chocolate having a minimum dry milk solids content of 10% and, secondly, from finely ground hazelnuts such that the product contains not less than 15% and not more than 40% of hazelnuts. 'Milk solids' refer to the addition of milk ingredients in their natural proportions, except that milk fat may be added or removed. The following may be added: almonds, hazelnuts and other nut varieties, either whole or broken, in such quantities that, together with the ground hazelnuts, they do not exceed 60% of the total weight of the product. Where required by the appropriate authority, a minimum content of cocoa butter plus milk fat may also be set.

25.4.1.10 Chocolate para mesa

Chocolate para mesa is unrefined chocolate in which the grain size of sugars is larger than 70 µm. It must contain, on a dry matter basis, not less than 20% total cocoa solids (including a minimum of 11% cocoa butter and a minimum of 9% fat-free cocoa solids).

25.4.1.11 Semi-bitter chocolate para mesa

Semi-bitter chocolate para mesa shall contain, on a dry matter basis, not less than 30% total cocoa solids (including a minimum of 15% cocoa butter and a minimum of 14% fat-free cocoa solids).

25.4.1.12 Bitter chocolate para mesa

Bitter chocolate para mesa shall contain, on a dry matter basis, not less than 40% total cocoa solids (including a minimum of 22% cocoa butter and a minimum of 18% fat-free cocoa solids).

25.4.2 Definitions of major types of USA chocolate confectionery

25.4.2.1 Breakfast cocoa

Breakfast cocoa is the food prepared by pulverizing the material remaining after part of the cocoa fat has been removed from ground cocoa nibs. Breakfast cocoa contains not less than 22% by weight of cocoa fat.

25.4.2.2 Cocoa

Cocoa is the food that conforms to the definition and standard of identity for breakfast cocoa, except that the cocoa fat content is less than 22%, but not less than 10% by weight.

25.4.2.3 Low fat cocoa

Is the food that conforms to the definition and standard of identity, for breakfast cocoa, except that the cocoa fat content is less than 10% by weight.

25.4.2.4 Cocoa with dioctyl sodium sulphosuccinate for manufacturing

Is the food that conforms to the definition and standard of identity, for breakfast cocoa, except that it contains dioctyl sodium sulphosuccinate (complying with the relevant requirement including the limit of not more than 0.4% by weight of the finished food additive).

25.4.2.5 Sweet chocolate

Is the solid or semiplastic food prepared by intimately mixing and grinding chocolate liquor with one or more optional nutritive carbohydrate sweeteners and may contain other optional ingredients specified. Sweet chocolate contains not less than 15% by weight of chocolate liquor (mass), as calculated by subtracting from the weight of the chocolate liquor used the weight of the cocoa fat therein and the weights therein of any alkali, neutralizing, and seasoning ingredients and multiplying the remainder by 2.2, dividing the result by the weight of the finished sweet chocolate, and multiplying the quotient by 100. The finished sweet chocolate contains less than 12% by weight of total milk solids based on the dairy ingredients specified (exclusive of any added sweetener or other dairy derived ingredient that is added beyond that amount that is normally present in the specified dairy ingredient). Semisweet chocolate or bittersweet chocolate is sweet chocolate that contains not less than 35% by weight of chocolate liquor complying.

25.4.2.6 White chocolate

White chocolate is the solid or semi-plastic food prepared by intimately mixing and grinding cocoa fat with one or more of the optional dairy ingredients specified and one or more optional nutritive carbohydrate sweeteners and may contain other optional ingredients specified. White chocolate shall be free of colouring material. White chocolate contains not less than 20% by weight of cocoa fat as calculated by subtracting from the weight of the total fat the weight of the milk fat, dividing the result by the weight of the finished white chocolate, and multiplying this by 100.

The finished white chocolate contains not less than 3.5% by weight of milk fat and not less than 14% by weight of total milk solids (calculated by using only specified dairy ingredients) and not more than 55% by weight of nutritive carbohydrate sweetener.

25.4.2.7 Milk chocolate

Milk chocolate is prepared by intimately mixing and grinding chocolate liquor with one or more of the optional dairy ingredients and one or more optional nutritive carbohydrate sweeteners, and may contain one or more of the other optional ingredients specified. Milk chocolate contains not less than 10% by weight of chocolate liquor and not less than 3.39% by weight of milk fat and not less than 12% by weight of total milk solids based on those dairy ingredients specified, exclusive of any added sweetener or other dairy-derived ingredient that is added beyond that amount that is normally present in the specified dairy ingredient.

25.4.2.8 Buttermilk chocolate

This chocolate conforms to the standard of identity for milk chocolate, except that the optional dairy ingredients are limited to sweet cream buttermilk, concentrated sweet cream buttermilk, dried sweet cream buttermilk, and any combination of these. In addition, the finished buttermilk chocolate must contain less than 3.39% by weight of milk fat and not less than 12% by weight of sweet cream buttermilk solids based on specified dairy ingredients (exclusive of any added sweetener or other dairy-derived ingredient that is added beyond that amount that is normally present).

25.4.2.9 Skim milk chocolate

This conforms to the standard of identity for milk chocolate, except that the optional dairy ingredients are limited to skim milk, evaporated skim milk, concentrated skim milk, sweetened condensed skim milk, non-fat dry milk, and any combination of these and the finished skim milk chocolate contains less than 3.39% by weight of milk fat and not less than 12% by weight of skim milk solids based on those dairy ingredients specified (exclusive of any added sweetener or other dairy-derived ingredient that is added beyond that amount that is normally present).

25.5 Future issues for chocolate manufacture – the EU picture

One of the conditions for establishing the list of vegetable fats permitted by Directive 2000/36/EC was for the Commission to conduct a study on the economic impact on African, Caribbean and Pacific countries. Although this study has now been completed it is difficult to draw any firm conclusion given that the Directive has only been implemented in Member States for a short period of time and therefore any changes in the use of vegetable fat are not readily apparent. Interestingly, it would appear that the introduction of the list has not made a huge impact on the use of vegetable fats *per se* in chocolate, since manufacturers in those countries which did not traditionally permit vegetable fats are not using vegetable fats. No doubt there will be a further review in future years.

Future legislative changes that will undoubtedly impact on chocolate manufacture concern the use of additives and labelling of products.

The Commission is working on revised regulations for additives and flavourings, as well as a new one on enzymes. These regulations will consolidate existing definitions, labelling, approval processes, etc., for colours, sweeteners, miscellaneous additives and flavourings, as well as creating a legislative framework for enzymes. Currently only two enzymes used are regulated at European level, one of which is invertase. The use of other enzymes is governed by Member States' legislation. A parallel Commission exercise will look into the reassessment of some of the presently approved additives.

Turning to labelling, the legislation in this area has developed in a piecemeal fashion over the years and a comprehensive review which is underway. The areas in which a consensus will be difficult to achieve concern declaration of country of origin, the declaration of additives or processing aids that do not serve a function in the final product, and compulsory nutrition labelling and its format. Nutrition labelling has and will always remain compulsory whenever a claim is made. A Regulation on Nutrition and Health Claims was published in January 2007, harmonizing for the first time the criteria for making these claims within the European Union. The biggest issue in this Regulation is the concept of nutrition profiling, whereby claims can only be made where the product fits a certain profile (e.g. levels of fat, salt and sugar).

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Chapter 26

INTELLECTUAL PROPERTY; PROTECTING PRODUCTS AND PROCESSES

P.J. Couzens

26.1 Introduction

The history of chocolate making is full of creativity and invention, from the very first chocolate tablet to the wide variety of chocolate products, brands and processes we have today. These creations of the human mind can be owned, and the owner may be able to stop other people using them. This is called *intellectual property* and the associated legal rights are *intellectual property rights*. Intellectual property is usually divided into two categories: Industrial property, which includes patents, trademarks and industrial designs; and *copyright*, which includes literary and artistic works. Intellectual property is an asset, and can be bought, sold or licensed just like any other property. The main types of intellectual property are listed in Table 26.1.

Although the concepts of intellectual property are fairly straightforward, the details can be complex. This chapter aims to provide an overview of the subject for chocolate manufacturers, but it is important to seek competent professional legal advice to answer specific questions. Infringing other people's rights or missing an opportunity to protect your idea could weaken or even destroy your business.

The laws governing intellectual property vary around the world, but for members of the World Trade Organisation (around 150 countries) the minimum level of protection is defined by the TRIPS agreement (Agreement on Trade-Related Aspects of Intellectual Property Rights) (WTO, 1994).

26.2 Patents

26.2.1 What is a patent?

A patent is an exclusive right, granted by a State, to make use of an invention. A patent allows the inventor to stop others from making, using or selling the

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Table 26.1 Summary of the main types of intellectual property.

Type	Description	Normal duration	Advantages	Disadvantages
Patents	A patent is a monopoly granted by a government in exchange for sharing knowledge. Patents are used to protect inventions, for example new products, ingredients, processes, equipment or packaging	20 years	Good broad protection of the concept. Most useful for ‘visible’ inventions such as new ingredients, products or packs	Releases know-how Less useful for ‘hidden’ inventions such as new processing methods
Trade secrets	Trade secrets are information that companies keep secret to give them an advantage over their competitors. A well-known example is the recipe for COCA-COLA$^{\circledR}$	Until it is no longer a secret	Costs nothing Useful for protecting production ‘know-how’	Unlikely to work for long periods Competitors may have the same idea and patent it
Trade marks	A trade mark is a badge of origin showing who makes a product. Words, logos, signs, shapes, colours or pieces of music can be registered as trade marks	Potentially for ever if it continues to be used	Long duration of protection	With only a trade mark to protect your product it may be copied by a competitor as long as they do not use your trade mark
Designs	New designs with ‘individual character’ can be registered to protect the way something looks. For example a new shape for a chocolate assortment box	Up to 25 years, but varies from country to country	The product itself need not be new as long as its visual appearance is new	Only protects the look of something not its technical function
Contracts	A contract is a legal agreement with another party to do or not do something. Examples include non-disclosure agreements, trials agreements and exclusivity agreements	Defined in the contract	Useful for working with others without losing control of any intellectual property	Non-disclosure agreements can be difficult to enforce in practice
Copyright	Copyright protects original literary, dramatic, musical and artistic works. Equipment instruction manuals and engineering drawings can all be protected by copyright	The rules are complex but copyright normally extends for a number of years after the author’s death	Automatic protection, no registration required	Does not protect an idea, only its ‘fixed form’ for example how it is written down

invention without their permission. Patents only last for a limited period, typically 20 years. The idea behind a patent system is that, without patents, inventors would keep their inventions secret for fear that their competitors would copy them. This secrecy would prevent others from building on the earlier knowledge and so the scientific knowledge and technology of society would not advance. In exchange for granting a patent, the State requires that the invention be fully disclosed so that other people can learn from the invention and, once the patent has expired, can use the invention. The extent to which the present international patent system balances the needs of business with those of society is a contentious topic, which is outside the scope of this chapter.

In most countries, in order to be patentable an invention must be:

Novel. Novel is another word for new. To be considered novel the invention must not be available to the public anywhere in the world, in any form before the patent application is filed. This is why it is often advisable to file a patent before performing market research on an inventive chocolate product. Showing the product to the public may mean your invention is no longer novel and so cannot be patented. The USA have different patent rules to much of the world and allow inventors to disclose their inventions publicly as long as they file a patent within one year. However, many confectionery businesses are global, and so to obtain patents outside the USA it is important not to make your invention public before filing the patent.

Inventive. Something is inventive if, when compared with what is already known, it would not be obvious to someone with a good knowledge and experience of the subject.

Capable of industrial application. 'Industry' is used in a very wide sense here and it is unlikely that inventions related to chocolate manufacture and use (on any scale) would not be considered industrially applicable. Inventions which relate to purely intellectual or aesthetic activities are not allowed.

Excluded. There are a number of things which are not patentable in most countries. Some of these are:

- An aesthetic creation such as a literary, dramatic or artistic work
- A discovery
- A scientific theory or mathematical method
- Inventions encouraging offensive, antisocial or immoral behaviour.

However, the detailed situation is complex and varies around the world so it is worth seeking professional advice. In particular, the situation regarding patents for software or business methods varies around the world.

Patents are generally intended to cover products or processes with new technical or functional aspects. Patents are therefore concerned with, for example, how things work, what they do, how they do it, what they are made of or how they are made. There is a misconception that patents are only for ‘groundbreaking’ inventions. In fact, the vast majority of patents are for incremental improvements in known technology.

26.2.2 International protection

Patents are territorial rights, so, for example, a patent granted just in the UK would not stop someone using the invention in Japan (although it would stop someone importing the product of the invention into the UK). Even if your business operates only in one country, you should think carefully about whether you might want to file patents abroad. Your business might grow in the future, or you might want to make money by licensing your patent to a company in another country.

If you wanted a patent in many foreign countries it would be difficult to make a separate application in each country. Fortunately there is a system to help you. Around 130 countries have signed up to a treaty called the Patent Co-operation Treaty (PCT). As long as you are a resident or a national of one of the PCT countries you can file a single international patent application and designate any of the member countries. This is equivalent to filing the patent in each of the countries individually, but much more convenient. There is no such thing as an international patent however. Each designated country will have to examine the patent individually and decide whether or not to grant it. It is generally cheaper to use the PCT route if you know you will want protection in more than five countries.

When one patent application results in several patents in many different countries, all of the patents and applications associated with the original patent application is called the *patent family*. However, the details of exactly what is covered by the individual patents in each country may vary, even though they all originated from one application.

There are a few regional patent offices which can grant patents for member states of that region. Examples are the African Regional Intellectual Property Organisation (ARIPO) and the European Patent Organisation (EPO). Most European countries are members of the EPO (including Switzerland) and when you file a European patent application it will (if granted and if you pay the correct fees) be effective in every country you have listed on your application.

The US patent system has important differences to those of the rest of the world. A major difference is that priority is given to the patent application with the earliest invention date rather than the application which was filed first. For this reason it is advisable to keep detailed dated records such as a bound notebook for recording inventions, and have someone who is not an inventor counter-sign the entries. However, it is important to understand that documenting the date of invention does not secure any patent rights, you have to file a patent application for that. It is only useful if someone else files a patent for substantially the same invention and you need to provide evidence that you made the invention first. This procedure at the US Patent Office is known as an 'interference action'. As with all legislation, the situation can change. There is currently proposed legislation before the US House of Representatives (Patent Reform Act, 2005) which may bring the US patent system closer to that of the rest of the world.

Some countries have laws which restrict patents being filed abroad without permission. The restrictions are generally aimed at military technology or matters of national security, so there is not normally a problem getting permission to file patents relating to the chocolate industry.

26.2.3 The life of a patent family

As was described earlier, in order to be granted a patent your invention must be novel. This makes the date of filing important as, when determining novelty, the invention in your patent will be judged against anything published before that date. Fortunately, after you file a patent application in one country you can file applications in most other countries up to twelve months later and they will be treated as if they were all filed on the original date. An international treaty dating from 1883 called the Paris Convention governs this. The date of filing the first application is called the 'priority date'.

There are many different permutations in the way you can file the individual patents in a patent family. A typical sequence for a UK company is shown in Figure 26.1 but a legal advisor such as a patent attorney (see Section 26.9) will be able to advise you on the best approach for your particular situation and the exact timings. For example you might suspect that competitors are likely to copy your invention in a particular country and so you want to be in a position to take action against them as soon as possible.

Obtaining the grant of a patent takes time. Patent offices around the world are under pressure to examine patents more quickly, but it is likely to take several years for a patent to be granted. In some countries, other people have the opportunity to oppose your patent. For example in Europe, an opposition can be filed against a patent once it is granted, but this must be done within 9 months of the publication of the grant. If your patent is opposed it may take several years before the opposition procedure is complete. Japan and Australia also have a system of oppositions. The US has a slightly different system called 're-examination'.

26.2.4 The cost of a patent

How much a patent will cost depends on a number of factors. Generally the costs associated with patents increase with time. The main cost in the first year associated with filing a patent in one country will be the professional

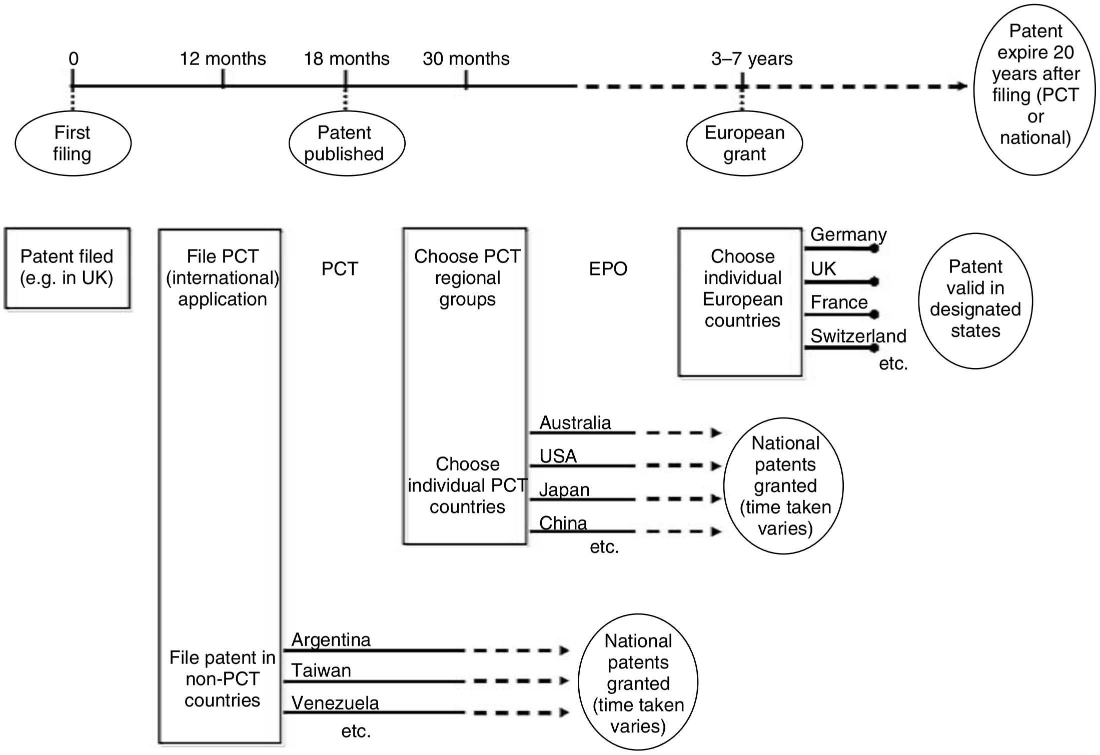


Figure 26.1 Typical timetable for patenting an invention in a number of countries using the PCT system.

fee paid to a patent attorney for writing the patent. It is not strictly necessary to employ a patent attorney to write the patent, but a mistake in the patent text could render your patent useless, so it is usually money well spent. The patent attorney's fees will depend on the length and complexity of the patent so it is not really sensible to generalize. However, at 2007 prices you should expect to pay at least £1500 ($2700, €2000) for the preparation and initial filing of a straightforward patent application. Filing the patent on an international basis 12 months after the first filing is likely to cost a further £5000–£10 000 ($9000–$18 000, €7000–€14 000).

