ENERGY PRODUCTION FROM RUBBER PROCESSING EFFLUENTS THROUGH BIOMETHANATION

By

HARI B. KRISHNAN
MUHAMMED RANEEF S.
SURYA A. S.

Department of Farm Power, Machinery, and Energy
KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
TAVANUR – 679 573, MALAPPURAM DISTRICT
KERALA, INDIA

2008

ENERGY PRODUCTION FROM RUBBER PROCESSING EFFLUENTS THROUGH BIOMETHANATION

By

HARI B. KRISHNAN
MUHAMMED RANEEF S.
SURYA A. S.

PROJECT REPORT

Submitted in partial fulfillment
of the requirement for the degree of

Bachelor of Technology
in
Agricultural Engineering

Faculty of Agricultural Engineering and Technology
Kerala Agricultural University

Department of Farm Power, Machinery, and Energy
KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
TAVANUR – 679 573, MALAPPURAM DISTRICT
KERALA, INDIA
2008

DECLARATION

We hereby declare that this project report entitled **'ENERGY PRODUCTION FROM RUBBER PROCESSING EFFLUENTS THROUGH BIOMETHANATION'** is a *bonafide* record of the project work done by us during the course of the academic programme in the Kerala Agricultural University and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Hari B. Krishnan	**Muhammed Raneef S.**	**Surya A. S.**
(2003-02-06)	(2003-02-07)	(2003-02-24)

Dated: 11.01.2008

Kelappaji College of Agricultural Engineering and Technology
Tavanur

CERTIFICATE

Certified that this project report entitled **'ENERGY PRODUCTION FROM RUBBER PROCESSING EFFLUENTS THROUGH BIOMETHANATION'** is a *bonafide* record of the project work done jointly by Mr. Hari B. Krishnan (*Admn. No. 2003-02-06*), Mr. Muhammed Raneef S., (*Admn. No. 2003-02-07*) and Ms. Surya A. S. (*Admn. No. 2003-02-24*), under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship, associateship, or other similar title of any other University or Society to them.

Tavanur

11.01.08

Er. Hamza Mollakadavath
Assistant Professor
Dept. of Farm Power, Machinery and Energy
KCAET, Tavanur

ACKNOWLEDGEMENT

With deep sense of gratitude we record our reverence to our dear guide, **Er. Hamza Mollakadavath,** Asst. Professor, Department of Farm Power Machinery and Energy, KCAET Tavanur for his valuable guidance, constant backing, due encouragement and indefatigable concern throughout the work.

We express our heartfelt gratitude to **Dr. Shaji James P.**, Associate Professor and Programme Coordinator, KVK, Pattambi, for his unfailing support and readiness to spare and share his treasure of knowledge during the course of the project work.

At this juncture, we would like to engrave our sincere thanks to **Prof. M. Sivaswami**, Dean (i/c) and HOD, Dept of FPME, KCAET, Tavanur for his support and encouragement.

We sincerely acknowledge the help and cooperation given by **Ms. Remya R**., Project Fellow and **Mr. Biju K. P**., Technical Assistant, KSCSTE Project, KCAET, Tavanur.

We extend our sincere thanks to **Mr. Joe Joe L. Bovas**, M. Tech student, Dept. of FPME, KCAET, Tavanur, for his help and guidance.

We also grant our special thanks to **Mr. Aslam Subair, Mr. Anup A., Mr. Deepak P. H.**, and other B. Tech students for their timely help and support.

We prelate to exploit this opportunity to express our sincere gratitude to all our respected teachers and dear friends who have helped us one way or the other in the completion of this study.

The affection and unfailing support of our parents can never be forgotten at this moment.

Above all, glory and honor to the God almighty for making it possible to bring the report to this shape.

Hari B. Krishnan
Muhammed Raneef S.
Surya A. S.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

SYMBOLS AND ABBREVIATIONS

AAFEB	- Anaerobic Attached Film Expanded Bed
ABR	- Anaerobic Baffled Reactor
APHA	- American Public Health Association
BD	- Bulk Density
BIS	- Bureau of Indian Standards
BOD	- Biochemical Oxygen Demand
C:N	- Carbon : Nitrogen
COD	- Chemical Oxygen Demand
CSFE	- Cassava Starch Factory Effluent
Dept.	- Department
DO	- Dissolved Oxygen
DRC	- Dry Rubber Content
EC	- Electrical Conductivity
FPME	- Farm Power Machinery and Energy
GHG	- Green House Gases
GoI	- Government of India
HA	- High Ammonia
HRT	- Hydraulic Retention Time
IS	- Indian Standards
KAU	- Kerala Agricultural University
KCAET	- Kelappaji College of Agricultural Engineering and Technology
KSCSTE	- Kerala State Council for Science, Technology and Environment
KVK	- Krishi Vigyan Kendra
MNRE	- Ministry of New and Renewable Energy
NRSE	- New and Renewable Source of Energy
PVC	- Poly Vinyl Chloride
RPE	- Rubber Processing Effluents
UASB	- Upflow Anaerobic Sludge Blanket
VFA	- Volatile Fatty Acids

Dedicated
To our
College
And
The profession
Of
Agricultural
Engineering

Introduction

Chapter 1
INTRODUCTION

The generation and disposal of large quantities of biodegradable waste without adequate treatment results in significant environmental pollution. Besides health related problems for the population near the sites where waste is dumped, further degradation of waste in the environment can lead to the release of greenhouse gases (GHGs) such as methane and carbon dioxide. In the absence of waste treatment plants, as is normally the case, the environmental damage costs to the society works out to be more than the financial costs to the industry. Some of the waste streams are treated by conventional means like aeration, which is both energy intensive and expensive, and generates a significant quantity of biological sludge that must then be disposed of. In this context, anaerobic digestion offers potential energy savings and is a more stable process for medium and high strength organic effluents.

Apart from treating the wastewater, the methane produced from the anaerobic system can be recovered. Besides reducing the amount of GHGs by controlled use of methane from waste, the substitution of oil and coal with bio-energy will result in saving the global environment by reducing the use of fossil fuels. An increasing realization of the potential of anaerobic treatment is evident from the large number of recent research works on this field. Till the late 1960s, aerobic processes were very popular for biological treatment of waste. The energy crisis in the early 1970s, coupled with increasingly stringent pollution control regulations, brought about a significant change in the methodology of waste treatment. Energy conservation in industrial processes became a major concern and anaerobic processes rapidly emerged as an acceptable alternative. This led to the development of a range of reactor designs suitable for the treatment of low, medium, and high strength wastewater.

The anaerobic process has several advantages over the other available methods of waste treatment. Most significantly, it is able to accommodate relatively high rates of organic loading. With increasing use of anaerobic technology for treating various process streams, it is expected that industries would become more economically competitive because of their more judicious use of natural resources. Therefore, anaerobic digestion technology is almost certainly assured of increased usage in the future.

India is perhaps next only to China as far as anaerobic digestion of animal dung in small-scale plants is concerned. To meet the growing energy needs of the country, the Government of India (GoI) has placed growing emphasis on New and Renewable Sources of Energy (NRSE) as is evident by growing financial outlays earmarked for the Seventh (Rs 5.8 billion) and Eighth (Rs 8.51 billion) Five Year Plans (UNDP 1994). During the Eighth Plan period, Rs 3.2 billion was allocated for promotion of biogas through the concerted efforts of the MNES. So far, 3.8 million biogas plants have been installed in India, with a further potential to install 120 million plants (MNRE 2007). Also, in India, there is potential for 2700 MW energy that can be recovered from waste with an installed capacity of 43.45 MW.

1.1 Rubber Processing Effluents

Many plant species produce natural rubber. Considerations of quality and economics, however, limit the source of natural rubber to one species, namely *Hevea brasiliensis*. It is a native of the Amazon basin and introduced from there to countries in the tropical belts of Asia and Africa during late 19th century. It can be termed as the most far reaching and successful introduction in plant history resulting in plantations over 9.3 million hectares, 95 per cent of it across the globe in Asia. *Hevea brasiliensis*, also known as the Para rubber tree after the Brazilian port of Para, is a quick growing, fairly sturdy, perennial tree of a height of 25 to 30 metres. Fruits are three lobed, each holding three seeds, quite like castor seeds in appearance but much larger. The seeds are oil bearing.