The costs mount up significantly thereafter, depending on the number of countries in which you wish to protect the patent. Costs can easily reach £60 000 ($108 000, €84 000) over the first five years. Some countries will require the text to be translated which adds cost. Once a patent is granted you need to pay renewal fees in each country to maintain the patent. These fees generally increase with the age of the patent, the logic being that if you are continuing to maintain a patent it must be generating commercial revenue and so the various governments want their share. If you are a private inventor, or work for a very small 'start-up' company, you will probably need to obtain external funding within the first few years to finance your patent. Be sure to at least have a Confidential Disclosure Agreement with the other party (see Section 26.6), but preferably file your patent before approaching potential industrial partners with your invention.

26.2.5 Where to find patents

Patents are an important source of technical information along with reference books and journals. In recent years it has become much easier to access patents from the major countries of the world as they are available on the Internet free of charge. The European Patent Office has a searchable database called *esp@cenet*®, which has patent information about published patents from over 72 countries and regions of the world. In most cases it is possible to view the actual patent text, or at least text from an equivalent patent from the same family.

There are also commercial databases for which you have to pay a fee. These can provide extra information and wider coverage. Examples include *FSTA – Food Science and Technology Abstracts*® which covers a wide range of literature sources including patents, and *Derwent World Patents Index*® which is a specialist patent database.

Making your own patent search may be sufficient when you want to get a general understanding of the patents in your area, for example at the planning stages for a new chocolate process or product development. However, there are times when a professional patent search is required, perhaps to check that your new product launch is not going to infringe someone else's patent, or before filing your own patent. These are situations where it would be best to contact a patent attorney for advice.

26.2.6 How to read a patent

When you first look at a patent it can seem unintelligible, almost as if it were deliberately written to be unreasonably repetitive and awkward. However, once you understand how a patent is structured and what information is found in the different sections it all becomes clearer. The language used can also be confusing, with some words in patents having a very particular meaning, which can be different from the way the word is used in everyday conversation. I will attempt to give some pointers to help you if you are new to reading patents.

The way a patent is structured is broadly similar between different countries, although the order of the different sections and the terms used may vary.

When you first see a patent, do not try and read all of it from beginning to end. Start by looking at the front page, then read the claims and then look at the drawings (if there are any). That will give you an overview of what the patent is about before you start to read it in more detail, or perhaps decide it is not relevant.

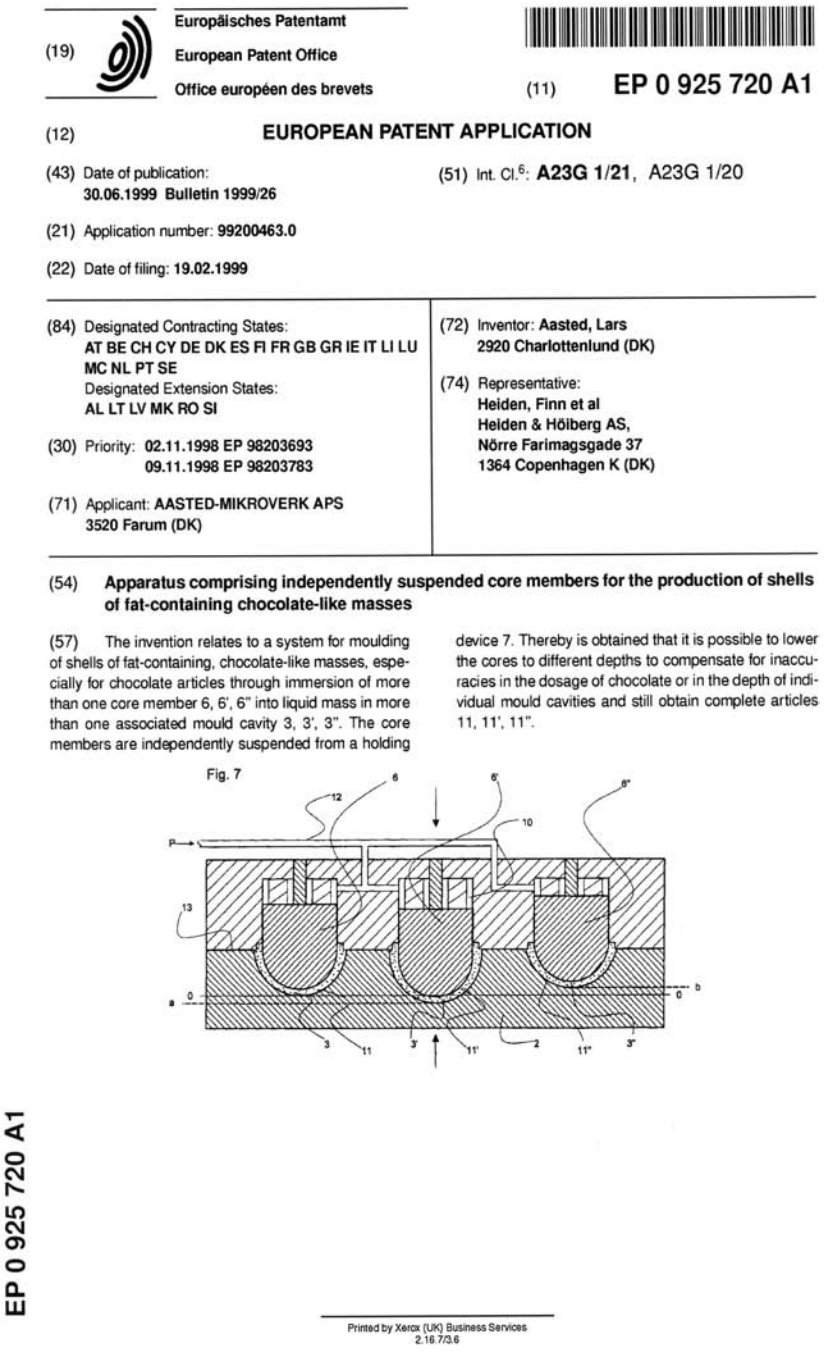
Think about why you are reading the patent before you start. If you want to know if the patent could stop you from doing something, then concentrate on the claims, comparing what you plan to do with what it says in the claims. Use the rest of the patent to help you understand what the claims mean. You will also need to establish whether the patent has been granted in the relevant country and is still valid.

If you have recently made an invention and are reading a published patent to check whether your invention is novel, then the whole patent is relevant. It does not matter if the patent has been granted, or has expired. If your invention has already been described in a patent (or any other publication) then it is not novel.

26.2.6.1 Front page

A reproduction of a European Patent front page is shown in Figure 26.2, downloaded from the *esp@cenet®* service of the European Patent Office. Each item of information is marked by a number in brackets. These numbers are called ‘INID codes’ (‘internationally agreed numbers for the identification of bibliographic data’) and because these numbers are consistent in every country, they allow you to identify important information from a patent even if you do not understand the language it is printed in. For example the title of the invention is marked (54).

The patent number (11) is at the top right of the page. The first two letters, ‘EP’, mean that it is a European Patent, this is followed by a number to identify the patent and then there is a code such as A1 or B1. The patent in Figure 26.2 has A1 after the number. The ‘A’ means that this version of the European Patent is an application. You might want to look on a database such as *esp@cenet®* to see if there is the granted version (which in fact there is for the patent in Figure 26.2), and this will have a ‘B’ after the number.



(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 0 925 720 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
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(51) Int. Cl.^{6}: **A23G 1/21**, A23G 1/20

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(72) Inventor: **Aasted, Lars**
2920 Charlottenlund (DK)

(74) Representative:
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Heiden & Höiberg AS,
Nörre Farimagsgade 37
1364 Copenhagen K (DK)

(54) **Apparatus comprising independently suspended core members for the production of shells of fat-containing chocolate-like masses**

(57) The invention relates to a system for moulding of shells of fat-containing, chocolate-like masses, especially for chocolate articles through immersion of more than one core member 6, 6', 6" into liquid mass in more than one associated mould cavity 3, 3', 3". The core members are independently suspended from a holding device 7. Thereby is obtained that it is possible to lower the cores to different depths to compensate for inaccuracies in the dosage of chocolate or in the depth of individual mould cavities and still obtain complete articles 11, 11', 11".

Fig. 7

EP 0 925 720 A1

Printed by Xerox (UK) Business Services
2.16.7/3.6

Figure 26.2 Example of a front page from a European patent application. (Downloaded from the *esp@cenet*® service of the European Patent Office with permission of EPO.)

The granted version may be quite different from the version that was originally filed. Since 2001 the US Patent Office has also adopted 'B' to signify a granted patent, but different countries use different codes in their patent numbers and these have changed over the years, so it is worth checking the exact meaning of the codes on the appropriate patent office website.

The filing date (22) is towards the top of the page on the left-hand side. This date is important because generally patents are only valid for twenty years after the filing date. (There are some exceptions to this, particularly for US patents, so if it is critical, seek advice.) For this patent there is another important date, the 'priority date' (30). This is printed below the filing date and for the patent in Figure 26.2 there are two priority dates, corresponding to different material within the patent. The priority date is the date of an earlier patent filing (or in this case, two filings) from which this patent 'claims priority'. When the patent office examines the patent to see if the invention is new, they will normally only consider publications earlier than the priority date. (An exception to this is if extra material has been added to the patent in the first year after filing, this extra material must have been novel at the time it was added.)

The names of the inventors (72) and the name of the applicant (71) are also printed on the front page. Generally the applicant is a company, and if the patent concerns chocolate you may well recognize them as a competitor or supplier. The applicant listed on the patent may not own the patent now as they might have sold it to another company. On US patents the name of the company is not always given, but a search for patents by the same inventors will often reveal another patent in the same patent family where the company is named.

The patent's title may help you understand what the patent is about, but they can be quite general such as 'Confectionery Item'. There may also be an abstract and a reproduction of one of the drawings from the patent on the front page.

26.2.6.2 Claims

The claims are very important as they define exactly what the patent protects. The claims in US and European patents are towards the end of the patent. They take the form of a numbered list of paragraphs headed by text such as 'Claims' or 'What is claimed is:'. The rules require that each claim is a single sentence, so if the claims are long they can be difficult to read. You may find it helpful to mentally insert the words 'What is claimed is' before each claim when reading them.

When reading claims it can also be helpful to break them into sections. Sometimes the patent writer has done this for you, as in the granted version of the patent whose front page was shown in Figure 26.2. The first two claims of that patent EP 0 925 720 B1 are reproduced below:

1. *A system for the production of shells of fat-containing, chocolate-like masses, in particular for chocolate articles, comprising more than one* *mould cavity (3, 3′, 3″) to receive the mass (5, 5′, 5″), more than one core member (6, 6′, 6″) to be immersed into the mass,* ***characterized in that*** *the core members are independently suspended from a holding device (7).*

2. *A system according to claim 1, comprising means adapted to guide a vertical travel of the independently suspended core members (6, 6′, 6″) in relation to the holding device (7).*

(The numbers in brackets in the claims refer to numbered items in the drawings, found elsewhere in the patent.)

Make a note of any key words to check exactly what they mean in this patent. Do not assume you know what they mean as they may have been defined in a special way earlier in the patent. For example, the term *chocolate* may not be restricted to what can legally be labelled as chocolate. For these claims you would also want to check the meaning of *chocolate-like mass* and *independently suspended*.

When used in patent claims, the word ‘comprising’ has a very specific meaning. It means that the claim covers all the elements listed, but does not exclude additional unnamed elements. In the above example, the claim covers a system with *more than one mould cavity* and with *more than one core member*, but the system could also have additional components.

The contrasting term would be ‘consisting of’. This gives the claim more limited scope and if it had been used in the above example in place of ‘comprising’ it would mean that the claimed system could have *more than one mould cavity* and *more than one core member*, but nothing else.

Another type of phrase with special significance is used to separate two parts of a claim. Examples of such separating phrases include ‘wherein’ or, in the example above, ‘characterized in that’. The words before the separating phrase describe what was already known and the words after the separating phrase describe the improvement that the invention brings. In this case the improvement is that *the core members are independently suspended from a holding device.* This two-part structure for claims is common in European patents, but much rarer in the United States.

The second claim in the example refers back to the first claim using the words ‘according to claim 1’. This is known as a *dependent claim*, in contrast to claim 1 which is an *independent claim*. Dependent claims are always narrower in scope than the independent claim they are based on. They provide a ‘fall-back’ position to a more specific claim in case the patent examiner does not allow the broader independent claim.

It is worth remembering that the rules require that each claim means something different. If you initially think two claims say the same thing then that should act as a warning that you have not understood them properly. It may be worth studying those claims in more detail to identify the differences.

26.2.6.3 Main text

The main text is split into sections and it is worth flicking through the patent to see where they start and end. The first section will describe what was generally known about this subject at the date the patent was written. This can provide a useful review of the technology in the area, but remember that the patent was written to convince the patent office that this specific idea is new and inventive over what has gone before rather than to provide an objective review of the wider technology area.

Generally the text will then go on to explain what the problem is that the patent sets out to solve, why this invention is needed and why the previous technology was unsatisfactory. The word 'surprisingly' is often used to emphasize the point that the invention is not obvious. There will be a short paragraph summarizing the invention, which is often very similar to the first few claims.

The text then describes the invention in more detail. This part of the text may be headed 'Description'. Patent writers have two conflicting aims when writing the description. They need to set out in detail the invention for which they claim a patent, but they would not want to disclose any of their secrets that would not be protected by the patent, i.e. which are not covered by the claims.

Patent writers need to convince the patent office that they have explained the invention sufficiently well for a skilled person to be able to understand it and copy it. As explained earlier, in return for granting a patent, a State expects the technology in the patent to be disclosed to the public. If the patent office decides that the disclosure is insufficient, they would not grant the patent. In the US and some other countries there is also a requirement to disclose the best way you know of carrying out the invention. This is called the 'best mode'. Bear in mind that the owner of the patent may have improved the invention since writing the patent and describing the 'best mode'.

One of the things that make patents difficult to read is the inclusion of huge lists describing different options for the invention. For example, after saying that sugar should be used in a recipe, there may be a whole paragraph listing suitable sugars. When first reading the patent it is best to ignore those lists and come back to them when you need specific information. Similarly the patent description will often contain a whole series of seemingly repetitive ranges such as, 'the reaction time should be between 1 and 100 minutes, preferably between 20 and 80 minutes, more preferably between 40 and 60 minutes'. These are often repeated in the claims, and like nearly everything in a patent they are included for a purpose. During examination the patent office may refuse some of the claims or may require the patentee to limit their claims to a narrower range. By this examination stage the patentee cannot introduce new material to the patent, so there has to be a basis in the description for anything added to the claims, hence the large amount of 'back up' material found in some patent descriptions.

The description should also explain the meaning of key words and expressions. For example 'chocolate-like masses are suspensions of non-fat particles, such as sugar, milk powders and cocoa solids in a liquid fat phase'.

26.2.6.4 Figures

Not all patents have figures or diagrams, but when they do they can be very helpful in understanding how the invention works. The figures have numbers on rather than text labels so you need to read the description to find out to what the numbers refer. This is done so that the drawings do not need to be altered when the patent is translated into different languages. You may find it helpful to spend a few minutes adding labels to the figures before trying to understand them. An example of a patent figure is shown in Figure 26.3. To show that patenting inventions concerning chocolate is not new, the example is taken from a patent for aerated chocolate dating from the 1930s.

26.2.6.5 Examples

Many practical chocolate technologists find the examples the easiest part of the patent to understand. They are often in the form of recipes or process instructions, perhaps with measurements of the end-product to demonstrate the advantages of the invention. Not all patents have examples, but when they do it is important to realize that the patent claims probably cover more than just what is written in the examples or drawn in the figures. All the products described in the examples might be cakes, but that does not

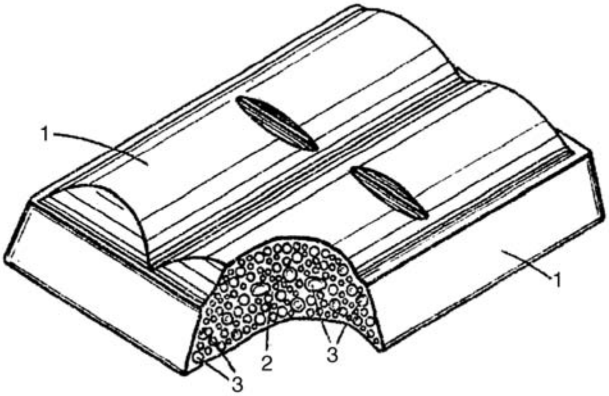

Figure 26.3 Example of a figure taken from GB 459,582, a Rowntree & Co Ltd patent for aerated chocolate filed in 1935. (Downloaded from the *esp@cenet*® service of the European Patent Office with permission of EPO.)

necessarily mean that the patent is restricted to cakes. To find out what is covered you need to read the claims!

26.3 Trade marks

Trade marks are signs that distinguish the goods or services of one company from another. For many companies a trade mark is a precious asset and can be worth millions of pounds. Probably the most valuable piece of intellectual property in the world today is the trade mark COCA-COLA®. It has been said that if all of the company's buildings, vehicles, factories and equipment were destroyed, Coca-Cola Inc would emerge from the ruins and rebuild itself provided that the trade mark survived.

A trade mark has to be distinctive, and not likely to be confused with someone else's prior trade mark. A trade mark also has to be capable of being represented graphically, but this is not as limiting as you might first think. Words, logos, colours, two-dimensional and three-dimensional shapes, musical jingles and even smells have been used a trade marks. (The smell of fresh cut grass has been registered in Europe as a trade mark for tennis balls, but this is very unusual.) A three-dimensional shape can be very powerful as a trade mark. Kraft Foods have registered a trade mark for the shape of the TOBLERONE® chocolate bar in some countries.

If you are thinking up a word to use as a trade mark for a new product, the strongest protection is obtained from fanciful, invented words such as KIT KAT®. It is not normally possible to obtain trade mark protection for words which describe the generic product. For example the word *Dark* could not be a trade mark for chocolate as it is clearly descriptive. In between these two extremes there is a range of possibilities, decreasing in level of protection as the words become less arbitrary and more descriptive. The same applies for other signs such as shapes. The shape of a strawberry is unlikely to be accepted as a trade mark for a strawberry-flavoured product, although it might be an acceptable trade mark for hair care products. Trade marks are registered for a specific class of goods.

There are a number of other restrictions on what can be used as a trade mark. Trade marks cannot be misleading, for example *sugar sweet* would not be allowed for a chocolate sweetened with artificial sweetener and they cannot designate the place of origin or mislead the public about the place of origin. There are also marks which are prohibited. You must not register a trade mark which resembles certain official emblems, such as the symbol of the Olympic Rings, and trade marks should not include profane language or include obscene visuals.

After selecting a trade mark it is important to search to see if anyone else has the same or a similar trade mark. Trade mark agents can assist with this, but it is possible to search the trade marks register yourself and this may be a good starting point. However, it is advisable to pay for a professional search before filing an application as the fee is not refunded if the application is refused. If the trade mark is to be used internationally, it is also good idea to check that the word does not have unintended or vulgar meanings in other languages.

In a few countries the legal rights to a trade mark are established simply by using it. However, it is generally advisable to register your trade mark as it makes it easier to enforce your rights, and in many countries this is essential. Like patents, trade marks are territorial rights and so need to be established in individual countries. There is no such thing as an international trade mark, but as with patents there is a system to simplify the registration of a trade mark in multiple countries. This is known as the Madrid system. Once you have filed an application to register a trade mark in your own country you apply for an International Trade Mark to be registered with WIPO (the World International Property Organisation). You specify the countries where you want trade mark rights (who must be members of the Madrid Union) and the application is equivalent to applying in each of the countries individually. Within the European Community there are both national trade marks and Community Trade Marks. Community Trade Marks cover all the member countries of the European Community.

Details of the registration process vary, but generally the trade mark office will check that the trade mark complies with the rules and has the required distinctive character. However, even if a trade mark lacks distinctive character it may still be possible to register it if you can prove that the public exclusively associates the mark with your product. This is called *acquired distinctiveness* (or *secondary meaning* in the USA) and typically applies to well-established products.

26.3.1 Maintaining trade mark rights

Trade mark rights will be lost over time if the trade mark is not used. For example, in the UK a person can apply to have your trade mark removed from the register if it has not been used for a period of five years. Incorrect use can also lead to a loss of protection if the trade mark starts to be used as a generic description. The word *margarine* was originally a trade name, but now it is a generic term for a wide range of butter substitutes. Trade marks are adjectives which should be followed by a noun – for example a box of ROSES® *chocolates*. Companies should use their trade marks correctly and also insist on other people doing the same. In order to prevent a trade mark becoming generic, the owners of the trade mark often contact publications that appear to be using the trade mark incorrectly and ask them to use the trade mark properly. It can seem petty, but legally it is important for the trade mark holder to be seen to be attempting to prevent the mark becoming the generic term for the product.

One way of identifying that a word is being used in a trade mark sense is to use the symbol TM after it. If the trade mark is registered, then you can use

RTM or ®, but it is not compulsory. In some countries it is an offence to use the RTM or ® symbol for an unregistered trade mark.

26.3.2 Unfair competition and 'Passing Off'

The laws of unfair competition provide some protection against a competitor confusing the public into thinking that their activities are associated with your business, even without a registered trade mark or any other IP right. However, this area of law is complicated and there are major differences between countries. The biggest differences stem from whether the country is a 'Common Law' or 'Civil Law' jurisdiction. Most common law jurisdictions descend from the English legal system and include countries such as the UK (except Scotland), the Republic of Ireland, the United States of America (except Louisiana), Canada (except Quebec), Australia, New Zealand and Malaysia. India and South Africa also have forms of common law. Continental Europe and much of the rest of the world use the civil law system. In a common law jurisdiction much of the law derives from previous judgements by judges hearing real cases, whereas in civil law countries the main emphasis is on the legal codes such as the French Napoleonic code and much less weight is given to judicial precedent.

The law of 'passing off' arises in common law countries. To sue for 'passing off' in England you need to prove that

- your products have acquired a goodwill or reputation in the market and are known by some distinguishing feature;
- the other party is doing something to confuse the public into believing that the products they sell originate from you; and
- you have suffered damage (including damage to your reputation) as a result.

A trade association for Swiss-based chocolate manufacturers, *Chocosuisse* successfully brought a legal action in England against Cadbury Ltd. for using the name *Swiss Chalet* on a chocolate that was not manufactured in Switzerland (Chocosuisse, Union des Fabricants Suisses de Chocolat & Others v Cadbury Ltd, 1999). However, it can be very difficult and expensive to prove 'passing off'. One advantage of registering a trade mark is that it is generally easier to prove infringement of a registered trade mark than 'passing off' of an unregistered mark. Once again, this is an area where you should seek professional advice.

26.4 Designs

Designs are concerned with the outward appearance of a product rather than its function. In chocolate confectionery, the legal protection of designs is commonly used to protect packaging, for example the shape and appearance of an assortment box, but it can also be used to protect the shape of chocolate products themselves. Once again the situation varies around the world, but generally, to be protectable, a design must be new and original.

In the European Community there is a two-tier protection system:

- The Unregistered Community Design (UCD)
- The Registered Community Design (RCD).

An Unregistered Community Design gives automatic protection for your design for 3 years after you made the design public. It has the advantage that you do not need to file any applications, but the major drawback is that the protection can be very difficult to enforce. An UCD gives the right to prevent the commercial use of the design only if the use results from copying.

A Registered Community Design gives you exclusive rights over the use of that design. An RCD initially has a life of 5 years, but it can be renewed in 5 year blocks up to a maximum of 25 years. You can register your design and keep it undisclosed for up to 30 months. There is a grace period which allows you to market your product for up to a year before applying for a Registered Community Design, but it is generally safer to register as soon as possible. A major advantage of having a registered right is that it is easier to prove infringement.

It is worth considering designs and trade marks together. It might be possible to protect a distinctive and novel product shape as a three-dimensional trade mark and this provides a valuable alternative to design registration, as it potentially gives protection indefinitely.

The equivalent protection in the USA for designs is the ‘Design Patent’. Like Registered Designs, a US Design Patent is concerned with appearance not function (the patents dealing with function in the US are called ‘Utility Patents’). The important difference however is that to get a Design Patent in the USA you must show that your design is not just novel, but is also inventive. In practice this makes Design Patents more difficult to obtain.

26.5 Copyright

Internationally, copyright is of huge economic value, covering such things as books, drawings, paintings, music, film, TV, radio and, in many countries, computer software. It is important however to realize that copyright does not protect ideas. If you have written down a great idea for a new chocolate product, your written words (the expression of the idea) will be protected by copyright, but the idea itself is not protected.

Copyright protection is automatic as soon as there is a record in any form of what has been created. There are a number of international conventions on copyright, so generally copyright protection is international. It is useful to mark copyright material with the international copyright symbol © followed by the name of the copyright owner and year of publication. This is not essential for many countries in the world such as the USA and Western Europe, but it is an advisable and simple step to take.

In the USA there is an official register for copyright works, but copyright is not dependent on registration. It can however be useful to be able to prove when you created your copyright material, for example if someone accuses you of copying their later work. Some people send themselves copies by registered post, which they leave unopened to be able to prove a date on which the work existed, or deposit the work with banks, solicitors or registration companies.

For chocolate manufacturers, copyright is mostly used for protecting the text and graphics on pack, as well as marketing and advertising literature. It can be a valuable tool in tackling counterfeit goods. It used to be possible to use copyright to protect three-dimensional shapes, but this is no longer the case and design registration should be used instead. However, documents detailing the design as well as any artistic or literary work incorporated within the finished product can be protected by copyright.

Chocolate manufacturers need to be aware of other people's copyright to avoid infringing. For example, adding music to your training or promotional video requires permission from the copyright owner of the music. When buying or commissioning copyright material it is important to be clear what rights you own. For example, you might purchase a painting of your factory to hang in your office reception area, but you may not necessarily own the right to reproduce the painting in publicity material. In 2005, a California jury awarded $15.6 million to a former model who claimed that his picture was used without his permission on Taster's Choice® coffee product labels. This action was bought under California's 'right of publicity' laws rather than copyright (and was reversed on appeal), but it highlights the importance of knowing exactly what rights you own.

26.6 Contracts and agreements

A contract is a 'promise' or an 'agreement' that is enforced or recognized by the law. Companies generally cannot work in isolation, they need to deal and co-operate with other companies and organizations. A good relationship clearly involves trust, for example between a manufacturer and a supplier, but legal contracts provide security and set out what each party has agreed to do or not to do. The law governing contracts varies from country to country, but contracts may be implied by the relationship between the two parties, they may be agreed orally or they may be agreed in writing. Agreeing a contract in writing is normally the best policy, as it avoids doubt and is easier to enforce than an oral contract.

A common contract is the confidential disclosure agreement (CDA), sometimes referred to as a non-disclosure agreement (NDA). These agreements are valuable when you want to disclose confidential information or trade secrets but need to make sure the information does not become public. For example, you may have developed a new chocolate product and would like to discuss with an equipment supplier what machines they would propose for its manufacture. In order to obtain good advice you need to explain your product in some detail, and the supplier in turn needs to share technical information about their process equipment. A CDA allows you to have open and useful discussions, but gives some legal security that the information would not be passed on to competitors. The wording of a typical CDA is given on the UK Intellectual Property Office Website (UK-IPO, 2005) but this is just an example and may not fit your specific circumstances.

Confidential disclosure agreements should be used with care. Once a secret has been made public you cannot get it back, and suing the other party for breaching the CDA may not provide you with much recompense and can be difficult to do in practice. It is important to find a good balance between sharing information with a business partner in order to work efficiently and keeping your secrets secure.

Written agreements can be used to prove that information has been passed under confidentiality. This can be important for patent applications, as the invention of the patent must not be disclosed to the public before the patent is filed and a competitor might try to invalidate your patent on the basis that you disclosed the invention to someone with no requirement for confidentiality. (Different rules apply in the USA, see Section 26.2.2.) The safest policy is to file the patent before telling anyone else about it, but in practice you may need other parties to help test the idea or build prototypes before you can finish writing the patent. Consumer research is a particularly dangerous area. It may be possible to agree confidentiality with a small group of consumers, but large-scale quantitative tests, or tests where the consumer takes the product away with them would not normally maintain confidentiality, so the patent should be filed first.

There are a number of other common types of contract. ‘Trials Agreements’ or ‘Development Agreements’ are used when two parties have the possibility of developing new intellectual property together. The agreement sets out who will own any new intellectual property generated. It is much easier to agree this in advance than to wait until the new discovery has been made and then start discussing who owns it.

Some speciality ingredient samples are supplied only if a ‘Non-Analysis Agreement’ has been signed. Such agreements prevent the receiving party from analysing the sample and ‘reverse engineering’ the ingredient from components found in the public domain.

‘Licence agreements’ allow others to use your intellectual property, typically for a fee. Licenses can be for registered rights such as patents, but also for confidential intellectual property such as trade secrets. The licence agreement sets out what the licensee is allowed to do and any terms and conditions applying to this use.

'Exclusivity agreements' typically agree that an ingredient or product will only be sold to one customer. These may be agreed as part of commercial negotiations involving both price and volume. The customer needs to decide whether having exclusive access to this ingredient or product will bring sufficient economic return to justify the price and conditions being asked for. You also need to ensure that you comply with competition law.

'Contracts of employment' are used to agree such things such as wages, hours of work and notice periods between a company and its employees. They may also explicitly state that the employee must keep his employer's information confidential, during and after employment. Employment contracts also commonly assign the ownership of any intellectual property that the employee may invent to their employer. Some employment contracts contain restrictive covenants which prevent an employee taking a job with a competitor. As with all legal contracts, professional advice is required to ensure such covenants are valid. For example in common law countries, the principle of 'restraint of trade' means that a person is entitled to undertake a lawful trade when and where he wishes. Any restrictive covenant has to be shown to be reasonable for both parties (and the public). Often, restrictive covenants are agreed in return for extra payment and are limited in duration. In most countries there are laws which govern the duties and responsibilities of employees and employers in addition to those written in an employment contract (see Trade Secrets, Section 26.7).

Contracts are often established between companies and organizations that are based in different countries. Written contracts will usually state under which country's law they should be interpreted. A change in legal jurisdiction can make a significant difference in the way the contract will be interpreted, especially moving between 'Civil Law' and 'Common Law' countries (see Section 26.3). This is another area where professional legal advice is likely to be required.

26.7 Trade secrets

Trade secrets are information that companies keep secret to give them an advantage over their competitors. The formula for the COCA-COLA® beverage is famous for being protected by a trade secret. The formula is known to only a few people and kept in a bank vault. The individuals who know the secret formula have signed non-disclosure agreements and it is rumoured that they are not allowed to travel together. Other examples of information that may be kept as a trade secret include customer identities and preferences, supplier lists, the prices paid for goods, marketing strategies, company finances and manufacturing processes.

Keeping your important information secret has advantages over other types of protection such as patents as there are no fees to pay and the protection does not run out after a fixed number of years. The major disadvantage however, is the practical difficulty of keeping the information secret. You need to take great care to keep the secret and be sure that everyone involved does the same.

Another risk with the strategy of keeping a technical invention secret is that someone may independently have the same idea and decide to file a patent. Despite the fact that you have known this idea for a long time, the knowledge was not made public so they will be entitled to the patent.

In chocolate manufacture, trade secrets are best used to protect technical insights and understanding, process settings and in some cases the process itself. Clearly, if competitors can analyse your product and determine what ingredients were used and how the product was made, there is no point trying to keep that information as a trade secret. One approach for keeping recipes and processes secret when working with co-manufacturers is to use different companies to produce different parts of the product. For example, the fat blend could be made by one company, while the milk components made by a second. All the components are then combined in yet another location. This avoids sharing the knowledge of the overall process, but is likely to add cost.

It makes sense to control who visits your factory and to avoid showing secret aspects of your process to those who do not need to see them. Visitors may not intend to pass on confidential information, but may do so inadvertently. Asking visitors to sign a secrecy agreement helps to remind them of their obligations. Some companies take great care not to allow any outsiders into their factories. Processing equipment is delivered to the door of the factory, and the supplier is not involved in the installation and may not even know exactly what the equipment is being used for, or whether further modifications are being made after delivery. This approach is not one to be taken lightly, as you lose the benefit of the supplier's expertise in specifying and maintaining the equipment and may limit your options regarding warranty. A good trusting relationship with your suppliers can be very valuable.

Most countries have laws to protect confidential information. This is required under the terms of the TRIPS agreement (WTO, 1994). To be protected, information must:

- Be secret (not generally known to the public)
- Have commercial value because it is secret
- Have been subject to reasonable steps to keep it secret.

An example of 'reasonable steps' would be the shredding of confidential information. Although someone might be able to piece together the shredded material and discover your secrets, you would be considered to have taken reasonable steps to protect your confidential information.

In the USA the Economic Espionage Act of 1996 (EEA, 1996) makes the theft or misappropriation of a trade secret a federal crime. Similarly, in

Switzerland 'breach of confidence' is a criminal offence and, unusually, there is no defence of acting in the public interest. In common law countries such as England, to bring an action for breach of confidence you must usually show the following elements:

- A confidential relationship existed
- The information was confidential and the owner had taken reasonable steps to protect it
- There was unauthorized use or disclosure.

In addition, for some situations you need to show that the disclosure had a detrimental effect. However, it is not always necessary to show that a confidential relationship existed. It is important to remember that legal obligations of confidentiality are not always as a result of a contract. Confidentiality may be expressly stated but it can also be implied. In many countries certain relationships are presumed to be confidential, such as between a husband and wife, or a solicitor and client.

Employees are likely to be exposed to a company's Trade Secrets and of course they may move jobs from time to time. Employment contracts were described earlier (Section 26.6) and these generally expressly oblige the employee not to divulge the secrets of their employer, during and possibly after employment. National laws often require an employee not to do anything against the interests of their employer during their employment and not to disclose confidential information even after their employment has ended. It can be a complicated issue however, as the distinction between the ex-employee's personal technical skills and the 'know how' of the ex-employer are not always clear.

Confidential information has been described as being like an ice cube. Unless you keep it in a refrigerator and make sure those you pass it to do the same, you will just be left with a pool of water (Donaldson, 1987).

26.8 Protection strategy

Protection strategies can be considered on two levels; there are 'low-level' strategies to protect an individual idea or development in the most efficient manner and there are 'high-level' strategies which are part of a company's overall business plan. Both types are important, and when done well are closely linked.

For an individual idea or development you need to consider carefully what advantage it brings. This is the heart of what you want to protect and ideally you would like to protect every way of achieving this advantage and so gain the broadest protection. Do not automatically assume that a patent will bring the best protection – you should consider the full range of protection tools. It is also important to realize that just because an idea is patentable it does not mean there is a market for it.

As a fictitious example of the points you need to consider, imagine you have invented an ingredient combination 'Floatium' that when added to chocolate makes the chocolate lighter than air so that it floats like a helium balloon. You would review the protection tools available and decide that keeping this invention secret is not an option, as once the product is on the market the key ingredients will need to be declared on the ingredient list. So patenting seems to offer the best protection. Your first thought might be simply to patent the ingredient combination. However, on further reflection you realize that the main advantage of your invention is that you can make chocolate float in the air. So a better approach is to patent any chocolate that floats in the air, explaining how this can be achieved using 'Floatium'. This means that even if a competitor finds a way of making chocolate float in the air without using 'Floatium', then your patent will still prevent them from using their invention in this way.

Other protection tools may also be appropriate. In our hypothetical example you might enter into a partnership with an ingredient manufacturer to produce 'Floatium' on your behalf, using a non-disclosure agreement for initial discussions and then agreeing a contract setting out the terms of your business partnership and protecting any confidential information exchanged. You also decide to trade mark the name FLOAT-O-CHOC and file a design registration and patent for your chosen packaging (where all the chocolates are held in place by tiny strings). So you have combined available protection tools to prevent others from copying the advantages your idea brings. Given the high cost of developing 'Floatium' and bringing it to market, it is important that you can sustain your competitive advantage for as long as possible.