The main crop from a rubber plantation is latex, a milky white dispersion of rubber in water, which is harvested by the tapping process. Latex is a white or slightly yellowish opaque liquid with a specific gravity, which varies between 0.974 and 0.986. Fresh latex, as it comes out from the tree is slightly alkaline or neutral. It becomes acidic rapidly due to bacterial action. The formation of organic acids neutralizes the negative charge on rubber particles and the latex gradually gets coagulated on keeping. Therefore, fresh latex cannot be kept for long without preservative treatment.

Latex can be processed into Preserved field latex and latex concentrate, Sheet rubber, Block rubber, and Crepe rubber. Each process requires the addition of some chemicals such as formic acid, ammonia, sulfuric acid etc. for coagulating or concentrating the latex. Water is also used in the processing. These treatments result in the production of large volume of effluent, which are polluting the environment. Thus it is necessary to dispose these effluents in a safer way.

The major form of processed natural rubber in India is Ribbed Smoked Sheet (RSS), which accounts for more than 70% of the total production. Therefore, the maximum quantity of wastewater also is generated from the processing of this form of rubber. Processing of natural rubber latex into RSS grades involves coagulation, washing etc. and liquid effluents are generated. Although the quantity of effluent discharged by small holdings is small, it is worth noting that even this small quantity of effluent, unless properly treated, lead to the emission of foul odour in the locality. Biogas production from this wastewater under the supervision of the Rubber Producers Societies (RPS) has become an economically viable alternative.

With the promulgation of Central Water (Prevention and Control of Pollution) Act, 1974, most of the industries are required to treat wastes to the degree as fixed by the Pollution Control Board, before discharging them into any water body or disposing them on land. It is mandatory for rubber-processing factories also to treat the effluent to attain the specifications stipulated by the Pollution Control Board.

1.2 Anaerobic digestion

Anaerobic digestion of complex organic substrates is a multiphase biological process affected by the integrated action of heterogeneous population of micro-organisms. This process offers an attractive alternative of handling organic waste since most of the carbon in it is converted to biogas and the nutrients from the waste remain in the digested residue. Pollution problems due to the organic effluents from agro-processing are a current environmental concern, along with the need for renewable energy.

Although the multiphase nature of digestion is now widely accepted, the complex process is often considered to consist of two main stages; a hydrolytic and fermentative first-stage and a methanogenic second stage. In the first stage, organic polymers are metabolised by neutral compounds and CO_2. The coordinated activity of the second stage bacteria, the obligate proton reducers, the acetogens and the methanogens, subsequently converts these products to methane and carbon dioxide.

1.3 High rate reactors

In India, as well as in many developing countries, anaerobic digestion has been providing a means of decentralised energy generation via biogas digesters. The popularity of these applications has been limited essentially due to the slow rate and process instability of anaerobic digestion. The slow rate means large digester volumes- consequently greater cost and space requirements- and process instability means lack of assurance of steady energy supply. But this situation is poised to change dramatically as a result of a string of break through which have occurred in recent years and are likely to occur in the future.

Introduction of anaerobic filter, up flow anaerobic sludge blanket reactor, expanded bed and hybrid anaerobic reactors of anaerobic digesters from 35- 40 days of typical unstirred reactors to a few hours. Such drastic reduction in HRT has a favourable impact in terms of smaller digester sizes and consequently lesser digester cost. Further, it has opened the possibility of treating high volume low strength wastes such as industrial water waste and sewage by anaerobic process. Earlier such wastes could be treated speedily only by aerobic process.

Once the two conventional disadvantages of anaerobic digestion viz. slow rate and process instability- are overcome the two major advantages- ability to generate energy and stable sludges- may overwhelmingly change the global bio waste management scenario from the one presently dominated by aerobic digestion to the one dominated by anaerobic digestion. For a country like India where energy continuous to be precious, with oil prices, put a heavy burden on the national economy, anaerobic digestion has far greater relevance than it has in too many other regions of the world. Due to their ability to produce energy, the modern anaerobic digesters are capable of treating biological wastes at much lesser cost than the energy-intensive aerobic digestion processes.

This aspect holds great hope for India in particular and the third world countries in general where monitory constraints preclude wider application of known but expensive technologies such as aerobic activated sludge processes which are the mainstay of biodegradable waste management in developed countries. Anaerobic digestion also continues to be of great relevance to us as a source of clean energy, especially for the semi-urban and the rural environment. The recent and the future breakthroughs have the potential of overcoming the technologies and economic barriers that have so far prevented the popular acceptance of biogas technology and full utilisation of its potential as waste stabilisers-cum-energy producers.

1.5 Objectives

The objective of this present investigation is to make available the recent breakthroughs in anaerobic digestion to rubber processing effluent biomethanation in order to overcome the technological and economical barriers that prevent the popular acceptance of this technology by small scale as well as large-scale rubber processing industries. The following were the specific objectives of this study.

2. To assess the pollution hazard caused by rubber processing units.
3. To study the biomethanation characteristics of rubber processing effluents.
4. To evaluate the performance of locally available agricultural wastes viz. coconut shell, rubber seed shell etc. as packing media in high rate anaerobic bioreactors.

Review of literature

Chapter 2

REVIEW OF LITERATURE

2.1 Rubber Processing and Effluent Generation

2.1.1 Natural rubber

Natural rubber may be obtained from the latex of about 2,000 species of plants containing rubber as its constituent. However, only a few species (Hevea brasiliensis, Parthenium argentatum, Castilla elastica, Ficus elastica etc.) are identified for commercial production of rubber. Considerations of quality and economics, however, limit the source of natural rubber to one species, namely *Hevea brasiliensis.* It is a native of the Amazon basin and introduced from there to countries in the tropical belts of Asia and Africa during late 19th century. It can be termed as the most far reaching and successful introduction in plant history resulting in plantations over 9.3 million hectares, 95 per cent of it across the globe in Asia. Natural rubber is obtained in two forms, namely field latex and field coagulum (or scrap rubber).

2.1.2 Latex Properties

The main crop from a rubber plantation is latex, a milky white dispersion of rubber in water, which is harvested by the tapping process. Two to three hours after tapping, the latex collected in the cup is transferred to a clean bucket. About 70-80 per cent of the crop from a rubber plantation is in the form of latex. The latex which gets solidified in the tapping panel (tree lace) and the collection cups (cup lump) also form part of the crop and are collected by the tapper in a basket just prior to tapping. The latex spilt and/or overflowed to the ground (earth scrap) when gets dried up is also collected as scrap once in a month. These are collectively called field coagulum.

Latex is a white or slightly yellowish opaque liquid with a specific gravity, which varies between 0.974 and 0.986. It is a weak lyophilic colloidal system of spherical or pear shaped rubber globules suspended in an aqueous serum. A protective layer of proteins and phospholipids, which impart the lyophilic nature to latex, surrounds the rubber globule. The stability of latex is due to the negative charge present on the protective layer. Also, it contains a variety of non-rubber constituents both organic and inorganic, in addition to rubber. The proportion of these constituents may vary with clone, soil nutrition, climate etc. The composition of rubber latex is as shown in the table 2.1.

Table 2.1 General composition of latex

Rubber	30-40 %
Proteins	2-2.5 %
Ash	0.7-0.9 %
Resins	1-2.0 %
Sugars	1-1.5 %
Water	55-65 %

Fresh latex, as it comes out from the tree is slightly alkaline or neutral. It becomes acidic rapidly due to bacterial action. The formation of organic acids neutralizes the negative charge on rubber particles and the latex gradually gets coagulated on keeping. Therefore, fresh latex cannot be kept for long without preservative treatment.

Latex can be processed into any of the following forms

1. Preserved field latex and latex concentrate
2. Sheet rubber
3. Block rubber
4. Crepe rubber

Field coagulum can be processed only into crepe rubber or block rubber.

2.1.2 Rubber Processing Industry

Rubber is produced mainly in three states of India, e.g. Kerala, Karnataka, and Tamil Nadu. The highest quantity of rubber is produced in Kerala that accounts to about 90 per cent of the total production in the country, i.e. 2.7 lakh tonnes as against the total production of 3.0 lakh tonnes.