There have been some successful innovations that were made more or less by chance, but generally companies need a strategy to maximize their chance of making profitable innovations. These strategies are part of the overall business strategy and it is beyond the scope of this chapter to explore this in detail. There are a number of books on this topic such as Rivette and Kline (2000), Knight (2001), Davis and Harrison (2001) and Miele (2001). It is important not only to be aware of your own strengths, both in your technical competencies and your patent portfolio, but also to be aware of the strengths of your competitors. It is not normally wise to invest development effort in an area that your competitors already control through market position and patents. You might be better advised to look for an opportunity where you have the chance of building a sustainable competitive advantage using appropriate protection tools.

The best opportunities for obtaining broad protection arise when you are the first to patent in this area. For example, Hershey filed a patent for low fat chocolate in 1992 making claims for a fat content between 20 and 24.5%. The first claim from the European version (EP 0667746 B1) being:

> A low-fat chocolate of full-fat texture comprising a fat and non-fat solids, comprising nutritive carbohydrate sweetener and an edible emulsifier, said chocolate containing 20–24.5% by weight total fat and being a free-flowing liquid at 40°C.

There has been a flurry of low fat chocolate patents in this area since that date, including patents from Cadbury, Mars and Nestlé. These later patents aim to protect a different technical aspects of low fat chocolate. However, the Hershey patent was filed first giving Hershey the opportunity to make the broadest claims and meaning that most of the subsequent patents cannot be used without the permission of Hershey (in countries where the Hershey patent was granted). To give an idea how long some patent processes can take, Nestlé and Mars opposed the Hershey patent in the European Patent Office and the case was finally resolved when Hershey effectively withdrew the patent just before the Appeal hearing, 14 years after the patent was filed in Europe!

One protection tool that can be a useful part of a protection strategy is defensive publication. By publishing details of your technology, perhaps in a scientific journal or technical magazine, you prevent others from being able to patent it and stop you using it. Clearly the disadvantage is that you do not have exclusive rights to the technology, but for ideas you do not wish to exploit, or for inventions where a patent would be impossible to 'police', it can be a cost-effective defensive option.

A large proportion of filed patents are never commercialized. The Institute of Patentees and Inventors estimates that the success rate of getting patented ideas to the market is only 2%! (IPI, n.d./2006) As ideas move from paper concepts, through small-scale prototypes, to pilot plant trials and then to industrial trials there is a series of selections to find the most promising ideas, with only a small number of ideas moving on to the next stage. These selections can be made on the basis of business insight, consumer research, preliminary costings or even the personal taste of the managing director. At the early stages of development there is a high chance of failure, especially if it is a technology new to the whole industry. However, this is also the stage where you have the best chance of securing broad patent coverage. As the development continues and successfully passes the selection stages the uncertainty reduces and the probability of success increases. A company aiming to compete in the market for many years would expect to have a mixture of developments at different stages of maturity.

Different aspects of the innovation can be patented during the development. Returning to the hypothetical example of 'Floatium', once the unique properties of 'Floatium' had been identified, a patent was filed for chocolate that floats in the air. However, 'Floatium' was not permitted to be added to chocolate in many countries, so further development work over three years identified a permitted ingredient that could be made to have the same desirable properties through ingenious processing of the chocolate. This new processing method and ingredient were then patented, and the twenty year life of these new patents extended the protection of the product, as they covered the only viable method of achieving the advantage of a chocolate that floats in the air. As the development continued, a number of machine modifications were found to improve the manufacturing efficiency, but it was decided to keep these as trade secrets.

26.9 How to find help

In some countries it may be technically possible to represent yourself or your employer without professional help, but IP law is complicated and a small mistake could leave you with no protection for your potentially valuable idea. Unless you are very sure of your competence it is advisable to seek legal or other professional advice, as the cost of not using a qualified professional could easily exceed their fees. Larger chocolate manufacturing companies may have in-house lawyers and intellectual property specialists, but smaller organizations will need to find external help. Make sure the person you employ is appropriately qualified, for example a qualified *patent attorney* (the term *patent agent*, used mostly in the UK and Canada, is equivalent). Qualifications differ between countries, but a quick web search should indicate the appropriate qualifications for representing clients. In the copyright and related areas, lawyers and/or one of the trade associations may be helpful. As in any profession, qualifications set the basic standard, but abilities and experience in a particular area may vary. It can be useful to seek recommendations from contacts in the Industry before choosing a representative.

When working with a patent attorney to draft a patent you should try and provide them with as much relevant information as possible. If the information you provide is well organized, the patent attorney can then easily select what they need to draft the application. Points to consider include a full description of the problems which the invention solves, a summary of the invention (including drawings if appropriate), as well as relevant background information and any earlier publications you are aware of. If you do not understand what the patent attorney has written then ask – it may be wrong. The patent attorney probably knows less about the technical area than you, and by working together you can improve the quality of the application and the chances of being able to enforce the patent.

Obtaining protection for your intellectual property can be expensive, and patent costs increase with time. Lone inventors and start-up companies usually need to find financial backers, and the ideal time to approach these is in the first year after filing the patent. The filed patent makes it difficult for others to steal your idea and shows that you are serious. After the first year the costs start to escalate. Government funding may be available for start-up companies but some forms of help can have 'strings attached'. For example, you may have to share some of your profits or set up a business within a defined geographical area. There are also firms known as Invention Promoters who offer to help evaluate, develop and market your idea, usually for a large fee. Be very careful about using the services of such companies. The UK Intellectual Property Office website has useful advice on dealing with Invention Promoters which may prevent you making a costly mistake (UK-IPO, 2004).

If you discover someone is using your protected intellectual property rights without permission (infringing) you should take professional advice immediately. Do not contact the other person before seeking advice as your communication could be construed as an unjustified threat and might be illegal. Similarly if you are threatened with legal action you also need to take professional advice. Such contacts are not always bad news – it is possible that you might be able to reach a profitable commercial arrangement with the other party.

It is up to the owner of intellectual property to make sure that their interests and rights are protected. The State does not normally 'police' your rights for you. However, insurance is available for all kinds of intellectual property rights to provide for the costs of litigation. For example, there are insurance policies which would cover you in the event that you needed to enforce your patent by launching an infringement action. Such policies are generally more suited to small companies who would otherwise not have the financial strength to enforce their rights.

Conversations with professional advisers such as patent attorneys, solicitors or patent office staff are usually confidential as these professions have a legal duty of confidentiality, but make sure you have an appropriate confidentiality agreement before disclosing your idea to anyone else. Even with professional advisors it is worth checking that they do actually owe you a legal duty of confidentiality!

Conclusions

This chapter provides an introduction to intellectual property, together with some pointers to help you find more information. The four key points to remember are:

(1) An idea may be patentable, but that does not mean that it has any commercial value.
(2) Obtain competent professional legal advice in good time and certainly before disclosing your 'great idea' to people not bound by confidentiality.

(3) You need to consider a range of protection tools, not just patents.
(4) Infringing other people's rights or missing an opportunity to protect your new product could weaken or even destroy your business.

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Useful web addresses

Web addresses can change, but the following list was correct at the time of writing. If the address has changed, the new address should be possible to find by using an Internet search engine.

UK Intellectual Property Office (formerly called The UK Patent Office): www.ipo.gov.uk
European Patent Office: http://www.epo.org
United States Patent and Trademark Office: http://www.uspto.gov
World Intellectual Property Organisation: http://www.wipo.int
European Patent Office searchable database *esp@cenet*®*:* http://ep.espacenet.com
Community Trade Marks and Designs, *Office for Harmonization in the Internal Market*: http://oami.europa.eu
Japan Patent Office: http://www.jpo.go.jp

The Chartered Institute of Patent Attorneys (a UK professional body): http://www.cipa.org.uk
Institute of Professional Representatives before the European Patent Office: http://www.patentepi.com
The Institute of Trade Mark Attorneys (a UK professional body): http://www.itma.org.uk

Chapter 27

NUTRITION AND HEALTH ASPECTS OF CHOCOLATE

J.P. Lambert

27.1 Introduction

The nutritional composition and health value of chocolate is dependent on the level of cocoa solids, whether it is milk or plain and the amount of added sugar and other ingredients such as nuts. It is also important to differentiate between block chocolate and other chocolate confectionery, such as filled bars, of which only a proportion are chocolate.

27.2 Macronutrients

Chocolate contains the energy providing nutrients fat, carbohydrate and protein as shown in Table 27.1.

27.2.1 Fats

Cocoa butter, which is the main, or only, source of fat in chocolate, is made up of about 34% stearic acid, a saturated fatty acid that has little effect on

Table 27.1 Typical macronutrient composition of chocolate (Food Standards Agency, 2002).

	Nutrients per 100 g (3.5 oz)				
	Protein, g	Fat, g	Carbohydrate, g	Energy	
Type of chocolate				kcal	kJ
Plain	5.0	28.0	63.5	510	2137
Milk	7.7	30.7	56.9	520	2177
White	8.0	30.9	58.3	529	2212
Fancy and filled	4.9	21.3	62.9	447	1878

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cholesterol levels. About 34% is oleic acid, a monounsaturated fat which is either neutral or lowers blood cholesterol and a further 27% is palmitic acid a saturated fatty acid which has moderate cholesterol raising properties. Most of the remaining is polyunsaturates. Cocoa butter is virtually *trans* fatty acid free.

Tropical oils (see Chapter 19), such as illipe butter and shea nut, and other cocoa butter substitutes, which in the European Community may be used to replace up to 5% cocoa butter in chocolate, are also stearic acid rich.

The fatty acid composition of chocolate confections will also depend upon the make-up of any other fats which are used.

27.2.2 Carbohydrates

Added sucrose provides most of the carbohydrate in chocolate, with additional amounts from glucose, maltodextrins and flour in some confectionery products. Small quantities of dietary fibre are present from the cocoa and added ingredients such as nuts and dried fruit. The amount and type of carbohydrate present is important because of its effect on the glycaemic index.

27.2.2.1 Glycaemic index

The glycaemic index (GI) is a ranking of the rise in blood glucose that occurs over the two hours following the consumption of 50 g (1.75 oz) of carbohydrate. Table 27.2 gives the GI of some common foods. Glucose is quickly absorbed into the body after ingestion leading to a rapid rise in blood glucose and is commonly used as the standard (GI 100) against which other

Table 27.2 Glycaemic index of some common foods.

Food	Glycaemic index (Glucose = 100)[a]
Glucose	99
Baked potato	85
Wholemeal bread	71
White bread	70
Sucrose	68
Raisins	64
Porridge made from rolled oats	58
Spaghetti	42–57
Banana	52
Chocolate	43
Oranges	42
Kidney beans	28
Fructose	19
Peanuts	14

[a] Mean values from Foster-Powell *et al.* (2002).

foods are assessed. Starchy products, such as bread and potatoes, are easily digested into their component glucose molecules so also produce a fairly rapid rise in blood glucose. Ingestion of sucrose results in a lower GI, since it is 50% fructose, which has a low GI. Fat in a food slows the absorption of carbohydrate, so chocolate has a relatively low GI.

27.2.3 Proteins

Cocoa is not a significant source of protein and the digestibility is low. However, the milk in milk chocolate is a good source of high biological value protein.

27.3 Vitamins and minerals

Cocoa and chocolate contain many essential minerals including iron, copper, zinc, magnesium, phosphorus, manganese and potassium, all of which have important roles in the metabolism of the human body. Typical values are shown in Table 27.3. The amounts vary and are dependent on the soil in which the cocoa is grown. Milk is a good source of calcium and phosphorus. The final mineral content of chocolate is therefore dependent on the proportions of cocoa powder and milk in the final product. Hence, high cocoa solid chocolate is richer in iron, copper and manganese, but milk chocolate provides more calcium.

Cocoa powder is less important for vitamins, but cocoa butter contains vitamin E and milk provides riboflavin and vitamin B12.

Table 27.3 Mineral and vitamin content of cocoa and chocolate, per 100 g (3.5 oz).

	Cocoa powder		Chocolate[a]		
	USA[b]	UK[a]	Plain	Milk	White
Iron, mg	13.9	10.5	2.3	1.4	0.2
Copper, mg	3.8	3.9	0.71	0.24	Trace
Zinc, mg	6.8	6.9	1.3	1.1	0.9
Manganese, mg	3.84	–	0.63	0.22	0.02
Calcium, mg	128	130	33	220	270
Magnesium, mg	499	520	89	50	26
Phosphorus, mg	734	660	140	220	230
Potassium, mg	1524	1500	300	390	350
Thiamin, mg	0.08	0.16	0.04	0.07	0.08
Riboflavin, mg	0.24	0.06	0.06	0.49	0.49
Niacin, mg	2.2	1.7	0.4	0.4	0.2
Vitamin B12, μg	0	0.4	0	1.0	1.0
Vitamin E, mg	0.10	0.68	1.44	0.45	1.14

[a] Food Standards Agency (2002).
[b] USDA (2005).

27.4 Flavanols

Cocoa contains a large number of phytochemicals; physiologically active compounds found in plants. Polyphenols are phytochemicals which have been shown to have antioxidant and other potential health benefits. Cocoa is particularly rich in flavanols, a sub-class of a group of polyphenols known as flavonoids. Cocoa contains the monomeric flavanols, epicatechin and catechin, and the larger oligomeric flavanols, the procyanadins. Apart from cocoa and chocolate, flavanols are also found in a number of other foods and drinks such as apricots, apples, tea and red wine. Studies have shown that flavanols in chocolate are absorbed into the body proportional to consumption. The larger oligomers are probably broken down in the gut into the epicatechin monomers before absorption. Biological availability is probably affected by the degree of polymerization of the flavanols and this can relate to several factors such as cultivar type, geographical origin, agricultural and post-harvesting practices and processing.

27.5 Methylxanthines and other potentially psychoactive compounds

27.5.1 Caffeine and theobromine

Methylxanthines, including caffeine, theobromine and theophylline, are a group of biologically active compounds that occur naturally in many common foods and beverages. The individual compounds are thought to have similar physiological effects in the body, including stimulation of the central nervous system (CNS), cardiac muscle and skeletal muscle, relaxation of smooth muscle (such as bronchial muscle), and diuretic effects. However, they differ greatly in their strength of action on each body system affected. Caffeine is a well-known CNS stimulant but theobromine is much weaker, having about one tenth of caffeine's potency.

Cocoa and chocolate contain relatively low concentrations of caffeine but about ten times as much theobromine. A third methylxanthine, theophylline, is detectable in chocolate at such low levels that its presence is usually ignored. An average 50 g (1.75 oz) bar of milk chocolate contains about 15 mg caffeine and a 50 g bar of plain chocolate up to 50 mg, although there is wide variation dependent on the amount of cocoa mass in the recipe. These values compare to about 100 mg in a mug of coffee and 35 mg in a cup of tea, depending on strength, and 30 mg in a 330 mL can of cola.

27.5.2 Biogenic amines and anandamide

Cocoa contains the biogenic amides, phenylethylamine, tyromine, tryptomine and serotonin, and their precursors, phenylalanine, tyrosin and tryptophan. In healthy people these substances are inactivated by the monoamine oxidase in the small intestine, and in the liver and kidneys. Cocoa has also been found to contain very small amounts of a cannabinoid-like substance, anandamide.

27.6 Chocolate's contribution to the diet

European dietary surveys indicate that chocolate confectionery contributes 2–5% of the total calories in the diet, 1–6% of the total fat and 2–9% of saturated fat. The variation is due to country differences in quantities of chocolate consumed and the amounts of fat from other sources. Consumption data from the UK National Diet and Nutrition Survey shows that chocolate makes a greater contribution to the calorie content of the diet in children than in adults, but adults eat more of similar products such as cakes and biscuits. Table 27.4 shows that as well as fat and calories, chocolate confectionery makes a contribution to the vitamin and mineral content of young people's diets in the UK. Available survey data from the UK and USA shows no relationship between chocolate consumption and poor micronutrient status or any indication of displacement of fruit by chocolate. In fact, those who enjoy sweet foods seem to eat more fruit.

Table 27.4 Contribution of chocolate confectionery to the diet of British young people aged 4–18 years.[a]

Nutrient	% Total intake
Energy (calories)	5
Total fat	6
Saturated fat	9
Trans fats	9
Carbohydrate	5
Total sugars	10
Riboflavin	6
Vitamin E	6
Copper	7
Iron	4
Magnesium	5
Calcium	5
Manganese	4
Sodium	1

[a] Gregory and Lowe (2002).

27.7 Cardiovascular disease

27.7.1 Cocoa flavanols

Chocolate's reputation for promoting good health dates back to the ancient civilizations of the Aztecs and Mayans in South America who drank a frothy beverage of ground cocoa beans beaten together with maize, spices and water. There are many documented medicinal uses for cocoa and chocolate and Europeans continued to use it in this capacity until the beginning of the last century. More recently there has been renewed scientific interest in the health benefits of cocoa and chocolate, mainly in relation to cardiovascular benefits. Epidemiological studies have indicated that the consumption of foods rich in flavanoids are associated with a reduced risk of cardiovascular disease.

Research on chocolate initially focussed on the antioxidant activity of flavonoids but, with increasing knowledge of the mechanisms of cardiovascular disease, it has become clear that their effects are more wide ranging. Cocoa flavanols have the potential to modify a number of processes involved in the initiation and progression of cardiovascular disease which include anti-platelet, anti-inflammatory and antioxidant actions as well as improving the health and functioning of the endothelial lining of the vascular system.

Platelet reactivity and aggregation enhance blood clotting and can lead to thrombosis. Cocoa flavanols can modulate platelet reactivity and reduce the tendency for platelets to aggregate. At normal levels of intake, flavanol-rich cocoa and chocolate have been shown to inhibit platelet activity with effects similar to those associated with low doses of baby aspirin. Heart disease and its risk factors can produce inflammatory reactions and cocoa flavonoids have been shown to suppress pro-inflammatory leukotrienes and increase anti-inflammatory nitric oxide. Nitric oxide is also important for the healthy functioning of the vascular endothelium which regulates the processes to maintain the actions and tone of the blood vessels and endothelium. Endothelium dysfunction and an associated reduction in nitric oxide are key factors in the development of cardiovascular disease. The increase in the production of nitric oxide following the consumption of a flavanol-rich cocoa beverage or chocolate bar has a positive impact on blood vessel vasodilation and improves blood flow. Some studies have demonstrated a reduction in systolic and diastolic blood pressure following the consumption of cocoa or dark chocolate.

Like many polyphenols, flavanols have antioxidant activity and are able to help the body's cells counteract the damage caused by free radicals. It is known that cocoa and chocolate have potent anti-oxidant activity comparable or greater than other anti-oxidant-rich foods such as green and black tea, red wine, blueberry, garlic and strawberry.