There are 218 industries for rubber processing. Out of these, 19 units carry out only preservation of latex by adding ammonia. Ribbed Smoked Rubber sheeting is done in about 10,000 registered units in Kerala and also by about equal number of un-registered units. These sheets are made in cottage scale units without much capital investment. The large units are in the industrial estate areas.

2.1.3 Processing

2.1.3.1 Preserved field latex

Field latex is preserved using suitable preservative for long term storage. The processing of preserved field latex consists essentially of adding the preservative (usually ammonia, minimum 1 per cent) to the sieved latex, bulking, settling, blending and packing. Field latex can also be preserved with LATZ (Low ammonia – TMTD – Zinc oxide) system.

2.1.3.2 Latex Concentrate

There is good market for preserved latex concentrate, as it is an important raw material with a wide range of applications. Two important methods of processing latex into preserved latex concentrate are commercially practised.

2.1.3.2.1 Concentration by Creaming

The processing of latex into creamed concentrate involves the mixing of a creaming agent such as ammonium alginate or tamarind seed powder with properly preserved field latex and allowing the latex to separate into two layers; an upper layer of concentrated latex and a lower layer of serum containing very little rubber. The lower layer of serum is removed, leaving the latex concentrate having about 50-55 per cent DRC (Dry Rubber Content), which is often tested, packed and marketed.

2.1.3.2.2 Concentration by Centrifugation

The processing of latex into latex concentrate by centrifugation involves the separation of preserved field latex into two fractions, one containing the concentrated latex of more than 60 per cent dry rubber and the other containing 4-8 per cent dry rubber (skim latex).

Skim latex is generally coagulated with sulphuric acid, made into crepe, dried and marketed as skim rubber, which is a low-grade rubber.

2.1.3.2.3 Preservation of Centrifuged Latex

Centrifuged latices are commercially available as high ammonia (HA – minimum 0.6 per cent ammonia) and low ammonia (LA - 0.2 to 0.3 per cent ammonia) types. The former is preserved solely with ammonia and the latter contains one or more preservatives in addition to ammonia. The most popular LA type latex is low ammonia TMTD – Zinc oxide (LA-TZ) which contains 0.2 to 0.3 per cent ammonia, 0.013 per cent TMTD, 0.013 per cent zinc oxide and 0.05 per cent lauric acid.

Preserved latex concentrates shall be graded and marketed in conformity with the standards specified by the Bureau of Indian Standards (BIS) as given in IS: 5430-1981 (centrifuged latex), IS: 11001-1984 (double centrifuged latex) and IS 13101-1991 (creamed latex).

2.1.3.3 Ribbed Smoked Sheet (RSS)

Latex is coagulated in suitable containers into thin slabs of coagulum and rolled through a set of smooth rollers followed by a grooved set and dried to obtain sheet rubber. Depending upon the drying method, sheet rubbers are classified into two: Ribbed Smoked Sheets and Air Dried Sheets (Pale Amber Unsmoked Sheets).

A major quantity of natural rubber produced in this country (74.7 per cent) is marketed in sheet form at present, as it is the oldest and the simplest method of processing latex into a marketable form.

For processing latex into sheet rubber, it is important that the latex collected is brought to the processing centre before pre-coagulation sets in. In cases where the latex is found to be prone to pre-coagulation, an anticoagulant is used.

Latex brought to the centre is strained through 40 and 60 mesh stainless steel sieves. The volume of latex is measured with a standard vessel and a calibrated rod. The dry rubber content (DRC) is estimated with a metrolac, which is a special type of hydrometer calibrated to directly read the DRC. However, laboratory methods are employed for accurate determination.

Latex is diluted in bulking tanks to a standard consistency of 1/2 kg of dry rubber for every 4 litres of the diluted latex (12.5 per cent DRC). The diluted latex is allowed to stand in the bulking tank for a fixed time (usually 15 to 20 minutes) for the heavy dirt particles to sediment. The diluted latex is drawn out from the bulking tank without disturbing the sedimented layer of impurities into the coagulation pans or tanks. Four litres of latex is usually transferred to each pan.

2.1.3.3.1 Coagulation

Formic acid or acetic acid is generally used for coagulation. The quantity of acid required for satisfactory coagulation depends on various factors like the amount and type of anticoagulant used the duration of coagulation, the season, and the nature of the latex. The acid requirements may slightly change under varying conditions and can be fixed up by experience. Only diluted acid should be used for coagulation and should be thoroughly mixed with latex.

After coagulation, the coagulum is removed from the pan or tank and thoroughly washed in running water. They are rolled either in a sheeting battery or smooth rollers to a thickness of 3 mm and finally passed through the grooved roller. While sheeting, the coagulum is continuously washed. The sheets are again washed in running water in a tank.

2.1.4 Effluent Generation

As the different types of operations are carried out in the processing of natural rubber into its various preserved forms, the type of effluents generated will have distinguished characteristics. In the preparation of Preserved Latex Concentrate by centrifuging, the effluent obtained after the separation of latex concentrate mainly have high ammonia content. Effluents are also generated from these plants due to the frequent washing of the centrifuge machine bowl in order to remove the sludge. About 0.5 per cent rubber is lost in this washing.

The characteristics of the effluent from centrifuging process changes after the addition of sulphuric acid to these effluents at the settling tanks in order to coagulate and recover the rubber lost through these effluents.

In the manufacturing of rubber sheets, acids are used to coagulate the rubber to form a sheet of rubber. This is then squeezed through a roller press to remove the effluent. The effluent is acidic in nature.

In the crepe and crumb units, in which field coagulum is processed, water is required for the soaking of field coagulum. However, the effluent is less polluting compared to other effluents.

It has been estimated that on an average 10 litres waste water is generated per kg of ribbed rubber sheet produced. Out of this, about 6 litres will be the serum from coagulation and 4 litres will be wash water used for cleaning at various stages. The serum contains readily oxidisable dissolved organic solids. This effluent is organic in nature, and studies have shown that this could be digested anaerobically.

2.1.5 Characteristics of the Rubber Processing Effluent

Karim (1998) studied the influence of effluent from rubber processing factories on the chemical, physical and microbiological properties of soil. Effluent application resulted in higher content of potassium in the soil compared to the fertiliser-applied soil.

Rubber latex effluent is a polluting source that has a high biochemical oxygen demand (Tang *et al*., 1999) and Concentrated rubber latex effluent contains acetic and propionic acids. He also found that the initial concentration of organic acids in the raw effluent was 3.9 g/l.

Suresh *et al* (2000) found that the effluent generated from the production of rubber sheet have a pH of 5.05 and have 4080 mg/l and 8080 mg/l BOD and COD respectively while the effluent generated by centrifuging have 3645 mg/l and 5873 mg/l BOD and COD respectively with a pH of 5.3.

2. 2 Biomethanation of food processing and Agro industrial wastes

The anaerobic digestion of organic wastes is recognised as an effective method for disposal of the wastes and production of energy at a decentralised level (Mathur and Rathore, 1992). Most agro processing wastes are highly organic in nature.

Landine *et al.* (1983) conducted a lab treatability study of high strength, high solids potato processing wastewater. They observed a COD removal of over 96per cent at a loading rate of 1.16 kg 100 rn3 d1 at an HRT of 4.5 days. Yang et *al.* (1984) examined the biogasification of papaya processing wastes and found that HRT can be reduced by sludge recycling.

Caizada *et al.* (1984) experimented with one and two phase anaerobic systems for biomethanation of coffee pulp juice. They found that a bi-phasic system with 0.5 and 8 day HRT respectively for acidogenic and methanogenic phases produced stable condition.

Lane (1984) conducted lab scale anaerobic digestion of fruit and vegetable solid wastes and reported that for balanced digestion alkalinity (mg l-1) of 0.7 x VFA (mg/l) is required and it should not be less than 1500. Stewart (1984) measured biogas yields from anaerobic digestion of banana and potato waste in 20 litre continuous digesters and observed almost complete conversion of volatile solids to yield 0.53 m^3 biogas per kg of VS added.

Bagasse, the fibrous ligno-cellulosic residue resulting from sugarcane juice extraction can be used for biomethanation. Narasimhamoorthy and Pushothaman (1986) reported that it is possible to obtain higher biogas yield from bagasse by biphasic digestion.