Those with raised low-density lipoprotein (LDL) cholesterol and low high-density lipoprotein (HDL) cholesterol are at greater risk of coronary heart disease (CHD). Oxidized LDL can injure arterial walls, which may ultimately lead to plaque formation and atherosclerosis. Feeding studies have demonstrated the ability of cocoa and dark chocolate to decrease the susceptibility of LDL-cholesterol to oxidation.

The mechanisms behind the potential benefits described above may also provide other health benefits. Research is beginning to show how there could be positive effects on renal function, cognition, immune function, insulin sensitivity and diabetes, exercise performance and oral health.

27.7.2 Cocoa butter

Studies have shown the effect of cocoa butter on blood cholesterol levels relative to cow's butter, beef fat and olive oil to be as predicted from their fatty acid compositions. Butter and beef fat have greater amounts of medium chain saturated fatty acids than cocoa butter. Olive oil has a much higher proportion of oleic acid and is low in saturates. In patients with raised cholesterol levels, compared with cow's butter, cocoa butter lowers LDL-cholesterol and compared with olive oil raises it. Stearic acid does appear to lower HDL-cholesterol relative to mono-unsaturated and poly-unsaturated fatty acids, but there is no evidence that this difference is large enough to be translated into an increased risk for CHD.

The specific effects of consuming milk chocolate have also been investigated. Subjects fed a diet containing 280 g (10 oz) chocolate per day, which supplied 81% of the total fat (37% of total energy), and providing 20% of total energy as saturated fatty acids, experienced a neutral response in blood cholesterol levels in comparison with their normal diet, which supplied 14% of total energy as saturated fat. In another study a 46.6 g (1.6 oz) bar of milk chocolate was substituted for a high carbohydrate snack of equal caloric value in a cholesterol-lowering diet, increasing the total fat content of the diet from 30% to 34% of the energy. This resulted in no significant differences in total or LDL- cholesterol, but HDL- cholesterol was significantly greater.

Studies also show that stearic acid has no adverse effects on thromogenic factors in humans.

27.8 Sugar

27.8.1 Sugar and calories

Sugar, or sucrose, is made up of two other sugars – glucose and fructose (Chapter 3). All digestible sugars provide 4 kcal (16 kJ) per gram, the same as the other major digestible carbohydrate in our diet, starch. Carbohydrates are less energy dense than fat (9 kcal/37 kJ per g) or alcohol (7 kcal/29 kJ per g). The relationship between sugar and obesity is covered in Section 27.9.

27.8.2 Insulin and diabetes

Sugar has a moderate GI and chocolate a low GI (see Section 27.2.2). Consumption does not produce reactive hypoglycaemia, which is when there is a very high insulin response followed by a rapid fall in blood glucose to below fasting levels.

No dietary cause has been found for insulin-dependent type 1 diabetes, the onset of which is usually in young people. There is a strong genetic predisposition to the more common type 2 diabetes of adulthood, but environmental influences are the key to whether the condition manifests itself. Being overweight is the most important risk factor, but other factors include lack of physical activity, low fibre diet, high intake of *trans* fats and low unsaturated:saturated fatty acid ratio. No association has been found with sucrose consumption.

27.8.3 Dental health

Dental health has improved dramatically over the last 35 years, so that in the UK today half of 15 year olds and over 60% of 12 year olds have no dental decay at all. Amongst those with decay, in 15 year olds an average of three teeth are affected and in 12 year olds an average of two teeth are affected. The proportion of sound teeth amongst young adults is also increasing and older adults are keeping their own teeth for longer. During this time confectionery consumption has increased.

Nowadays, the three main factors important for good oral health are fluoride toothpaste, good oral hygiene to remove plaque and good salivary flow. Only in the absence of any of these will a fourth factor, diet, have a major influence.

Tooth decay or dental caries is the progressive destruction of tooth enamel and underlying structure by acids. These acids are by-products of the breakdown of dietary carbohydrates (both sugars and starches) by oral bacteria found in dental plaque. The more frequently carbohydrate containing foods are consumed, the more often acids are produced and the less time available for saliva to initiate the neutralizing and repair processes that go on between eating occasions. In the presence of fluoride, teeth seem able to withstand up to seven acid attacks per day.

As chocolate contains sugar, it lowers the pH in the mouth and has the potential to contribute to the cariogenic process (formation of caries). However, relative to other sugar and starch-rich foods this seems to be fairly moderate. This may be due to a combination of factors, including the moderate acidogenicity of chocolate, its low retention time in the mouth compared to food containing cooked starches and the presence of cocoa polyphenols and other ingredients with cariostatic properties. Cocoa flavanols have been shown to reduce plaque deposition through anti-bacterial and anti-enzymatic activities. Milk in chocolate can also contribute to reduced cariogenicity by its buffering effects (ability to control acidity).

27.8.4 Hyperactivity in children

Scientific studies have demonstrated that the consumption of sugar and sugar containing products does not contribute to hyperactivity.

Similarly, there is no evidence to link chocolate or chocolate confectionery consumption with hyperactivity. Scientific reviews, which have considered the available published evidence, have also found no consistent association between food colours, or other food additives, and hyperactivity.

27.9 Obesity and weight management

Obesity is a contributory factor in a large number of conditions such as type 2 diabetes, coronary heart disease, some cancers, osteoarthritis, gallstones, disturbed sleep, reproductive and psychological disorders. People with central obesity ('apple' shaped), where fat accumulates around the abdomen, are at greater risk of diabetes and coronary heart disease than those whose excess fat is distributed on the limbs ('pear' shaped). The increasing incidence of obesity is of concern since it brings increased morbidity and enormous financial costs to the health service and to the wider economy through lost productivity. Of particular concern is the increase amongst children.

Obesity occurs when energy intake from food exceeds that expended through daily activities over a period of time and the body stores the excess energy as fat. Genetics is an important factor, especially in determining fat distribution, and may account for between 18% and 50% of the variance. However, since there has been a rapid increase in the prevalence of obesity whilst the genetic pool has remained fairly static, environmental factors, especially those related to diet and physical activity, are clearly important.

27.9.1 Diet

Although some individuals are more at risk of developing obesity than others due to genetics and lifestyle, the underlying reason why people put on weight is because they eat more food than they need. Diet composition can influence whether intake is matched to needs. The amount of fat and carbohydrate/sugars, energy density, alcohol, protein and eating frequency may all play a part.

Surveys of diet and body weight show that there is an inverse relationship between the proportion of total calories from sugar and body fatness. A dietary predictor of obesity is the fat: sugar ratio. Those whose diets contain the greatest proportion of fat and the smallest proportion of sugar are more likely to be obese. Fat intake is linked to obesity for a number of reasons. It appears to be less satiating and more easily converted into body fat than carbohydrate, but most importantly it is energy dense, providing 9 kcal (37 kJ) per gram compared to carbohydrate and protein which both provide 4 kcal (16 and 17 kJ respectively) per gram.

It has been suggested that the energy density of diets, which is mainly related to water content of food (water having weight but zero calories) and to a lesser extent fat content, has a more important role in obesity than just the amount of fat. However, most of the studies have been based on laboratory and clinical studies and population cross-sectional studies have produced conflicting results. So, although energy density may be more important than fat alone, the evidence is not clear-cut.

27.9.2 Snacking, chocolate and energy dense snack consumption

Observational studies examining the relationship between eating frequency (number of meals/snacks per day) and body weight either fail to find a relationship or find an inverse relationship. Positive relationships have not been found, even when under-reporting has been taken into account. Intervention studies are few and difficult to carry out. Those that have been done suggest that, in the short term, those who habitually eat only three meals per day do have difficulty fully compensating for additional snacks added to their diet and may gain weight in the short term, but regular snackers compensate, mainly by reducing the amount of other snacks.

Dietary surveys have failed to find specific associations between the consumption of sweet energy dense foods, such as chocolate confectionery, and overweight or obesity. For example data collected for the UK National Diet and Nutrition Survey of Young People aged 4–18 years showed that although overweight and obese children ate a greater quantity of chocolate, cakes and biscuits, these foods contributed the same proportion of total energy to their diet as to the diets of their normal weight peers. Overweight children ate more food in total, but were no more likely to over-consume chocolate, cakes and biscuits than any other sources of energy. Amongst this cohort of 1294 children, measures of physical activity and inactivity were greater predictors of overweight and obesity than diet.

Recent USA studies, and a systematic review across 34 countries, also failed to find relationships between snack food consumption and body mass index (weight in kilograms divided by the square of height in metres – kg/m^2) in children and adolescents. When measured, physical activity levels are usually lower and television viewing times higher, in the overweight compared to normal weight children.

The conclusion from the available literature indicates that chocolate confectionery is not uniquely 'fattening' and its consumption is unlikely to lead to obesity, unless large amounts of calories from other foods are also consumed. Nevertheless chocolate is energy dense, so those on a calorie-controlled diet, to shed excess weight, will need to limit consumption.

27.9.3 Energy expenditure

Over recent years total calorie consumption has declined, whilst body weights have increased due to our increasingly sedentary lifestyles. Until recently it has been difficult to measure habitual activity and hence demonstrate any direct link between obesity and levels of physical activity. At a population level, the amount of time spent in sedentary activities, such as watching television or sitting at an office desk, could have as great an impact on the prevalence of obesity as the amount of time spent doing voluntary intense physical activity, such as sports and gym work-outs. Obesity management usually combines advice on dietary restriction and physical activity.

Physical activity has many other benefits apart from helping in weight control. It has been shown to reduce the risk of coronary heart disease, type 2 diabetes, high blood pressure, some cancers and osteoporosis, as well as improving psychological well-being and mental health.

27.10 Other health issues

27.10.1 Acne

Acne vulgaris is an inflammatory skin condition caused by an increased production of sebum by the sebaceous glands, generally due to hormonal changes. There are few recent studies on chocolate, but one conducted 35 years ago on 65 subjects with moderate acne demonstrated no worsening of acne when consuming chocolate compared to consuming a placebo. Despite widespread beliefs to the contrary, doctors agree that fatty foods and chocolate consumption do not cause acne.

27.10.2 Migraine and headaches

Stress, disturbed sleep, hunger and hormonal changes commonly trigger chronic headaches such as migraines in susceptible individuals. Vasoactive amines, such as tyramine, histamine and phenylethylamine, are found in a number of foods that have been linked to headaches, including aged cheeses, processed meats, chocolate, peanuts and red wine. These amines can affect blood vessels in the brain, triggering a migraine in individuals that are sensitive to the amine. The migraine episode is thought to be associated with an initial period of vasoconstriction (often associated with visual flashing lights) followed by a reactive vasodilatation that is responsible for the sensation of throbbing pain.

Chocolate contains relatively large amounts of phenylethylamine and is frequently blamed for triggering a migraine attack. However, recent studies indicate that chocolate alone is rarely able to precipitate migraine headaches, particularly when eaten in amounts equivalent to an average-sized chocolate bar. Although many migraine sufferers report an association between chocolate consumption and headache, it is only in a small proportion that it is likely to be a trigger.

The situations which precede headaches are often those which induce cravings for sweet foods which are satisfied through eating chocolate, which explains why chocolate was thought to be causal. It is now accepted that chocolate is rarely the primary cause of headaches or migraine.

27.10.3 Allergies

Allergy to cocoa is rare. However, allergies to other proteins found in chocolate products, such as milk, nuts and wheat, are more common. Some people may also be intolerant to lactose in the milk and gluten from wheat.

27.10.4 Chocolate and mood elevation

The consumption of chocolate is widely believed to promote feelings of well being and sensory pleasure. 'Cravings' for chocolate are commonly reported, particularly in women during the premenstrual phase and often occur at times of emotional stress, such as boredom, depression or anxiety. Chocolate may be consumed on these occasions in the belief that it can improve mood and reduce tension.

A number of theories have been put forward to account for the apparent mood-elevating properties of chocolate. It has been suggested that the carbohydrate in chocolate increases the ratio of tryptophan to other large amino acids in the blood, resulting in increased synthesis of brain serotonin. However this is unlikely since, levels of protein in chocolate are too high for this mechanism to function and, any potential effect on mood would involve a time delay whereas the actual effect of eating chocolate is almost immediate.

27.10.5 Chocolate 'addiction'

Attempts to restrict the intake of chocolate can increase the desire for it, which when sufficiently intense becomes a chocolate craving. Those who call themselves a 'chocoholic' probably have this craving rather than a true addiction. It has been suggested that a true addiction could exist due to the presence of various chemicals such as 'brain cannabinoids' (anandamide), methylxanthines and phenylethylamine (see Section 27.5.2). However, these substances are unlikely to cause any addiction, because they are not present in great enough quantities and there is no scientific support for any effects on the brain when they are consumed orally.

Research has shown that chocolate cravings are not satisfied by the pharmacological constituents of cocoa and chocolate and that the desire can only be satisfied by chocolate itself, suggesting that it is the sensory properties of chocolate that are important for the overall pleasurable experience.

Conclusions

Chocolate is known for its 'naughty but nice' image. Whilst few would dispute that it is a pleasant food to eat, evidence for any negative effects on health is lacking. There is no good scientific support for direct links between chocolate and obesity, diabetes, dental caries, hyperactivity, acne or migraine. It does however provide valuable nutrients to the diet and recent evidence points to cocoa flavanols having some positive health benefits.

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Chapter 28

CHOCOLATE MARKETING AND OTHER ASPECTS OF THE CONFECTIONERY INDUSTRY WORLDWIDE

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28.1 Introduction

Cacao was named *Theobroma* by Linnaeus, the word meaning 'food of the gods', so called from the goodness of its seeds. Mexicans named the pounded seeds 'Chocolate'. Modern consumers share the ancients' appreciation for products made from cocoa beans. Chocolate or cocoa powder are present not only in confectionery, but also in a wide range of other foods including biscuits, cakes, ice cream, hot drinks and even some speciality beers. As for confectionery, far more chocolate is eaten in the form of filled or covered bars than as block chocolate which, in the UK, accounts for less than 20% of the total chocolate products sold.

Chocolate is therefore part of the food industry as a whole, but for 150 years or more it has been associated with sugar confectionery for marketing, administrative and legal purposes, as an industry in its own right. This chapter therefore concerns itself with the confectionery industry as a whole.

Chocolate confectionery accounts for 67% by volume and 73% by value of the current UK confectionery market. In Germany the preponderance of chocolate is slightly greater: it represents 68% of consumption, and the figure for France is 66%. For the EU as a whole chocolate accounts for over 59% of confectionery consumption. It is only in Denmark, Finland and the Netherlands where more sugar confectionery than chocolate is consumed. In the USA, where the warmer summer climate provides a less favourable environment for chocolate, sugar confectionery represents just under 53% of the total.

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*Based on Nutall, C. and Hart, W.A. (1999).

Industrial Chocolate Manufacture and Use: Fourth Edition. Edited by Stephen T. Beckett
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Table 28.1 Some ingredients used in confectionery products, and their sources.

Ingredient	Source
Cocoa	A principal crop in West African countries such as Ivory Coast and Ghana
Sugar (from cane)	Important to Caribbean countries and some other tropical islands
Hazel nuts	Turkey is the biggest supplier to the EU
Coconut	Important to Sri Lanka and the Philippines
Liquorice	From Iran, Afghanistan, Russian, China and Turkey

'Confectionery' is the collective term applied to edible products in which sugar is usually a key ingredient, although as we shall see later sugar-free confectionery has a growing share of the market. Most confectionery products contain, in addition to sugar, one or more of the following: cocoa and its derivatives; milk and other dairy ingredients; fats; nuts; pieces of biscuit etc. However products in which flour is the main ingredient (such as cakes or biscuits) are outside the scope of this chapter. The range of confectionery products is wide, offering consumers different flavours and textures and, in sugar confectionery, a variety of colours.

The confectionery industry is an important user of agricultural products, particularly those from developing countries as is shown in Table 28.1. Tropical countries depend heavily on the demands of confectionery manufacturers and temperate areas supply sugar (from beet), glucose, milk and dried fruits.

Confectionery eating is widespread. In many of the more highly industrialized countries nearly all the population have eaten it at some time and some 94% buy it regularly. This means that the industry is supported by a wide range of retail outlets, as will be shown later in the chapter. In the UK about 46% of confectionery is bought by women and about 16% by children, though they eat 32% of the total.

Confectionery products are foodstuffs, supplying nutrients to the human body. From their earliest days, however, they have seldom been eaten at mealtimes and are not regarded in the same way as bread, meat and other staple foods. Instead they offer the convenience of nourishment 'on the go' for those with busy lives, and their pleasurable taste and texture make them ideal as treats or gifts. The consumption of snack-foods accounts for about one quarter of consumer spending on food and confectionery competes directly with other forms of snack-foods. A measure of its success in doing so is that UK consumer spending on confectionery is equal to the combined total spent on bagged snacks, biscuits and ice cream.

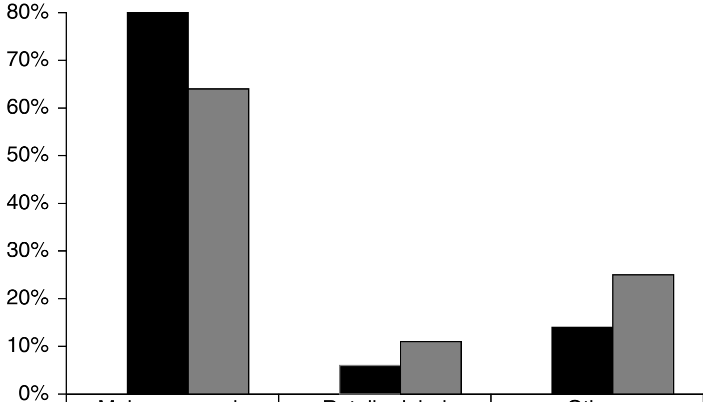
28.2 Characteristics of the market

The UK markets for chocolate and sugar confectionery exhibit a number of differences. Chocolate is dominated by branded products, and the three largest multi-national companies have between them over 80% of the market. In addition there are specialist manufacturers, who also supply branded products, albeit in smaller quantities than the mass produced offerings of the major manufacturers. Retailer own-label chocolate products occupy less than 7% of the market. The strength of the major chocolate confectionery brands is well illustrated by a comparison with chocolate biscuits where retailer own labels occupy 31% of the market.

For sugar confectionery, five multi-national companies are important players and between them they occupy 64% of the market – a significantly smaller share than that of the three major chocolate manufacturers. Several medium size companies have significant shares, either making branded products or retailer own-label products.