Ranade *et al.* (1987) conducted anaerobic digestion studies on market waste consisting of rotten vegetables, fruit skins, potatoes, onions etc. in 25 litre laboratory scale digesters. Maximum biogas was produced at 20 day retention time.

Pressmud is a sugar factory waste which is rich in organic content. Unni *et al.* (1987) conducted laboratory scale and pilot scale studies for producing biogas from press mud. They could obtain a biogas volume of 0.48 m^3/m^3/day at a loading rate of 2.1 kg VS/m^3 during winter and 0.59 m^3/m^3/day at a loading rate of 1.05 kg VS/m^3 during summer.

Gollakota and Meher (1988) reported that even de-oiled cake of non-edible oil seeds, such as castor could be considered as substrate for biogas production.

Ranade *et al.* (1989) studied biogas production from confectionery wastes generated by biscuit and chocolate manufacturing plants. They obtained a biogas yield of 2611 litres at 40 day HRT in 180 litre capacity plants.

Mahadevaswamy and Venkatraman (1990) observed that anaerobic digestion of mango peels produced 0.21 m^3 of biogas per kg TS with a methane content of 60 to 65 per cent.

Sharma and Madan (1992) recommended the integration of sericulture and mushroom cultivation with anaerobic digestion. They pointed out that it is possible to obtain microbial protein, biogas and fertilizer simultaneously minimising the pollution hazard.

El-Shini *et al.* (1992) experimented with orange, phaseolus, tomato, pea and carrot wastes. They obtained an volumetric biogas production in the range 0.49 m^3/m^3/day to 0.998 m^3/m^3/day with the mean value of 0.840 m^3/m^3/day.

Viswanath *et al.* (1992) studied the anaerobic digestion of fruit processing wastes and reported that the waste from fruits such as mango, pine apple, orange, banana, jack fruit and tomato could be successfully digested in anaerobic digester under mesophilic conditions with an average biogas yield of 0.50-0.60 m3/kg VS added.

Ghanem *et al.* (1992) examined the digestibility of beet pulp, a waste product from sugar industry and found that it could be utilized efficiently for biogas production when treated with 1 per cent NaOH. Hamdi and Garcia (1993) recommended detoxification of olive mill waste waters with *Aspergillus niger* before anaerobic digestion.

Weiland (1993) experimented with one step and two step processes for biomethanation of solid agro industrial wastes. He reported that, in general for different agro-industrial waste, 50 to 70 per cent of organic matter could be degraded in an HRT of 10 to 20 days. He recommended a one step process for agro industrial residues with a C:N ratio above 15 and two step process for those with a C:N ratio below 10.

Viswanath and Nand (1994) conducted anaerobic batch digestion studies in laboratory scale bioreactors to determine the biogas potential of defatted silk worm pupae waste. The maximum yield of biogas (0.53 m^3/kg VS) was obtained at a loading rate of 1 kg TS/m^3/day.

Sarada and Joseph (1994) studied the influence of HRT, OLR and temperature on CH_4 production rate and yield during anaerobic digestion of tomato processing waste. They could get a biogas production of 0.7 m^3/m^3/day.

Anaerobic digestion of banana trash and coir pith was carried out by Deivanai and Kasturi Bai (1995) for a period of one month in batch digesters. The reductions of total and volatile solids were 25.3 and 39.6 per cent in banana trash and 13.6 and 21.6 per cent in coir pith. The biogas production was 9.22 and 1.69 l/kg TS added with average methane contents of 72 and 80 per cent from banana trash and coir pith respectively.

Cho et *al* (1995) studied the anaerobic digestion potential of food wastes. They reported that the methane yields of cooked meat, cellulose, boiled rice, fresh cabbage and mixed food waste were 482, 356, 294, 277 and 472 ml CH_4 g/1 VS added.

Kalyazhnyi and Davlyatshina (1997) observed that among the factors influencing the process kinetics in anaerobic digestion of glucose, hydrogen concentration and pH value have the primary significance. They observed slight inhibition of methanogenic consortium by the excess of butyrate, propionate and ethanol.

2.3 High rate anaerobic bioreactors for waste water treatment and biogas production.

Biological processes for waste water treatment are generally classified as aerobic processes and anaerobic processes (Barnes and Fitzgerald, 1987). The choice between aerobic and anaerobic processes for waste water treatment has tended to favour the former in the past because the systems were considered to be more reliable, more stable and better understood in spite of the positive energy recovery aspect of the latter. But, with the advent of anaerobic high rate processes, the waste water treatment scenario has witnessed a tremendous change in favour of anaerobic processes (Lettinga, 1984).

Colleran *et al.* (1982) reported that the concept of biological solids recycle, which led to the introduction of the anaerobic contact or anaerobic activated sludge process, permitted a longer residence time for the active flora within the digester and resulted in high process efficiencies. But high rates of solids recycle were often required in order to maintain satisfactory treatment efficiency.

Maintenance of active flora within the reactor independent of waste flow is achieved in the second generation of methane reactors (high rate reactors) by maintaining biological growth on inert support materials (Collerans *et al*., 1982).

In the anaerobic fixed film reactors like Upflow Anaerobic Filters (UAFs), the biological solids or active biomass become attached to the support surfaces and are also entrapped as flocs in the void spaces between the support matrix particles (Young and McCarty, 1969). In the UASB reactor, (Lettinga *et al.*, 1980) biological growth is in the form of granules which grow initially around a tiny support particle and are retained at high concentration within the reactor by a gas solids separator device.

Jewell *et al*. (1981) attempted to develop an optimum biological reactor that would accumulate maximum active attached biomass, the process referred to as Anaerobic Attached Film Expanded Bed (AAFEB) system.

Guiot and Van den Berg (1984) among the newer designs instigate anaerobic Hybrid digesters. This process confines the advantages of both the anaerobic fixed film reactor and the UASB. Bachmann *et al.* (1985) developed the anaerobic baffled reactor (ABR) which is essentially a series of upflow sludge blanket reactors. Because of its unique characteristics, it does not require granular growth which may be difficult to obtain (Boopathy *et al*., 1988). The fluidized bed process also relies on the retention, within the reactor of a fluidized bed of biolayer covered partcies (Heijnen *et al.*, 1989). The biolayer covered particles are maintained in a fluidized state by an upwards directed flow of water.

The upflow anaerobic filter (UAE) systems were initially developed by Young and McCarty (1969). It consists essentially of a column packed with an inert support material such as gravel, plastic, ceramic, fired clay etc. The distribution header for the UAFs at the bottom of the unit, thereby creating an upward flow through the submerged matrix bed. The biomass in the reactor is attached to the media surfaces as a thin biofilm, is entrapped within the media matrix.

The application of the UAF design to a variety of soluble wastes was subsequently investigated by El-Shafie and Bloodgood (1973), Jennet and Dennis (1975), Mueller and Mancini (1977), Mosey (1978), Donovan (1981) and Young (1981). Newell (1981) experimented with a waste containing milk washings from a dairy plant and waste from a pig fettering unit. A 9 m^3 UAF was constructed after preliminary studies with lab scale filters. The percentage COD removal was 82 per cent with an average methane production.

Anaerobic digestion of agro- industrial effluent is an environmental friendly way to combat the problem of environment pollution and acute energy shortage (James and Kamaraj, 2002).

James (2000) conducted studies on the biomethanation characteristics of Cassava Starch Factory Effluent and developed a high rate anaerobic reactor. He revealed that a large extend of energy needed in the cassava processing can be recovered from the anaerobic digestion of effluents.

2.3.1 Factors affecting the design and performance of high rate reactors

Factors affecting the performance of conventional anaerobic digesters have been studied in detail by several workers. It is fairly well known that temperature (Acharya, 1958; Van den Berg *et al.*, 1976; Kamaraj, 1984; Chawla, 1986), Carbon:Nitrogen ratio of feed stock (Singh, 1974; Barnett *et al*, 1978; Hills, 1979), HRT (Knol *et al*, l 978; Hills, 1980; Hofson *et al*., 1981; Singh *et al.*, 1993), and pH (Bansel *et al.*, 1977; Wise, 1987) and influent substrate concentrates (Hashimoto, 1982) are the major factors affecting the anaerobic digestion process. The significance of several other factors like mixing, presence of toxic substances and initial seeding inoculums also cannot be over looked (Chawla, 1986; Mathur and Rathore, 1992).