Figure 28.1 summarizes the UK market shares in chocolate and sugar confectionery.

Having noted the strength of the chocolate confectionery brands it is also important to be aware of their longevity. The ten best-selling single bar lines have a combined age of over 400 years and they generate over one third of the total sales. All three major chocolate producers have highly successful heritage brands, including, but not restricted to, Cadbury's Dairy Milk range (introduced in 1905), Masterfoods Mars bar (Milky Way in the USA) (1932), and Nestlé Rowntree's KitKat (1935). Very few of the new introductions of the past 20 years have established and retained their place in the top 20 products. There is indeed some similarity with the market for ladies' clothing, which has a strong base of fashion classics and a succession of shorter lived high-fashion items, which sell very well but for only a relatively short time.



	Major companies	Retailer labels	Others
■ Chocolate	80%	6%	14%
▨ Sugar confectionery	64%	11%	25%

Figure 28.1 Shares of the UK confectionery market.

Chocolate sales depend heavily on events such as Christmas and Easter and are also affected by the weather. As a result the market is very seasonal – chocolate sales in December are twice those of January. Boxed assortments are especially seasonal – for example almost half of boxed chocolate mint sales are achieved in the last twelve weeks of the year. In the UK over 30 000 tonnes of Easter Eggs are sold, with a consumer value of £370 million. The seasonality of chocolate sales is also affected by the weather – a warm summer results in significantly lower sales.

28.3 A short history of the industry and its products

The first surviving references to sugar-containing products were written down in ancient Persia about 2500 years ago. Middle Eastern civilizations before the Christian era developed types of sweets, still sold today, such as sugared almonds, Turkish delight and *fruits confits*. Products such as these were taken westwards by the Muslims and later by the Crusaders. As sugar became more plentiful in Western Europe in the sixteenth and seventeenth centuries, apothecaries began to 'sugar the pill', and discovered a demand for confections that left out the medicine. Some of the work of these early entrepreneurs resulted in major businesses, such as Terry's of York and Dunhill's of Pontefract.

In the early nineteenth century the steam engine was harnessed to manufacture sweets on a bigger scale and the availability of glucose and condensed milk made possible the development of boiled sweets, toffees and fudges. Urban populations were expanding rapidly in Europe and incomes, though still low, were increasing, allowing a network of retailers to become established in the factory towns. Rising levels of literacy encouraged advertising.

Until the Spanish invasions, the cocoa bean formed the basis of both staple and ceremonial products in Central America. On being brought to Europe it gained popularity as a drink. It was not until the nineteenth century that methods were developed, in The Netherlands, France and Switzerland, to make chocolate as we now know it. At first only plain (dark) chocolate was produced and was used to coat nut or fondant centres for the luxury trade. Then UK firms, particularly Cadbury, developed lower cost methods for making products that appealed to a wider market – first boxes of chocolates, then chocolate bars. The popular filled (composition) bar emerged in the USA in about 1910.

In the twentieth century social circumstances, such as the rapid growth in the population of the developed world, rising consumer incomes and increased mobility, favoured the expansion of the confectionery industry. Throughout Europe, North America, the former British dominions and in parts of the former USSR, consumption increased until, by 1939, annual consumption generally exceeded 6 kg per head in these areas. During World War II, in several Allied countries the special virtues of confectionery were recognized by its inclusion in food rationing schemes. Meanwhile, the American and British armies introduced confectionery products to many other countries in the world.

Because confectionery products provided an inexpensive luxury, as a relief from diets that were often drab, the industry was one of the first to consider the need for mass production and mass marketing. Rowntree pioneered such work in its factories and Cadbury were one of the first companies to use market research. In both the USA and the UK, Mars developed operational research in the distribution trade. Contributions were made to particular branches of science, such as rheology (viscosity measurement). At the same time, partly because a number of large manufacturers held strong religious beliefs, the industry was one of the first to encourage pure food standards in production. It also pioneered better welfare and development opportunities for its employees. Hershey in the USA followed the example of UK manufacturers in building model towns for employees.

In the early twentieth century, in a notable instance of industrial co-operation, UK and European firms sought better conditions for those employed in cocoa production and encouraged the establishment of cocoa growing by smallholders in West Africa. The issue of unsatisfactory working conditions for some of those engaged in cocoa growing was to recur in the late twentieth century and was again to be met by concerted action by the global chocolate industry.

Following post-war austerity and the end of rationing there was a rapid rise in confectionery consumption, but since then in the UK and many other developed countries average consumption per head has risen very slowly. During this period the industry's main scope for increased sales has been through development of products with higher added value. Rising incomes favoured chocolate consumption and that increased its share of the confectionery market to the point where, in the UK, by the end of the twentieth century it represented 73% by value of the confectionery market.

European firms were the first to export chocolate and sugar confectionery to other countries and to set up factories overseas. While exporting is still important, and within the EC it is on the increase, local production is better able to meet demand as the world market grows in size and complexity. Many of the major brands are now global, appearing identical in whichever country they are offered, although sometimes differing in recipe to meet local requirements. Some of the countries that received western European exports in the past have now returned the compliment so that some of the products sold in Western Europe are now manufactured in countries where manufacturing costs are lower.

28.4 Consumption of confectionery around the world

An annual Statistical Bulletin is collated and published by CAOBISCO, the organization of confectionery trade associations within the EU. The Bulletin is compiled in association with the CAOBISCO Statistics Network and the International Confectionery Association (ICA). The Bulletin brings together data on biscuit and confectionery products in the EU, Switzerland, Norway and other members of the ICA (USA, Canada, Australia, Japan and Brazil). In order to harmonize the figures it collects from its member associations, CAOBISCO draws data from PRODCOM (PRODucts in the COMmunity), as reported officially by EUROSTAT (The statistical office of the EU based in Luxemburg).

Ensuring an accurate, comprehensive and coherent set of statistics is no easy task, but the diligence of CAOBISCO itself, together with that of its members and those of ICA, ensures that the figures are as accurate and comparable as can reasonably be achieved. In this task they are aided by the existence of the world-wide Harmonised System of classification, which appears in greater detail in Section 28.7.

Tables 28.2–28.4 are reproduced by kind permission of CAOBISCO and show by country the tonnes of production of sugar confectionery, chocolate, and biscuits (including certain other baked products) for the years 1999–2004.

Table 28.5 shows for each of the three categories the total number of tonnes eaten in the ten highest consuming countries. It also shows in kilograms how much the average person consumes in a year. Figures are shown for 1999 and for 2004, so it is possible to see whether consumption has been increasing or decreasing. The total tonnages for consumption were derived using the formula:

(production – exports) + imports = consumption (tonnes)

and the average consumption per head was obtained by expressing that tonnage in kilograms and dividing that by the population.

It is worth noting that the figures quoted here are for tonnages. From time to time reports appear in the press suggesting that the increase in consumption has been considerably larger. Invariably such reports are based on consumer spending on the industry's products and therefore reflect the tendency for average values per tonne to increase over time.

The CAOBISCO/ICA 80 page Statistical Bulletin contains a wealth of data on the industry and its international markets. Readers with an interest in these subjects can obtain details from their national trade association or direct from CAOBISCO.

Many national trade associations can provide more detailed breakdowns of the tonnages of particular product types and can offer time series going back many years. For example, in the UK the Biscuit Cake Chocolate and Confectionery Association has been measuring the industry's performance since 1953 when sweet rationing was abolished. Details are available from www.bccca.org.uk.

Table 28.2 Production of sugar confectionery (metric tonnes).

Countries	1999	2000	2001	2002	2003	2004
EU15						
Austria	23 775	21 075	17 875	21 070	22 940	24 705
Belgium	61 950	65 110	70 865	69 555	67 745	66 690
Germany	431 950	446 080	475 055	509 575	516 410	458 025
Denmark	49 920	51 540	52 290	51 820	54 010	56 065
Spain[a]	193 500	205 730	214 875	215 240	209 250	204 100
Finland	25 815	28 275	30 340	32 460	32 895	33 650
France	194 370	208 190	208 410	213 060	196 855	202 470
Greece	16 850	15 770	15 485	16 055	15 470	15 315
Italy[a]	121 600	122 800	121 000	118 200	117 900	117 300
Ireland[b]	715	715	145	1 020	850	1 760
Netherlands	121 300	116 080	131 135	139 485	150 675	146 375
Portugal	9 815	9 330	8 945	8 200	8 480	7 950
Sweden[c]	43 835	49 075	41 775	40 680	49 260	7 135
United Kingdom[c]	309 760	287 045	274 380	244 885	248 515	249 840
Total EU15	1 605 145	1 626 815	1 662 575	1 681 305	1 691 255	1 601 410
EFTA						
Switzerland	23 450	23 770	22 570	23 270	25 130	26 940
Norway	8 540	7 490	9 005	8 670	7 360	7 935
Total EFTA	31 990	31 260	31 575	31 940	32 490	34 875
ICA						
Australia	79 500	83 075	85 734	78 115	82 020	84 480
Brazil	438 000	464 000	467 000	463 800	477 000	509 000
Canada[d]	121 000	121 000	138 000	145 000	145 000	145 000
Japan	196 700	193 600	194 600	201 100	207 800	207 100
USA	1 541 475	1 530 170	1 385 040	1 322 705	1 312 725	1 308 390
Total ICA	2 376 675	2 391 845	2 270 374	2 210 720	2 224 545	2 253 970
Grand Total	4 013 810	4 049 920	3 964 524	3 923 965	3 948 290	3 890 255

[a] Figures provided by National Associations.
[b] No details of production by type are available.
[c] Please note alternative figures are available from the National Association.
[d] Provisional figures 2003 + 2004 (2002 figures).

28.5 Reasons for eating confectionery

Confectionery is eaten all over the world quite simply because people find pleasure in it. Through its taste and texture there is probably no other product that gives so much enjoyment to so many individuals in so many countries. Chocolate and sweets bring colour and excitement into everyday lives and throughout adult life continue to symbolize gaiety, festivity and good will. Confectionery is fun, and the range of products and prices is such that its enjoyment is within the reach of almost everybody.

Table 28.3 Production of chocolate confectionery (metric tonnes).

Countries	1999	2000	2001	2002	2003	2004
EU15						
Austria	55 665	56 860	63 030	56 175	55 285	68 150
Belgium	160 995	173 665	171 605	195 850	196 405	218 765
Germany	874 590	897 985	921 725	963 235	985 940	1 075 965
Denmark	28 465	29 395	32 995	30 365	31 180	33 400
Spain[a]	111 780	116 725	123 735	124 625	123 625	123 065
Finland	35 490	34 840	34 750	34 750	33 700	33 320
France	370 800	370 180	375 180	386 650	376 625	398 195
Greece	27 000	28 200	29 000	29 700	30 500	31 750
Italy[a]	212 550	216 400	224 050	241 400	245 350	256 700
Ireland[b]	4 610	3 775	5 435	1 150	5 235	915
Netherlands	127 365	149 505	153 755	116 145	137 900	160 640
Portugal	4 165	4 155	3 910	3 475	2 000	1 790
Sweden[c]	69 280	74 485	74 540	74 165	70 270	23 720
United Kingdom[c]	496 685	501 945	494 030	489 275	518 570	475 410
Total EU15	2 579 440	2 658 115	2 707 740	2 746 960	2 812 585	2 901 785
EFTA						
Switzerland	110 505	116 410	119 915	121 480	118 185	127 980
Norway	32 475	27 690	30 945	28 950	30 300	31 250
Total EFTA	142 980	144 100	150 860	150 430	148 485	159 230
ICA						
Australia	119 980	123 560	126 050	99 020	101 990	105 050
Brazil	309 300	318 000	327 000	336 100	339 200	423 200
Canada[d]	133 000	137 000	145 000	135 000	135 000	135 000
Japan	224 215	239 650	245 415	235 920	243 560	243 830
USA	1 458 790	1 492 870	1 478 450	1 508 635	1 520 675	1 500 935
Total ICA	2 245 285	2 311 080	2 321 915	2 314 675	2 340 425	2 408 015
Grand total	4 967 705	5 113 295	5 180 515	5 212 065	5 301 495	5 469 030

[a] Figures provided by National Associations.
[b] No details of production by type are available.
[c] Please note alternative figures are available from the National Association.
[d] Provisional figures 2003 + 2004 (2002 figures).

Confectionery supplies energy and is often eaten when the body signals some need for it. If the immediate energy resources of the body become deficient due to exercise or lack of regular food intake, the sugars in confectionery provide one of the quickest ways of restoring the balance. This energy is packed into a small volume, so it is easily portable and can be eaten almost anywhere and at any time. Some of the industry's products are designed for consumption by one person at one time, such as a Mars bar (Milky Way), whilst others, such as block chocolate, allow for sharing or for consumption over an extended period of time.

Table 28.4 Production of biscuits and other baked products (metric tonnes).[a]

Countries	1999	2000	2001	2002	2003	2004
EU15						
Austria	127 940	132 115	130 790	153 975	155 670	139 755
Belgium	261 720	267 910	270 280	282 615	269 145	287 390
Germany[b]				816 870	791 410	803 735
Denmark	105 625	112 440	119 080	123 365	131 115	139 845
Spain[c]	448 475	459 055	484 950	490 645	473 505	485 185
Finland	80 610	78 260	82 040	75 795	79 280	79 535
France	730 345	733 345	743 785	747 800	721 075	713 560
Greece	75 620	69 525	77 175	83 160	84 760	86 935
Italy[c]	849 400	863 200	876 600	904 700	910 750	924 300
Ireland[d]	34 610	31 900	91 945	43 545	69 690	58 860
Netherlands	389 400	371 250	328 725	325 600	309 545	349 075
Portugal	87 285	93 470	106 940	101 975	105 150	118 645
Sweden[e]	132 805	129 315	142 565	162 795	143 075	107 795
United Kingdom[e]	2 091 265	1 894 380	2 036 030	1 959 905	2 155 185	2 298 665
Total EU 15	5 415 100	5 236 165	5 490 905	6 272 745	6 399 355	6 593 280
EFTA						
Switzerland	45 255	46 000	47 175	44 810	45 540	46 570
Norway						
Total EFTA	45 255	46 000	47 175	44 810	45 540	46 570
ICA						
Japan	218 800	223 000	218 300	209 700	218 800	214 300
Total ICA	218 800	223 000	218 300	209 700	218 800	214 300
Grand total	5 679 155	5 505 165	5 756 920	6 527 255	6 663 695	6 854 150

[a] *These Totals include:*

1. Gingerbread and the like
2. Chocolate-coated biscuits/wafers
3. Other sweet biscuits
4. Crispbreads and the like
5. Rusks, toasted bread & similar products
6. Matzos
7. Salt or savoury biscuits and the like
8. Extruded snacks
9. Cakes and pastries (fine bakers' wares) including national specialities

[b] Production data not available for the years 1999–2001.

[c] Figures provided by National Associations.

[d] No details of production by type are available.

[e] Please note alternative figures are available from the National Association.

Note: no figures available for the biscuits & baked goods sector in Norway, USA, Australia, Brazil and Canada.

A second, perhaps less obvious, reason why people buy confectionery is the need for one person to transmit to another, by way of a physical object, some element of feeling – such as affection, gratitude, hospitality, even remorse. Confectionery makes a very acceptable gift. The traditional gift product in English speaking countries is a box of chocolates; in

Table 28.5 Consumption figures for the top 10 consumer countries for each product category (data extracted from six separate tables from CAOBISCO/ICA, 2006).

	Tonnes consumed		**Consumption kg/head**	
Country	**1999**	**2004**	**1999**	**2004**
Sugar confectionery				
Netherlands	79 675	102 800	5.01	6.35
USA	1 737 390	1 741 365	6.26	5.92
Germany	403 965	461 635	4.92	5.23
Australia	76 030	100 295	3.98	4.96
UK	283 990	288 280	4.85	4.87
Belgium	39 225	46 175	3.84	4.44
France	202 815	225 765	3.47	3.75
Canada	90 000	109 000	3.00	3.40
Austria	26 920	27 650	3.32	3.38
Switzerland	22 710	24 385	3.17	3.27
Spain	122 605	118 800	3.09	2.69
Chocolate				
Germany	805 925	917 905	9.82	11.13
Switzerland	75 075	80 480	10.48	10.80
Austria	60 730	82 710	7.49	10.12
Belgium	81 215	98 690	7.95	9.49
UK	516 860	556 720	8.84	9.40
Norway	37 795	42 350	8.44	9.19
Denmark	42 620	47 185	8.00	8.72
Finland	30 970	36 195	6.00	6.92
France	404 090	438 955	6.91	7.29
USA	1 492 860	1 556 175	5.38	5.29
Biscuits				
UK	836 340	927 025	14.30	15.65
Netherlands	232 125	234 700	14.60	14.49
Italy	453 375	518 640	7.94	8.97
France	509 205	539 075	8.70	8.95
Switzerland	48 350	60 370	6.75	8.10
Belgium	111 460	83 125	10.91	8.00
Finland	41 430	41 415	8.02	7.92
Portugal	63 295	78 460	6.36	7.89
Germany	N/A	645 825	N/A	7.83
Denmark	40 935	42 110	7.68	7.78
USA	N/A	N/A	N/A	N/A

Note:
The sugar confectionery figures include: chewing gum; boiled sweets; toffees, caramels and similar sweets; gum and jelly confectionery including fruit pastes; and other types of confectionery.
The chocolate figures include: unfilled chocolate; filled tablets and bars; bonbons, pralines and other chocolate confectionery; sugar confectionery containing cocoa; white chocolate; spreads containing cocoa; and sweetened cocoa powder.
The biscuit figures include: gingerbread and the like; chocolate-coated biscuits and wafers; other sweet biscuits; crispbreads and the like; rusks, toasted bread and similar products; matzos; and salt or savoury biscuits and the like.

continental Europe it is a box of *fruits confits*. Each of these has characteristics of high product quality, where the excellence of the packaging is important and where the labour cost of production is high. These factors give an impression of luxury, which expresses the degree of caring. There is demand for such products throughout the year, but there are peaks at various times in different countries. In the UK the chocolate egg is a symbol of Easter. In the USA and UK Mother's Day and Valentine's Day are occasions to be marked. Almost everywhere, specially designed boxes are produced for Christmas.

Confectionery is often bought as treats for children, in the USA especially at Halloween. The more expensive products are often bought by adults for own consumption or for sharing. Products such as chocolate mints and *petits fours* form part of a meal on special occasions. A world-wide demand, which springs from humans' natural liking for sweet things, is met by a wide variety of products: at one end by artistic hand-made products; at the other by items manufactured on highly automated plant for sale by the million each day.