Young (1991) has made a comprehensive review of the factors affecting the waste treatment performances of anaerobic filters and made recommendations for taking these factors into consideration for design purpose.

Full scale UAF configuration have included cylindrical and rectangular tanks ranging in diameter/width from 6 to 26 m and in height from 3 m to 13 m (Young and Yang, 1989). Volumes for full scale reactor systems had ranged from 100 -10,000 m.

Young (1991) observed that media: height ratio is important and reactors having 5per cent or less media volume generally have experienced increased solids loss and reduced efficiency. He recommended that the media be placed m the upper two thirds of the height of up flow reactors with a minimum height of 2 meters for the full scale reactors.

2.3.2 Selection of media

Young and Dahab (1983) opined that bacterial retention seems to be as related to medium shape and void size as to unit surface area. The accumulation of suspended solids or biomass the packing often leads to plugging and channelling which eventually deteriorates the reactor efficiency (Young, 1985).

The purpose of the media as observed by Young (1991) is to retain biological solids within the reactor either as a fixed film attached to the media, as solids entrapped within the media matrix, or suspended within or beneath the media as a granulated or flocculent sludge mass. Therefore, the media acts as a gas-solids separator, helps to provide uniform flow through the reactor, improves contact between the waste constituents and the biomass contained within the reactor, and permits accumulation of the large amount of biomass needed to produce long HRT.

During the course of development of anaerobic filters, a wide variety of media have been investigated and used. Young and McCarty (1969) used quartzite stones while Smith *et al.* (l997) used drain pipe pieces. Hudson *et al.* (1978) found that the reactors packed with whole oyster shell media performed better than those with rock media. They recorded the higher specific surface area and porosity as factors responsible for better performance. Barry and Colleran (1982) used limestone chips and Kennedy and Van den Berg (1982) used fired clay media for treatment of piggery wastes.

Robinson *et al.* (1984) reported that the microscopic observation of biofilms formed on various materials during pig slurry treatment showed that biofilms found on the various supports do not differ significantly in microbial content or overall aspect. They are 1 to 3 mm thick and they display a rough and uneven surface. Many mineral precipitates containing Ca, Mg and P are embedded in the biofilm and a higher density of material is present towards the base of the film, lower layers being characterized by the presence of a thick matrix.

Gadre and Godbole (1986) used stone rubbles of 25 mm mean diameter. Sharma and Bandyopadhyay (1991) used earthenware rings of potters clay having an average length l.88 cm, outer diameter 1.20 cm and internal diameter 0.80 cm with a specific surface area of 133.2 m^2/m^3 as medium. Yap *et al.* (1992) and Chua *et al.* (1997) reported that they got satisfactory performances with fire expanded clay media.

Nordstedt and Thomas (1985 a) operated bench scale UAFs containing oak, cyprass and pine wood block media at HRTs as low as 2 days using supernatant from settled swine waste as feed stock in comparison to plastic media and no media reactors. They reported that the wood block media reactors performed as well as plastic media and showed no visual signs of deterioration after one year of operation. In another study conducted by them (Nordstedt and Thomas, 1985 b) the pine wood media exhibited some inhibition which could be overcome by a longer soak time. Andreoni *et al.* (1990) also got a similar result with wood chips and PVC media when used for the treatment of residues from wood pyrolysis with swine slurry.

Sorlini *et al*. (1990) investigated the microbiological aspects of swine slurry digestion in UAFs with different packing media viz., PVC supports, wood chips and expanded clay. The composition of the microbial consortia in the biofilm attached to wood chips and PVC supports were not significantly different.

Pascik (1990) recommended the use of modified porous polyurethene carriers as packing media. Hill and Bolte (1992) also investigated bacterial retention by polypropylene felt, polyurethene foam and nylon mesh. They found that polypropylene felt gave a higher methane productivity and VS reduction. Aivasidis and Wandrey (1988) reported on the use of porous sintered glass with a porosity of 50 per cent in a fixed bed loop reactor.

Young (1991) reported that the specific surface area of media used in full-scale anaerobic filters averages about 100 m^2/m^3 regardless of the type of media. He opined that site specific consideration, economics and operating factors should ultimately be the determining factors in the selection of media. He clarified that media specific surface area seemed to have only a minor effect on waste treatment performance and it is unlikely that the additional cost of high density media can be justified by the slight improvement in efficiency and the increased potential for plugging. He recommended a specific surface area of about 100 m^2/m^3 to avoid plugging.

James and Kamaraj (2004) conducted investigations on the use of coconut shells as media for cell immobilization in Aerobic Bioreactors. They found that coconut shells inhibit methanogenic bacteria in anaerobic batch digesters due to the leaching of phenols. Pre-treating of coconut shell is advised to overcome this problem.

Start-up characteristics of Upflow Anaerobic Hybrid Reactor with coconut shell as well as PVC media as matrix for treating an energy conversion of Cassava Starch Factory Effluent (CSFE) was done by James and Kamaraj. They found that even though CSFE was acidic, the reactors were start-up without addition of alkali at a start-up HRT of 15 days.

Materials and methods

Chapter 3

MATERIALS AND METHODS

The procedure adopted for the analysis of physico-chemical characteristics of effluent samples, the methodology for batch anaerobic digestion study of Rubber Processing Effluents, procedure adopted for selecting suitable media for high rate reactor, and the design procedures for high rate reactors are outlined in this section.

3.1 Collection of Samples

Two types of samples are identified as effluent generated from the production process of sheet rubber in the homesteads and the effluent generated when it is treated with ammonia and sulphuric acid for the production of preserved field latex and latex concentrate. These effluents were collected from Rajas Healthy Acres Estate, Koottanadu, Malappuram and Malabar latex, Melattur, Malappuram district respectively.

Effluent generated during the production of sheet rubber in homesteads is considered as Rubber Processing Effluent 1 (RPE1) and the industrial effluent produced during conversion of latex into concentrate is termed as Rubber Processing Effluent 2(RPE 2).

3.2 Assessment of pollution hazards

In order to assess the pollution hazard caused by the different effluents, a survey was conducted in a number of rubber processing plants. The quantity of effluent generated in sheet rubber processing plants and centrifuged concentrated latex plants were estimated.

3.3 Study of Effluent Characters

The effluent samples were analysed to obtain values of the Total solids (TS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Electrical Conductivity (EC), Total Dissolved Solids (TDS) and pH of the effluents.

The following methods were adopted for estimating different physico-chemical characters of the waste water samples and biogas.

3.3.1 Total Solids

The Total Solids (TS) was determined by the procedure outlined by APHA(1989). A measured volume of well mixed sample was transferred to a pre-weighed dish and evaporated to dryness in a drying oven. The evaporated sample was dried for 24 hours in the oven at 103-105 °C. The dish was then cooled in a dessicator and weighed. The process of drying, cooling and weighing was repeated till concordant weights were obtained.

$$\text{TS, mg/l} = \frac{\text{(weight of dried residue + dish), mg - weight of dish, mg}}{\text{Sample volume, ml}} \times 1000$$

3.3.2 Chemical Oxygen Demand

The chemical oxygen demand is used as a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by strong chemical oxidant. The dichromate reflux method is preferred over procedures using other oxidants because of superior oxidising ability and applicability to a variety of samples.

The requirements for the experiment were heating block for digestion and digital photometer for measuring COD (digestion and measurement of COD done using suitable vials available in market (Plate 3.1). Each vial contains standard potassium dichromate solution, ferrion indicator, std. ferrous ammonium sulphate, mercuric sulphate and standard potassium hydrogen phthalate which are the reagents for open reflux method)

Vials of suitable concentration was selected from the three ranges according to the sample as given in the table 3.1. Appropriate amount of sample was added to the vial using pipette. Blank was also prepared by adding water instead of sample. The vials were shaken well. Heating block was switched on and the time and temperature were set to 120 min and 150 °C. The blanks and tests were kept in the heating block. After one hour the vials were taken out and kept again in the digesting block. After 2 hours, the vials were taken out and kept for 10 min for cooling. Then the photometer was switched on and the readings were adjusted to zero by placing the blank solution. Then the test vials were kept in the photometer and the readings were noted.