Recent research has shown that the eating of chocolate, in particular that containing high levels of polyphenols, can have significant benefits in reducing the chance of heart disease. This, together with other aspects of chocolate nutrition, is described in detail in Chapter 27.

28.6 The marketing of confectionery

When George Cadbury took responsibility for the business in 1860 his ambitions were:

> To manufacture a better product than competitors; to distribute it widely; and to advertise it so that people knew it was there. (Williams, 1931)

It remains one of the most concise and comprehensive summaries of the marketing function.

If they are to survive, confectionery products must be formulated to eat well. The product must be designed – and redesigned from time to time – to fulfil the functions required by the identified market. Continuous market research is carried out on the numbers and classes of purchasers and consumers, on the products they buy and eat, and on when and where the purchasing and eating takes place. This provides a matrix of information on which decisions can be taken; from detailed changes to the formulation, price or packaging of an existing product, to the choice of new markets and new products.

A new product, or an improvement to an existing product, can arise in two ways:

- technical staff can bring forward a new combination of ingredients, flavours and colours for which a set of consumers may subsequently be identified by product development specialists; or

- those specialists can identify a market sector worthy of attention and ask the technical staff to formulate a product.

It is standard market research practice to seek out those sectors of the buying and eating population whose needs are not covered adequately by existing products, or where competition is weak or non-existent. By a succession of product tests on potential consumers the concept and formula can be revised, culminating in a full-scale test involving every aspect of commercial selling. This includes price, trade terms and advertising, all of which must be evaluated before taking the final decision for full product launch.

The final product offered will result from consideration of factors including:

- fundamental rules on taste and texture for the chosen market;
- the primary function of the product: energy-giving versus high-taste/low volume, own consumption, sharing, or gift – and preferably fulfilling more than one of these functions;
- portion size or sizes, and the number of units to be offered in each pack size;
- price per unit weight and unit price.

The whole area of product style will have to be considered, covering the packaging, display characteristics and advertising. Each of these factors will have to be consistent with:

- the economic and social characteristics of the chosen market;
- the efficiency of the packaging in transit and storage;
- legal requirements on formulation and labelling.

Costings will be made and related to expected selling prices, while the form, content and media to be employed for advertising will have been determined almost as early as the product design. A fundamental decision will be whether or not to give the product a brand name, as opposed to accepting a generic product name or a collective house name.

All the above factors interact, and all the tasks are complex, so the final result is often the best compromise that can be achieved. The product development process does not produce one correct answer, so those involved have to exercise their experience and judgement when making decisions. On occasions, when there is a fairly short window of opportunity for a potential product, managers may believe that there is insufficient time to follow the full process and may risk backing their own hunches as to how the product should be formulated, packaged and marketed. Just occasionally such risks prove to be justified!

The market can be considered as two distinct parts. On the one hand are mass produced products, designed for economic manufacture and packaging, offering excellent value for money and sold in very large quantities. On the other are smaller artisan producers making relatively small quantities of specialist products. Often these products are complex, some are hand-made, and almost all occupy niche markets, exploiting gaps left by the major mass producers. They cannot compete on price with the major manufacturers so they must differentiate their products in ways which give them higher perceived value. Currently some organic and fair trade products fall into this category as do products with no artificial colours or flavours, but if demand for such products becomes sufficiently large then there is no inherent reason why they too could not become part of the mass-produced sector.

The arrival on the market of new ingredients also provides an opportunity to launch new products, especially if these meet a need that consumers have already perceived. A good example is to be found with the advent of speciality sweeteners which encouraged production of sugar-free chewing gum. For several years that was the fastest growing sector of the confectionery market and by 2005 chewing gum had achieved almost 10% share of the sugar confectionery market.

In an overall market which is growing slowly manufacturers have used great ingenuity to attract additional custom by expanding their product range. In some instances this has been achieved by exploiting new technology – Fox's Echo (aerated white chocolate on a biscuit all *moulded in a thin layer* of milk chocolate) is an interesting example of what can be achieved in this way. However such introductions require significant capital expenditure, and manufacturers often prefer to use existing technology to make a variant of a current product – for example a milk chocolate wafer biscuit may be offered as a dark chocolate version, or the vanilla cream in the wafer may be replaced with mint or with fruit flavours. Established favourites may also be offered in a different format. Recent examples include KitKat Chunky in which the traditional four-finger bar is replaced with a single bar with a considerably larger cross-section. Great success has also attended the twist-wrap assortments that were launched a few years ago by Masterfoods ('Celebrations' Plate 24) and Cadbury ('Miniature Heroes'). These consist of assortments of miniature versions of popular countlines. The purpose of such variants is to create an additional demand for the product, not to damage the sales of the existing version. Some of the variant versions establish themselves as successful long-term products in their own right, but others are marketed as limited editions to encourage consumers to buy the product during the limited period that it will be available. These rapid variations require a strong new product development capability and flexible production and packaging facilities.

Well-loved brand names also offer the possibility of brand extension in which a different product is offered with the same name as the original confection. Many of the major chocolate confectionery lines are also available as ice creams, cakes or drinks. Confectionery products also appear as components in other products – for example Smarties or M&Ms feature in cookies. Care must be taken when deciding on variants or on brand extension to ensure that the greater variety of products bearing the brand name does not confuse the consumer or in other ways damage the integrity of the original brand. The variants or extensions must be of a comparable quality to the original brand and should appeal to broadly the same segment of the population.

Another approach is to make use of someone else's brand. This occurs in two main ways: Manufacturers may produce supermarket brands where these command consumer loyalty; whereas some manufacturers use licensing arrangements which allow them to market products bearing the names of cartoon or film characters etc.

If, to quote George Cadbury, the company is to offer 'a better product than competitors' it is vital that it should be as fresh as possible at the point of sale. The joy of eating is lost if the product is stale, its taste has faded or its packaging looks tired. Packaging is therefore designed to preserve freshness for as long as possible. Packs are date coded so that distributor, retailer and purchaser can check freshness during storage and at time of purchase. Out-of-date product is usually withdrawn. Many manufacturers employ special staff or agencies to make regular assessments of the state of the product in distribution.

The major multi-national manufacturers are keen to ensure that their products become global brands, instantly recognizable in any of the markets in which they are offered. However local regulations may require subtle changes in formulation and product developers have also to be aware that systems of distribution vary widely. In Western Europe large self-service stores take a substantial proportion of the trade and there are smaller high-class shops selling highly priced confectionery. Other important outlets include:

- in the USA, small convenience stores, often attached to gasoline stations;
- in Australia, the milk bar;
- in the UK the confectioners, tobacconist and newsagent;
- in less well developed countries, market stalls and itinerant vendors.

The intermediate distributor system also varies. In Europe wholesalers usually confine themselves to breaking bulk and supplying small retailers. In the USA the rough equivalent, the jobber, performs more of the marketing function, such as encouraging display and assisting with market research.

Operational research has demonstrated that the level of consumer purchases of any one confectionery product depends on the number of outlets stocking the product.

Over half of confectionery purchases are made on impulse so it is important that opportunities to buy are frequent and widespread. The industry has therefore been adept at finding outlets for its products. The traditional outlet in the UK was the CTN (confectioner, tobacconist and newsagent) and these remain important, but they have long been supplemented by a range of other outlets. These include: vending machines, of which there are some 500 000 in the UK; food service outlets providing annual sales worth £500 million; garage forecourts, off licences, cinemas and theatres. More recent outlets have included mail order, the internet and chocolate clubs.

Important though many of these outlets are, few can match the multiple retailers' supermarkets and variety stores in terms of volume of product moved. In 2002 the multiples accounted for over 44% of the UK market. At most small outlets, confectionery products are mainly bought for immediate consumption, but this is not the case with product bought from multiples. Almost half of that is stored for later consumption at home, with gifts and seasonal purchases making up much of the remainder. It is estimated that less than 20% of product bought from multiple stores is for immediate consumption. For this reason much of what the industry supplies to multiple stores is in the form of multi-packs, variety packs, tubs or tins of twist wrapped assortments and the like. Good merchandising is essential: the right range, attractively packaged and displayed and in the right location within the store. The market is highly competitive so products must offer excellent value for money. For many products this value will be enhanced from time to time by offering vouchers or competitions, or by price discounting by way of special offers such as 'buy one, get one free' or 'two for a new low price'.

Price is, of course, a crucial element in the marketing mix. There are two factors to consider:

- the price per ounce or gram; and
- the price of the unit offered – for example 50 cents.

There are often quite narrow limits of dimensions outside of which the product loses its identity. If changes in the price per gram would take the product outside these limits at an unchanged unit price, then the unit price must be changed. Sales of many confectionery products are directly related to the cost per unit weight, but for products aimed at the gift market the opposite is often true. Within quite wide limits a higher unit price makes gift products appear more attractive, so manufacturers of such lines strive to improve appeal irrespective of its effect on price.

Whatever the outlet – supermarket, small shop, garage, etc. – good display is vital. Research shows that items should be on open display, ready to be picked up by the purchaser. The number of display facings is also important and they should never be allowed to be empty. Manufacturers therefore seek to influence retailers to maintain displays to recommended standards; and some manufacturers also provide their own merchandising staff to assist the retailer.

This review of marketing would not be complete without mention of advertising, be it by television, radio, internet, printed publications such as newspapers or magazines, event sponsorship, or text messages to mobile phones. Television advertising is expensive but can be cost effective. Apart from when a new product is launched, the cost of advertising seldom amounts to more than 5% of turnover. For branded products advertising, packaging and display are all interlinked, each one being planned to enhance the effect of the other two.

28.7 Official classifications of confectionery

Official product classifications were first introduced for national customs authorities, and the current system evolved out of that in 1993, in the form of the European Community Combined Nomenclature (CN) and EUROSTAT's PRODCOM (PRODucts in the COMmunity) system. The other major trading countries have adopted broadly similar systems. The CN and PRODCOM systems distinguish between raw materials, semi-finished products, and finished products. The analysis is based on product type – sugar confectionery is distinguished from chocolate, and within each of those broad categories there is a further breakdown.

Trade associations compile data on despatches by their member companies. In the UK the BCCCA obtains returns covering some 90% of the markets for chocolate, biscuits and sugar confectionery, showing both tonnages and values. Grossing up of these returns enables an accurate estimate to be made of the total market so that companies can see whether the market for particular categories of product is growing or shrinking and their own share of that market.

Data from fourteen national trade associations is fed to CAOBISCO and that organization also has access to the official PRODCOM statistics. It is therefore possible to see not only the size of each national market within the EU but also the amount produced within each participating country. As mentioned earlier, it is also possible to calculate average consumption per head of population in each of the countries for which the despatch statistics are available.

Table 28.6 shows the classifications under which CAOBISCO compiles its statistical review.

Valuable though this information is, it does not provide all that a marketing department requires. It is important to know not just what sort of products are selling well, but also where they are being purchased. Commercial agencies such as A C Nielsen, Taylor Nelson Sofres, and Information Resources Inc (IRI) are valuable sources of such information, though inevitably their data must be collected on a sampling basis and their extrapolations of total market size need to be reconciled against the more comprehensive trade association data on total despatches.

28.8 Legal requirements affecting confectionery

Like other foods, confectionery must comply with national labelling legislation. In the UK this is described in the Food Labelling Regulations (1996 HMSO (2003) and subsequent amendments). A full explanation of these is outside the scope of this book, but briefly they require pre-packed foods to carry a label showing: the name of the food; a list of ingredients; the quantity of certain ingredients or categories of ingredients; the appropriate durability

Table 28.6 The headings used in the CAOBISCO/ICA statistical bulletin (extracted from three separate CAOBISCO tables).

Product	PRODCOM Code and Combined Nomenclature		Definition
Sugar confectionery			
(a) Chewing gum	1584–2310	1704.10	Whether or not sugar coated
(b) Boiled sweets	1584–2373	1704.9071	Filled or unfilled boiled sweets
(c) Toffees, caramels and similar	1584–2375	1704.9075	Obtained by boiling sugar but contain added fat
(d) Gums and jelly confectionery including fruit pastes	1584–2365	1704.9065	Made from gelling agents (such as gum Arabic, gelatine, pectin, and certain starches) together with sugar and flavourings
(e) All other confectionery	1584–2355	1704.9055	Throat pastilles, cough drops
	1584–2363	1704.9061	Sugar-coated (panned) goods
	1584–2383	1704.9081	Compressed tablets
	1584–2390	1704.9099	Other
Chocolate			
(a) Unfilled chocolate	1584–2235	1806.3210	With added fruit, cereals, nuts
	1584–2239	1806.3290	Other (solid) bars/tablets of chocolate, milk or plain
	1584–2255	1806.9039	Other unfilled chocolate products
(b) Filled tablets and bars	1584–2233	1806.3100	Other bars, blocks or slabs of chocolate
(c) 'Bon bons' pralines and other chocolate confectionery	1584–2243	1806.9011	Containing alcohol
	1584–2245	1806.9019	Other chocolates whether or not filled
	1584–2253	1806.9031	Other filled chocolate confectionery
(d) Sugar confectionery containing cocoa	1584–2260	1806.9050	Toffees, nougat and sugar-coated goods containing cocoa
(e) White chocolate	1584–2330	1704.9030	Normally unfilled
(f) Spreads containing cocoa	1584–2270	1806.9060	
(g) Chocolate powder (for the consumer) and other preparations for beverages	1584–2280	1806.9070	Preparations containing cocoa for making beverages

indication; any special storage conditions or conditions of use; the name, or business name and an address of either the manufacturer, packer or seller established within the EU; particulars of the place of origin of the food, if failure to give this information might mislead a purchaser and instructions for use, if it would be difficult to make appropriate use of the food in the absence of such instructions (see also Chapter 25).

The requirement to indicate the quantity of certain ingredients – the so-called QUID regulation (Quantitative Ingredient Declaration) has been interpreted by BCCCA in their *Guide to QUID* (BCCCA, 1999).

The EU Directive relating to cocoa and chocolate products intended for human consumption was passed in 2000. A three-year implementation period was provided so that member states could transcribe the Directive into their own legislation. The legislation sets 'reserved descriptions' under which products labelled as chocolate, milk chocolate etc. have to meet certain compositional standards. In most EU countries 'milk chocolate' must contain at least 25% cocoa solids and at least 14% milk solids. However in Ireland and the UK 'milk chocolate' may be made with a minimum of 20% cocoa solids and 20% milk solids. Such chocolate can be sold in other member states, but in that case it must be labelled as 'family milk chocolate' (or equivalent term in the language of the member state in which it is sold). The Directive also permits the addition to chocolate of up to 5% of certain vegetable fats other than cocoa butter provided that this is accompanied by a declaration 'contains vegetable fats in addition to cocoa butter'. Further details are given in Chapter 25 (see also Food Standards Agency, 2003).

At the international level cocoa and chocolate products are governed by a Codex standard, which was revised in 2003 (Codex Alimentarius, 2003). This standard is important since it prevents countries from erecting non-tariff barriers based on local compositional requirements. The standard includes details of permitted additives as well as labelling and composition. However it proved impossible for the large Codex committee concerned to reach agreement on all aspects of the standard, so some anomalies remain. These are identified by the wording referring to 'the authorities … on whose territory the product is marketed … may prescribe'. Such alternative standards affect the labelling of the products that contain vegetable fats other than cocoa butter and, as shown in Table 28.7, minimum milk solids and milk fat in milk chocolate. It seems unlikely that the Codex committee will wish to revisit the standards in the near future since the path to obtaining the existing agreement was long and difficult.

Conclusions

Perhaps the greatest challenge facing the industry is to close the gap that exists between consumption levels in advanced and developing countries. However this does not mean that opportunities are not available elsewhere.

For confectionery designed to supply appreciable quantities of quickly available energy, the old boundaries of the industry have widened and will continue to do so. Producers and distributors increasingly think in terms of the total market for snack foods, where confectionery competes successfully with crisps, sandwiches, soft drinks, nuts etc. in the market for products to be eaten between meals. Confectionery enjoys the advantages of

Table 28.7 Extract from Codex standards for chocolate products (2003).

	Constituents (%)				
Products	**Cocoa butter**	**Fat-free cocoa solids**	**Total cocoa solids**	**Milk fat**	**Total milk solids**
Chocolate	≥18	≥14	≥35		
Milk chocolate		≥2.5	≥25	≥2.5–3.5	≥12–14
Family milk chocolate		≥2.5	≥20	≥5	≥20
White chocolate	≥20			≥2.5–3.5	≥14

Notes:

1. 'Milk solids' refer to the addition of milk ingredients in their natural proportions except that milk fat may be added or removed.
2. Where two figures are shown, for example ≥2.5–3.5 for milk fat in milk chocolate, this indicates that agreement could not be reached and that the authorities in the country where the product is marketed are free to determine which standard shall apply.
3. The chart above is an extract from the Codex standards which are far more comprehensive, covering fourteen types of chocolate other than those listed above. Readers with an interest in such matters are advised to consult the original document (see References at the end of this chapter for details).

ease or transportation, superior taste and product size in relation to quantity of energy. The opportunities are considerable since demographic and social forecasts suggest no reduction in the trend away from formal eating.

Across the world healthy eating is of increasing concern to consumers and regulators. The industry has responded with introduction of products with reduced levels of fat, sodium and sugar and with products that are free from artificial flavours or colours or are low calorie. Traditionally the industry has been based on sugar, but in developed countries its sugar-free products are steadily increasing their share of the market. In the EU forthcoming regulations on claims, and on addition of nutrients to foods, will challenge the industry, but may also provide greater opportunities to offer and promote foods aimed at the healthy eating market.

In advanced countries the general level of consumer incomes will continue to rise. This will steepen the trend, already apparent in Europe and the USA towards the separation from the general confectionery market of a sub-market for higher priced chocolate and sugar confectionery sold through specialized outlets. The shop will be a display item in its own right. Products will be a delicious treat, for consumption by the purchaser, for sharing or as a gift.

In parts of the world outside the regions of high incomes the statistical trend is towards higher consumption. Populations are growing most rapidly in Africa and Asia and industrialization is rapid in the latter. Barring major tragedies, the pattern of growth in those regions could be expected to follow the lines of Western Europe after the industrial revolution: consumption would rise in line with incomes, increasing urbanization (resulting in more retail outlets) and increasing literacy. In the more rapidly advancing countries local manufacture is already well-established and is likely to grow to meet increasing demand.