Table 3.1 Sample for varying COD values

Sl. no.	Range (mg/l)	Sample (ml)
1	0 - 150	2
2	150 - 1500	2
3	1500 - 15000	1.2

3.3.3 Biochemical Oxygen Demand

The Biochemical Oxygen Demand (BOD) is determined by 5 day BOD test. The method consists of filling with sample to overflowing, an air tight bottle and incubating it at specified temperature for 5 days (Plate 3.2). Dissolved oxygen (DO) was measured initially and after incubation, and the BOD was determined as the difference between initial and final DO.

Dilution water at the rate of 1000 – 1200 ml per sample per dilution was prepared. The diluted water temperature was maintained at 27 °C. Then the diluted water was saturated with air by shaking in a partially filled bottle. The mixture of sample and dilution water was taken according to the table 3.2. The bottle was then stoppered and kept for incubation at 27 °C for 5 days. The BOD nature of glucose-glutamic acid standard check solution (2 per cent dilution) after 5 days was also noted for evaluating the data. Dissolved oxygen of unseeded dilution water blank was also noted. The final DO of all samples after 5 days were calculated. BOD of the samples were calculated by using the equation

$$\text{BOD, mg/l} = \frac{D_O - D_T}{P}.$$

where,

D_O - Initial amount of Dissolved Oxygen

D_T - Final amount of Dissolved Oxygen

P - Decimal volumetric fraction of sample used

Plate 3.1 COD analyzer with heating block and vial

Plate 3.2 BOD incubator

Table 3.2 Dilutions for varying BOD values

Using % mixture		By direct pippeting into 300 ml	
Range of BOD	% mixture	Range of BOD	ml sample
1000-3500	0.2	1200-4200	0.5
400-1400	0.5	600-2100	1.0
200-700	1.0	300-1050	2.0
100-350	2.0	120-420	5.0
40-140	5.0	60-210	10.0
20-70	10.0	30-105	20.0
10-35	20.0	12-42	50.0
4-14	50.0	6-21	100.0
0-7	100.0	0-7	300.0

3.3.4 pH Value

The pH of the effluent is the measure of acidity or alkalinity. The pH was estimated using the electrometric method (APHA, 1989). A Eutech make pHScan, pocket sized pH meter was used (Plate 3.3).

3.3.5 Electric Conductivity

The electric conductivity (EC) is directly proportional to the amount of dissolved solids in the sample. The EC of the samples were estimated using the electrometric method (APHA, 1989). A Eutech make ECScan, pocket sized EC meter was used (Plate 3.4).

3.3.6 Total Dissolved Solids

The total dissolved solids of samples were estimated using the electrometric method (APHA, 1989). A Eutech make TDScan, pocket sized TDS meter was used (Plate 3.5).

Plate 3 .3 EUTECH pH meter

Plate 3 .4 EUTECH ECScan- EC meter

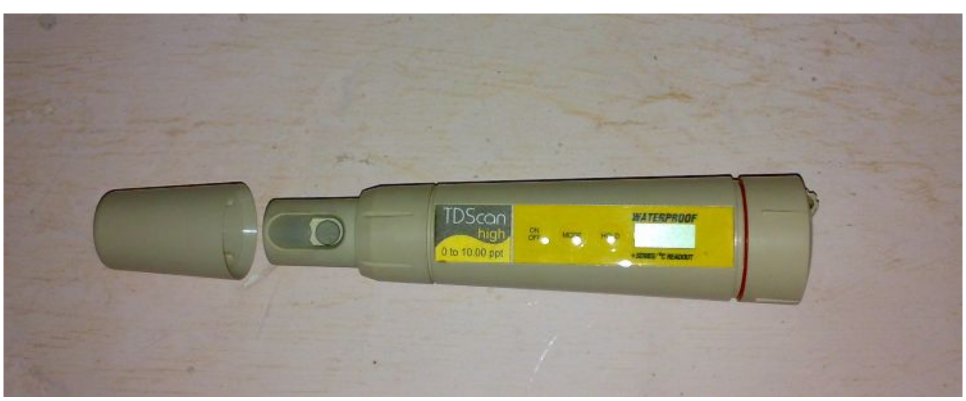

Plate 3 .5 EUTECH TDScan- TDS meter

3.3.7 Gas Volume

Daily biogas outputs were initially measured using a calibrated water displacement meter (Lo and Liao, 1986). The water displacement meters were made by placing an inverted clear jar over a plastic dish. The gas volumes were converted to equivalent volumes at STP. Clear jars of 3.5 litre capacity were used for this purpose and were calibrated.

3.4 Biomethanation Study

Plastic cans of 10 litres capacity were converted into small scale bio-reactors to study the biomethanation characteristics. The locally available cans were fabricated into biogas reactors as shown in plate 3.6. The experimental set up was shown in plate 3.7.

Batch digestion studies were carried out in two phases, first phase and second phase. Anaerobic digestion of rubber processing effluent (RPE) samples were done in 10 litre capacity digesters attached with 3.5 litre capacity water displacement meters.

3.4.1 Preliminary Study

Batch digestion studies were carried out in the first phase to study the biomethanation characteristics of rubber processing effluents (RPE). In the first phase the following treatments with 3 replications were used for the study.

T_0 – Control

T_1 – $E_1N_0I_1$

T_2 – $E_2N_0I_1$

T_3 – $E_2N_1I_1$

where,

E_1 – Effluent generated from the production of Sheet rubber (RPE1)

E_2 – Effluent generated from the production of Latex concentrate (RPE2)

N_0 – No neutralisation

N_1 – Neutralisation to pH 7 using 20 per cent NaOH solution

I_1 – Initial addition of 50 per cent inoculum

Plate 3.6 Experimental batch digester

Plate 3.7 Experimental setup for batch digestion study

The control consists of cow dung solution with a TS of 15000 mg/l. The treatments for both RPE1 and RPE2 were conducted separately, due to the problems in the availability of the effluents. All the treatments were inoculated by initial addition of 50 per cent cow dung solution.

3.4.2 Media Compatibility

In the second phase, batch digestion studies were carried out to test the compatibility of different media by placing medias inside the digesters. The performance of the selected media can be compared so that, the most suitable media can be selected for the high rate reactor. Three types of media, viz coconut shell (Media1), rubber seed outer shell (Media2) and rubber seed inner shell (Media3), were used for the study. These were selected because of their advantage that they are locally available and are agricultural by-products.

The study was also aimed at analyzing the amount of inoculum needed for the initial start-up of the reactors. For this purpose, the treatments included different quantities of inoculum i.e. 1:4 and 1:1 ratios of cow dung solution and effluent.

Thus, the following treatments with three replications were used for the study.

T_0	-	Control	T_1	-	$E_1I_1M_0$
T_2	-	$E_1I_1M_1$	T_3	-	$E_1I_1M_2$
T_4	-	$E_1I_1M_3$	T_5	-	$E_1I_2M_0$
T_6	-	$E_1I_2M_1$	T_7	-	$E_1I_2M_2$
T_8	-	$E_1I_2M_3$			

where,

E_1	-	Effluent generated from the production of sheet rubber
I_1	-	Initial addition of 20 per cent inoculum
I_2	-	Initial addition of 50 per cent inoculum
M_0	-	No media
M_1	-	Coconut shell
M_2	-	Rubber seed outer shell
M_3	-	Rubber seed inner shell

The inoculum used was the cow dung solution with 40000 mg/l TS. As in the first phase, here also, a treatment with 100 per cent cow dung solution of same TS was carried out as control.

3.4.2.1 Coconut shell

These are the hard outer body of coconut and are usually available as half pieces. Coconut shells were broken into pieces such that it has an approximate specific surface near to the recommendation. Coconut shells were available as half pieces and each half piece was broken into 4 to 5 pieces so that it can be easily accommodated in the digester (Plate 3.8).

3.4.2.2 Rubber Seed Inner Shell

Rubber inner shells are hard body covering each of the rubber seed. These have an elongated spherical shape and dark in colour. After removing the seed, the shells were available as broken pieces (Plate 3.9).

3.4.2.3 Rubber Seed Outer Shell

The rubber seeds are usually present as a cluster of 3 seeds. Rubber outer shells are the harder body which encloses seeds together to form a cluster. Once the seeds mature and the pods dry up, they explode dispersing the seeds. The exploded broken pieces are available in the rubber plantation and are some times collected for use as firewood. It has an outer skin of dark colour. Before filling this into the digesters, the outer skin was removed and cleaned so that, the digestible skins does not affect the biogas production (Plate 3.10).

3.4.2.4 Media Characteristics

The different media were taken and cleaned and soaked in water one week prior to feeding into the digesters. Two litres of each media were taken and filled in the digesters before filling it with effluent mixture. The different characters of the media were determined as follows.

Plate 3.8 Coconut shell

Plate 3.9 Rubber seed Inner shell

Plate 3.10 Rubber seed outer shell

3.4.2.4.1 Porosity

To determine the porosity (P), the media were filled in a cylindrical vessel with a predetermined volume of water. The media were filled in the vessel so that they are submerged and filled up to the water level. The new volume was noted down.

$$\text{Porosity of media (P), \%} = \frac{\text{Iniitial volume of water}}{\text{Volume after filling with media}} \times 100$$

3.4.2.4.2 Bulk Density

The bulk density was estimated by finding the weight of a known volume for each type of media.

$$\text{Bulk density (BD), kg/m}^3 = \frac{\text{Weight of the media, kg}}{\text{Bulk volume occupied by the media, m}^3}$$

Result and Discussion

Chapter 4

RESULTS AND DISCUSSION

The results of the investigation carried out to study the characteristics of Rubber Processing Effluents, assessment of pollution hazards, batch anaerobic digestion study, and media selection study are presented and discussed in this chapter.

4.1 Characteristics of Rubber Processing Effluents

Two types of the effluent, RPE1 and RPE2 that were analyzed showed differences in their characteristics. The characteristics are shown in Table. 4.1.

Table 4.1 Characteristics of rubber processing effluents

Characteristics	***RPE 1***	***RPE 2***
pH	4.2	2.8
Total Dissolved Solids (TDS), ppm	3.1	3.6
Electrical Conductivity (EC), ms	4.2	1.5
Total Solids (TS), mg/l	40000	45000
Biochemical Oxygen Demand (BOD), mg/l	450	1000
Chemical Oxygen Demand (COD), mg/l	2260	4479
BOD/COD	0.20	0.22

The low pH shown by the RPE 1 was due to the acids added to the latex in order to coagulate the rubber present in it.

The effluent generated from the centrifuge showed a low pH nearly 2.8. This happens mainly due to the addition of sulphuric acid to the wastewater from the centrifuge plant in a settling tank. Addition of strong acids is mainly for coagulating the remaining part of rubber present in the wastewater, which in turn generate highly acidic effluent.

Total Solids content of both the effluents did not vary much. TS of RPE1 and RPE2 were 40000 mg/l and 45000 mg/l respectively.

The low BOD/COD ratio of RPE 1 and RPE 2 indicates similar biodegradability characteristics.

4.1.1 Pollution Hazards

It has been estimated that the high degree of pollution was caused by these rubber processing effluents, both air and water. It has foul smell and this cause many ecological problems. On an average, six litres of waste water is generated during the production of sheet rubber weighing 1 kg. On the other hand, nearly 10-12 litres of waste water is generated while processing latex into unit volume of latex concentrate.

The comparative study of the various characteristics of the effluent and the Pollution Control Board (PCB) norms for safe disposal of waste water are given in table 4.2.

Table 4.2 Comparison of effluents with the standards

Characteristics	***RPE 1***	***RPE 2***	***Waste water ****
pH	4.2	2.8	5.5-9
Biochemical Oxygen Demand (BOD), mg/l	450	1000	100
Chemical Oxygen Demand (COD), mg/l	2260	4479	250

* General effluent standards of Central Pollution Control Board (CPCB)

From the table 4.2, it is well understood that both the effluents are highly polluting in nature. The BOD of RPE 2 is ten times more and COD is nearly 18 times more than the general standards. In the case of RPE 1, BOD is nearly 4.5 times and COD in 10 times more than the standards.

4.2 Batch anaerobic digestion of RPE

The batch anaerobic digestion of RPE was carried out to investigate the biomethanation characteristics of RPE with a view to find out the feasibility of methane production. The first stage batch digestion studies of the RPE1 and RPE2 were carried out separately as per the availability of the effluents.

4.2.1 Batch Digestion of RPE 1

Batch digestion study was continued for a period of 135 days. RPE 1 had considerable amount of gas production throughout the period and revealed that methane could be effectively produced from it (Fig. 4.1).

The peak gas production of the control, cow dung solution was occurred on the 28th day (1010.4 ml) and it showed considerable amount of gas production up to 50 days. After the 60th day onwards, the gas production from the cow dung solution was negligible.

In the case of RPE 1, peak gas production occurred three times in the entire period of 135 days. Peak gas productions for RPE 1 on 40th and 105th day were 942 ml and 705.5 ml respectively.

An initial gas production was observed in one or two days after the initial feeding in RPE 1. The gas production shows a first peak on the 3rd day after the initial feeding registering 513.1 ml (Fig. 4.1). This initial gas production extended for a period of 15 days and the cumulative gas produced during the 15 days period was 1833.2 ml.

After the initial gas production for 15 days, all the digesters with RPE 1 showed no gas production which extended for a period of 10 days. From the 25th day onwards, gas production regained and attained peak in the 40th day.

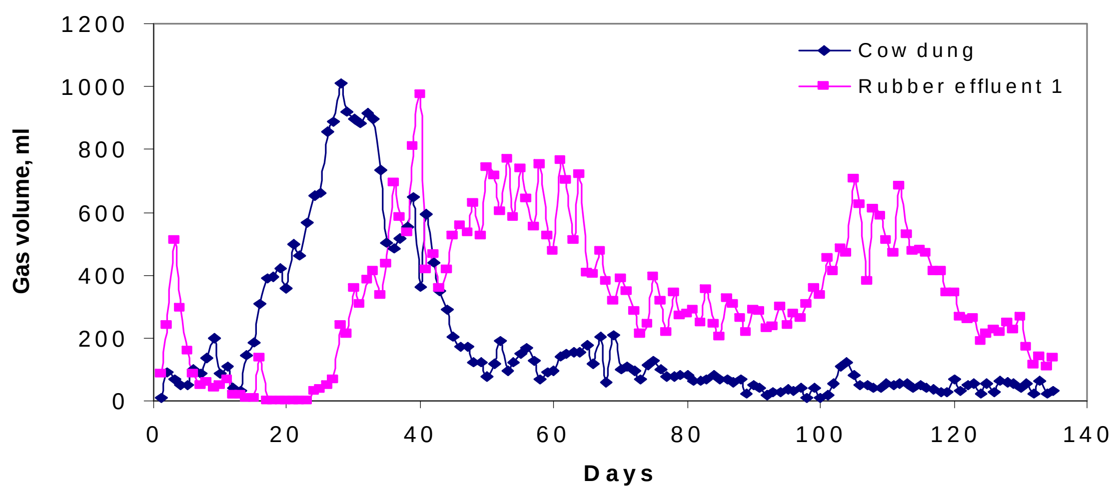

Fig. 4.1 Daily average gas production from RPE 1

Daily average biogas production for the RPE1 reduced to an amount of 277 ml/day on 77th day and increased thereafter and attaining the second peak in 105th day. The gas production reduced to 133.62 ml/day on the 135th day in which the final observations were taken.