The industry will continue, through its trade associations and by other relevant methods, to counter ill-informed criticism of the role of its products in a healthy diet and, aside from any unpredictable world catastrophes, few other factors seem to point to any downturn in confectionery manufacture as its market expands both in product type and geographic areas.

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Chapter 29

FUTURE TRENDS

S.T. Beckett

'According to the old adage, there is nothing new under the sun. There is, however, an infinity of possible variations on any one theme, and it is to the divergent conceptions of the chocolatier, confectioner, food chemist, packaging and mechanical experts that the industry owes its multitude of interesting product'. So wrote C. Trevor Williams (1964) in his book on *Chocolate and Confectionery* over forty years ago. This to a certain extent is still true today, and will continue to be so. However, before trying to predict future developments, it is interesting to read how this past author thought the art of chocolate-making would develop, and then to compare this with current methods.

29.1 Past predictions

Three areas of development were reviewed by Trevor Williams (1964): new materials, package design and novel processing.

29.1.1 New materials

The hydrogenation of fats were once thought to open up new fields for the chocolatier with regard to texture and bloom resistance. This was surpassed by the widespread development of cocoa butter equivalents and substitutes, as partial or total replacers for cocoa butter in compounds and some chocolate markets (see Chapter 19). More recently the use of tempering, bloom retarding (Mori, 1990) and lower calorie fats and the development of enzyme interesterification to produce some of the components of cocoa butter from new oil sources, are just two of the many new ingredient types and processes with great potential for the future. New legislation (Chapter 25) in many countries has limited their use in products labelled chocolate and it is only in markets like Japan that it is possible to see their true potential. Health concerns over trans fats has also led to food scientists having to develop alternative fats to replace the original hydrogenated ones, which will give products with the correct texture and shelf life (Talbot, 2006).

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Some plastics and whey concentrates were regarded as possible alternative new ingredients. Although the former have yet to be developed, the latter, as whey- or lactose-derived substances are in fact incorporated in many chocolates, particularly in continental Europe. Their wide variety and importance has led to the fourth chapter in this edition of the book titled 'Ingredients from milk'.

The public's perception of the food value, or harmful effects of certain products, was considered a problem for the future of the industry. Over forty years ago the need for the industry to educate the public was noted. How much more so is this true today! Natural 'healthy' products such as soya, groundnut, sunflower seed oils, pectins and yeasts were considered as possible additions. The present health-food trend is certainly an important one, with many developments in the field of 'functional foods', i.e. ones with positive health benefits. During past twenty years a large amount of work has been carried out which has shown the very positive health effects of eating cocoa (see Chapter 27). A major problem for the manufacturer is that an ingredient, which has a positive image one week, can be regarded as unhealthy the following week. Even more strangely an additive which is beneficial in one market would be difficult to sell in others.

Also included in William's list was the possibility for alternative sugars. Dextron in particular was noted. Although this has not found a major application in the confectionery industry, the development of new sweeteners has been a major part of present research within the sugar/sweeteners industry (see Chapter 3) and the ideal low calorie sucrose replacer that is free from laxative effects is probably yet to be fully developed.

29.1.2 Packaging

A possible future prediction was the use of an edible moisture-proof film, sprayed on confectionery to eliminate the necessity of wrapping media. This appears to be totally impractical, however, as packaging is designed to protect the product from dirt and physical damage. This necessitates the packaging material being removed to take with it the dirt. It also needs to be relatively bulky so as to withstand knocks.

The importance of the correct use of colour, packaging design, and of symbolic devices to denote different manufacturing houses, are as important today as they were in the past. The development of new machines means that the range and quality of packaging has changed rapidly. The increase in speed of the machines, and the growth in importance of large super/hypermarket outlets, has led to the rapid growth of packaged countline goods. Trevor Williams noted that in the 1960s, 80% of the chocolates and confectionery produced in the USA was packaged as countline goods. This trend has since continued in other markets.

In recent years, the influence of the environmental movement has tended to lead to a reduction in the amount and the thickness of the packaging material used, coupled with a preference for the use of bio-degradable or recyclable packaging materials where possible. Some materials are now available, particularly for boxed chocolates, which will in fact degrade with moisture over a relatively short timescale.

29.1.3 Processing

Probably as a result of the influence of Mosimann (1963), ultrasonics was considered likely to find a major role within the confectionery industry. It was thought to be able to take part in the emulsification, particle comminution and conching of chocolate. At present the use of ultrasonics as a tempering aid and consequent bloom inhibitor appears to be the most commercially viable applications (see Chapter 17).

29.2 Present position

This section looks at some of the developments which have taken place over the past forty years and which were not reviewed above.

29.2.1 Materials

The source and quality of the basic raw material of all chocolate, cocoa has been changing dramatically over the period. New regions such as Indonesia have expanded, while certain traditional West African supplies have decreased owing to external factors such as the change to an oil-based economy in Nigeria, whilst owing to cocoa disease Brazil has changed from being a major exporter of beans to having to import cocoa products. Each cocoa origin provides its individual flavour, and thus the overall flavour of some chocolate is changed as new sources and types of beans are introduced. It is interesting to note that at least four authors have stressed the importance of obtaining high-quality properly fermented and dried beans, also noting that processing is at present unable to overcome any defects. It is, therefore, of great concern to many manufacturers that changes in the source of cocoa should not lead to a deterioration in quality.

One of the main areas of development of new ingredients has been in the low calorie or sugar-free markets. New sugar substitutes (Chapter 3) are not the only area being developed. By adding a long chain, difficult to digest, fatty acid with two smaller chain fatty acids it has been possible to produce triglycerides with only 4 calories/g compared with the normal 9 calories/g and with adequate crystal structure. Commercial fats such as 'Caprenin' and 'Salatrim', have led to many new products entering the marketplace, even if currently they are largely incompatible with cocoa butter (Chapters 19 and 20).

Other fats have also been developed for specific purposes. One Japanese product produces a 'chocolate' which bends like rubber, whilst several fat manufacturers sell fats which improve heat resistance by dramatically reducing bloom formation. Many of these are, however, only legally permitted in a few markets. New emulsifiers, such as fractionated lecithins are now widely available, whilst others such as PGPR (see Chapter 10) are permitted in most markets. A large percentage of lecithin is obtained from soya, some of which is obtained from genetically modified crops. With the European customer's demand for GM-free ingredients this has led to the manufacture of lecithin from soya from new sources, or from new crops such as sunflower, or to develop alternative emulsifiers.

29.2.2 Processing

Here many changes have occurred. In the field of roasting, the roasting of whole beans has often been replaced by nib or even cocoa mass roasting. The thin-film or batch devices developed to do the latter have also been used to reduce conching times and/or change the flavour of the chocolate. The conches themselves have tended to become bigger, while the use of the long conche has almost disappeared altogether.

Overall there has been a movement amongst the larger manufacturers towards large-volume processing lines, which are operated as far as possible in a continuous manner. The installation of advanced computer control and instrumentation has also resulted in a vast reduction in the man-hours required per tonne of chocolate produced. The processing of the vast majority of the world's cocoa is carried out by about half a dozen companies and there are also fewer and fewer factories actually making chocolate, although probably an increasing number using it. This was emphasized by Jeffery (1997) who said that 'in the United States there are perhaps only 15–20 chocolate makers and literally hundreds of companies 'adding value' to it in producing an enormous variety of confections'.

Many of the more recent innovations have, in fact, been concerned with chocolate usage for example to make it into a mesh, or to convert a standard moulding line into produce-filled product without the complexity of a full shell moulding plant. It is interesting to note that the ideas behind two of the latter, i.e. 'single-shot' depositing and the cold forming method (Chapter 15), originated more than forty years ago, but have only more recently become widely available as commercially built plants. This has been very much helped by the greatly improved process control techniques which are now available, and which are playing a vital role in the industry today.

29.3 Possible future trends

Predicting the future is always very risky, as unforeseen circumstances can totally change the course of events. For example, an incurable disease in cocoa could destroy the industry, while the consumption of chocolate might suddenly increase manyfold. One can of course extrapolate present trends in the belief that at least some of them will continue.

It was noted above that large manufacturers are installing larger and faster machinery. These firms have captured a substantial proportion of the market and their products are known internationally. At the same time small specialist firms, normally retailing their own goods, appear to be flourishing in many countries. It is likely that this will continue, with an even greater polarization into the two types of manufacturers. The use of large machinery makes it impossible for the chocolatier to fully develop the potential of each individual type of bean. Thus although there may be a variety of 'house' flavours, it will be left to the smaller manufacturer to exploit the full range of possible chocolate flavours. It may also be that eventually the chocolate assortment box will be primarily produced by this type of firm, with bars, countlines, etc. composing the chief market of the major manufacturers.

The increasing difference between the two types of manufacture is also likely to be reflected in the two types of chocolate, namely 'real' chocolate and coatings. Whilst it seems likely that legislation will remain strict for the former, the latter is likely to extend in its range of constituents and quality. The range of other fats and techniques for their manufacture will enable better products to be made. At the other end of the market, work on chocolate flavour will probably continue with the discovery of several hundred new contributing compounds. The probability is very low, however, of finding an economical alternative which cannot easily be distinguished from cocoa.

In his look at chocolate making into the next millennium, Jeffery (1997) regarded low fat and low calorie products as being particularly important. He noted that old ideas, such as the Cadbury Ltd (1976) one of using sugar rather than fat as the continuous phase of chocolate, might be revived. Currently, however, the target of having a low calorie product, with a texture and flavour equivalent to that of normal chocolate, with no laxative or other side-effects, has not been achieved. Many products are, however, much nearer this goal than they were 10 years ago.

As traditional markets have tended to remain fairly static in size, the search for new markets will continue. As many of these are in hotter developing countries, the developments in heat-resistant chocolate, like the Hershey Desert Bar (which incorporates water and egg white), are likely to continue. There is also the Japanese approach of making chocolate softer from the refrigerator or freezer to increase summer sales. The former communist states in Eastern Europe are also providing new markets for the large multi-national chocolate companies. Here it is perhaps a two-way exchange, with the newer processes being introduced into these countries, to make their traditional confectionery products, which might then be introduced to new markets.

In addition to new markets, chocolate is increasingly being used as a component of other food products such as frozen deserts, mousses and ice creams etc. This field is likely to expand. The general liking of the public for chocolate frequently means that the chocolate variant is the biggest seller.

An increase in engineering capability has in the past been reflected by larger machines, for example 2.5 m (8.2 ft) roll refiners, 10 tonne conches or larger, and more sophisticated machinery such as the cocoa mass treatment machines. This increase in machine size may have now reached its limit, but as was noted earlier, improved process control has already played a major role and is likely to develop further. Automatic on-line instrumentation, neural networks, computer management and expert systems are likely to find increasing roles within the confectionery industry within the next few years. In addition, it should also be remembered that processes which have failed to operate satisfactorily in the past may have done so because the degree of engineering skill then available did not meet the required standard. New developments in materials, machines and process control may mean that old ideas are worth another consideration. Perhaps, for example, the jetmill/ultrasonic system of Mosimann (Chapter 17) may be viable in some circumstances.

Research and development workers in almost every industry are frequently dispirited when the novel methods which operated satisfactorily in the laboratory, or pilot scale area fail to do so under the more stringent conditions of the production line. Little progress will be made, however, unless the industry is prepared to take the financially great risk of trying very different machines and processes. The introduction of new processing technology is likely to prove of benefit both to the confectionery industry and to the many consumers of chocolate throughout the world.

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GLOSSARY

Alkalizing A treatment used during the making of cocoa powder to give particles better suspension properties when they are used in a drink (commonly known as the Dutch process).

Amorphous Not having a distinct crystalline form.

Bloom Fat or sugar on the surface of the sweet giving a white sheen or sometimes individual white blobs.

Cacao Botanical name referring to the tree, pods and unfermented beans from the pods.

Chocolate liquor Another name for cocoa mass.

Chocolate mass(e) May refer to either cocoa mass or partially processed chocolate. In this book masse is used exclusively to mean partially processed chocolate. This was chosen to try to avoid confusion with cocoa mass.

Cocoa Traditionally the manufactured powder used for drinks or food manufacture. At present often refers to fermented beans in bulk.

Cocoa butter Fat expelled from the centre (kernels or nib) of cocoa beans.

Cocoa butter equivalent (CBE) Vegetable fats which are totally compatible with cocoa butter and can be mixed with it in any proportion.

Cocoa butter replacers (CBR) Vegetable fats of a non-lauric origin with similar physical, but not chemical characteristics to cocoa butter and which can be used to replace most of the cocoa butter in coating applications and can be used with some cocoa liquor.

Cocoa butter substitutes (CBS) Vegetable fats of a lauric origin with similar physical, but not chemical characteristics to cocoa butter and which can only be used with cocoa powder due to their low compatibility with cocoa butter.

Cocoa liquor Another name for cocoa mass.

Cocoa mass(e) Cocoa nib ground finely to give a liquid above 35°C (95°F).

Cocoa nib Cocoa beans with the shell removed.

Cocoa powder Cocoa nib with some of the fat removed and ground into a powder.

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Cold forming A technology to make chocolate shells, or other shapes, wherein an exact amount of liquid chocolate is put into a cavity and a plunger at a temperature of less than 0ºC (32ºF) applies pressure to distribute and partially set the masse, so that it holds its shape.

Conche A machine in which the chocolate is kept under agitation, so that the flavour is developed and the chocolate becomes liquid.

Sometimes used for machines which treat cocoa mass to remove volatile components.

Chocolatl Drink made from crushed cocoa beans developed by the Aztecs.

Countline An individual unit normally purchased and eaten by the consumer in informal surroundings, for example Mars bar.

Couverture Legal use, high-fat (i.e. over 31% cocoa butter), normally high-quality chocolate.

Common UK and USA use as biscuit-coating chocolate, which often containing non-cocoa vegetable fats.

Crumb Intermediate material in the milk chocolate making process, composed of dehydrated milk, sugar and usually cocoa mass.

Dietetic chocolate 'Chocolate' made for people with special dietary requirements, for example diabetics.

Enrober Machine for coating sweet centre with chocolate, by pouring molten chocolate over it.

Fermentation A process in which cocoa beans are treated such that chemical change is brought about by enzyme action. This usually involves removing the beans from the pods and placing them in covered heaps for an extended period.

Husk The shell round the nib or kernel.

Lecithin Class of organic compounds similar to fats but with molecules containing nitrogen and phosphorus. Used in chocolate as a surface-active agent to improve its flow properties.

Lipid Generic term for oils, fats and waxes.

Micronizer Device for the radiant heating of cocoa beans so as to loosen the shell.

Milk fat replacer A vegetable fat used to replace milk fat in chocolate.

Non-Newtonian liquid A liquid whose viscosity varies according to the rate at which it is stirred (sheared).

Origin liquor Cocoa mass manufactured in the country of origin of the beans.

Outer Box containing a number of retail units.

Plastic viscosity Relates to the amount of energy required to keep a non-Newtonian liquid moving once it has started to move (see also yield value).

Polymorphism The existence of the same substance in more than two different crystalline forms.

Precrystallization A method of producing a small percentage of crystals of the correct form within the chocolate, for example as occurs in a temperer.

Refiner Roll mill, often with five rolls, used to grind solid chocolate ingredients. In some countries it also refers to machines for changing the flavour of cocoa mass. This is not used in this context in this book.

Temperer A machine for cooling/heating chocolate to form stable fat crystals.

Winnowing The separation of a light material from a denser one by blowing air over them. In the case of cocoa, the shell is blown away from the cocoa nib and collected separately.

Yield value Relates to the amount of energy required to start a non-Newtonian liquid moving (see also plastic viscosity).

USEFUL PHYSICAL CONSTANTS

Thermal conductivity

Ingredient	State/temp. range	W/m°C (SI unit)	BTU/h ft°F (IMP unit)	Source
Cocoa mass	60°C (140°F)	0.21	0.123	[a]
Cocoa butter	Liquid 43°C (110°F)	0.12	0.07	[b]
Chocolate	40°C (104°F)	0.26	0.15	[c]
	35°C (95°F)	0.26	0.15	[c]
	30°C (86°F)	0.27	0.16	[c]
	27°C (80°F)	0.28	0.16	[c]
	15°C[a] (60°F)	0.22	0.13	[c]

[a] Measurement complicated by the long crystallization process and the associated heat of crystallization.

Sources:
[a] A. Dodson (1975) *Thermal Conductivity of Foods.* BFMIRA, Leatherhead, UK.
[b] *The Manufacturing Confectioner,* August 1991, p. 43.
[c] S.M. Clegg (2001) *Thermal Conductivity of Chocolate*: Summary Report Scientific & Technical Note 203, Leatherhead Food International, July 2001.

Specific heat

Ingredient	State/temp. range	J/kg°C (SI unit)	BTU/lbs°F (IMP unit)	Source
Cocoa butter	Solid/15–21°C (60–70°F)	2010	0.48	[a]
	Liquid/32–82°C (90–180°F)	2090	0.50	[a]
Chocolate	Liquid/solid 15–40°C (60–120°F)	1590	0.38	[a]
	Liquid/40–60°C (104–140°F)	1670	0.40	
Cocoa mass	Solid/4–25°C (39–77°F)	1970	0.47	
	Liquid/30–59°C (86–131°F)	1420	0.34	

Source: [a] *The Manufacturing Confectioner,* August 1991, p. 43.

Latent heat

Ingredient	J/g (SI unit)	BTU/lbs (IMP unit)
Cocoa butter	157	67.6
Dark chocolate	46	20.0
Milk chocolate	44	19.0

Source: J. Chevalley *et al.* (1970) A study of the physical properties of chocolate. *Reviews in International Chocolate* **25** (Jan.) 4.

ERH

Ingredient	Moisture content (%)	a_w range	ERH (%)
Chocolate	0.1–0.5	0.4	35–40

Source: The Manufacturing Confectioner, January 1987, p. 65.

Density

Ingredient	State/temp. range	g/cm^3 (SI unit)	lb/ft^3 (IMP unit)
Cocoa butter	Solid/15°C (59°F)	0.96–0.99	60
	Liquid	0.88–0.90	55
Chocolate	Solid	1.3	80
	Liquid/40°C (104°F)	1.2	76
Cocoa mass	Solid	1.1	68

Source: The Manufacturing Confectioner, July 1969, p. 49.

Flash point of Cocoa butter (with 1% free fatty acid (FFA)) is 315°C (600°F). It will however be lower if more FFA or solvent extracted butter is present. (Rossell, J.B. (1998) Leatherhead Food RA, private communication.)

INDEX

Industrial Chocolate Manufacture and Use: Fourth Edition. Edited by Stephen T. Beckett

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