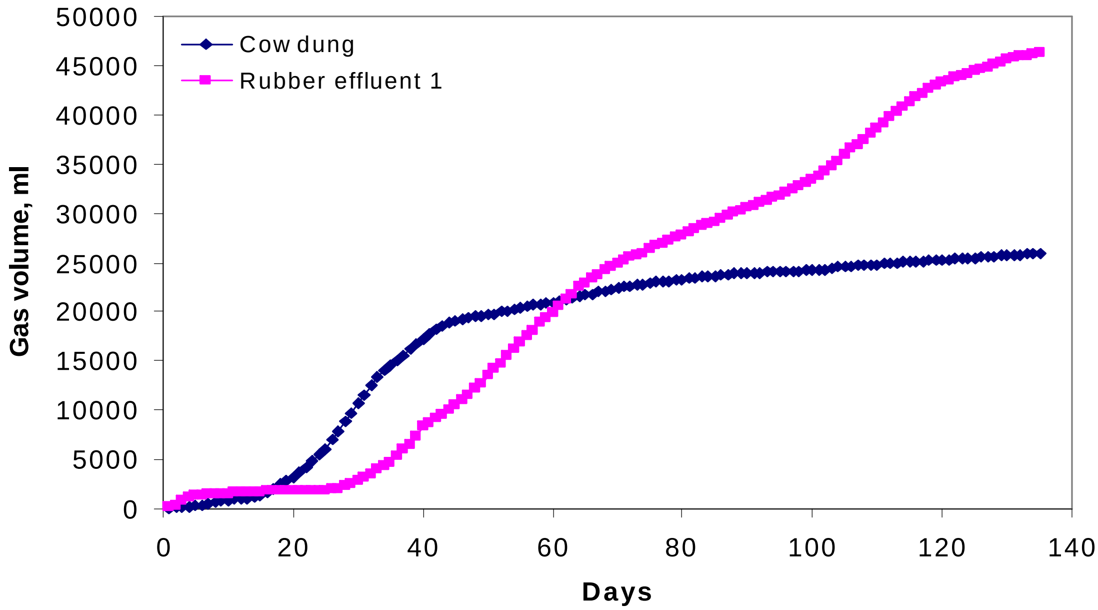

Fig. 4.2 Average cumulative gas production from RPE 1

The total gas produced in the entire period for RPE1 having rubber effluent and cow dung solution mixed in the ratio 1:1 and with a Total Solids of 40000 mg/l was 46290 ml and it was 25927 ml for cow dung solution having a Total Solids content of 15000 mg/l (Fig. 4.2).

The biogas productivity of different effluents and the control are given in table 4.3.

Table 4.3 Biogas productivity

Parameter	Control	RPE 1 + cow dung	RPE1
Biogas productivity, ml/l	2592.7	4629.0	6665.3

4.2.2 Batch Digestion of RPE2

The effluent generated from the centrifuged latex production unit had a very low pH and there was little possibility for biomethanation to occur. Investigation on the feasibility of biogas production from this effluent was carried out by neutralizing the effluent. The investigations revealed that biogas cannot be effectively produced from the non-neutralized effluent whereas neutralized effluent showed minor gas productions.

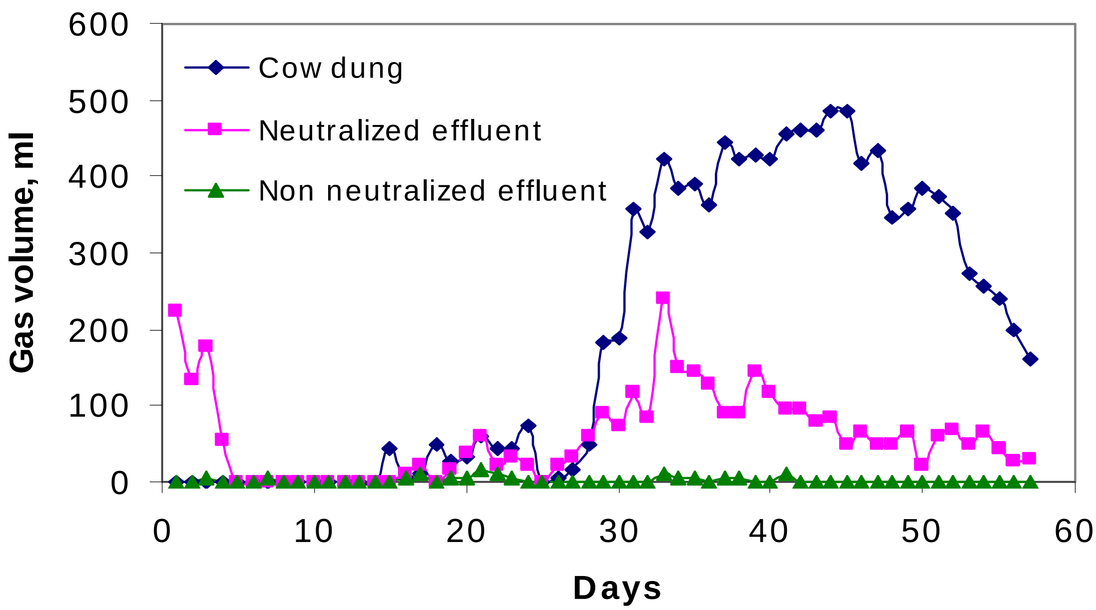

Fig. 4.3 Average Daily Gas Production from RPE 2

Control showed a daily average gas production of more than 33 ml from the 30th day onwards (Fig. 4.3). It showed an increased production but the data collection paused due to the lack of production from the rubber processing effluent under study.

Neutralized effluent showed an initial gas production of 224 ml/day and a cumulative gas production of 588 ml in four days. Twelve days after the initial gas production, the effluent showed no gas production. On the 33rd day, Neutralized RPE peaked to a value of 240.5 ml whereas the gas production from the non-neutralized sample was negligible.

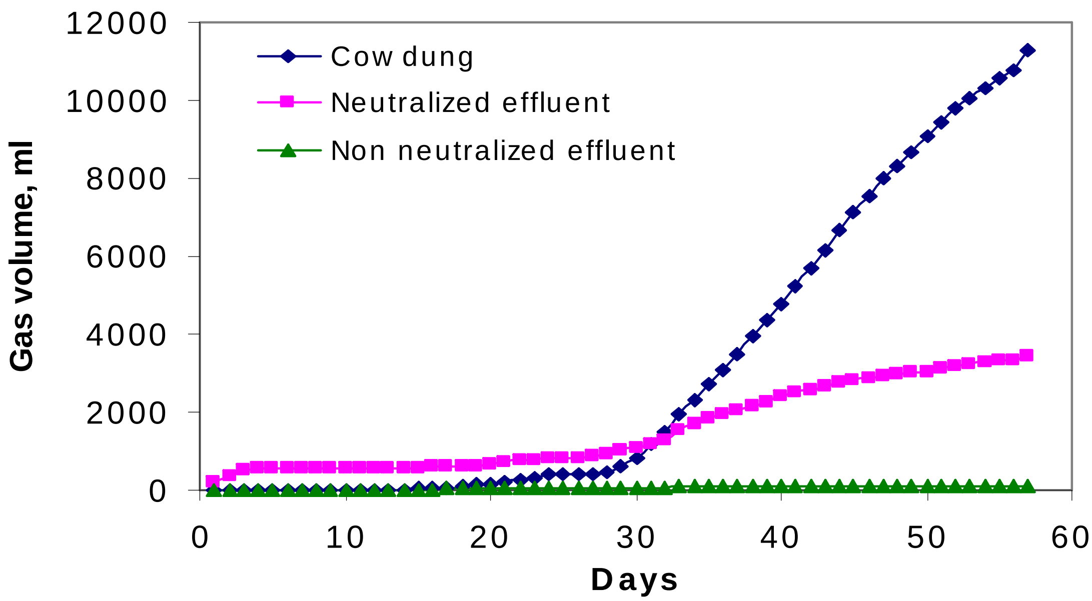

Fig. 4.4 Average cumulative gas production from RPE 2

Cumulative gas production from the neutralized rubber effluent was 3458 ml for a period of 60 days whereas it was 112.24 ml in the case of Non-neutralized effluent. On the same time, the control (cow dung) showed a cumulative gas production of 11,282.6 ml (Fig. 4.4). This indicated that the biogas production capability of RPE 2 was very low.

The lack of biogas production from the RPE 2 may be due to the presence of sulphate which in turn inhibits the growth of methanogenic bacteria in the effluent. From the Fig. 4.4, it is well understood that the gas production of RPE 2 was very poor. Gas production from the cow dung behaved normally and continued with an acceptable rate.

4.3 Batch Digestion for Media Selection

Suitability and inhibition characteristics of the media selected for the High Rate Reactors were analyzed in this stage. The three media selected for the study viz. coconut shell, rubber seed inner shell, and rubber seed outer shell had significant differences in their physical characteristics.

4.3.1 Characteristics of the media

The various characteristics of the different media are given in table 4.4.

Table 4.4 Physical characteristics of media

Characteristics	Coconut Shell	Rubber Seed Outer Shell	Rubber Seed Inner Shell
Porosity, per cent	62.5	83	72
Bulk density, kg/m^3	643	397	431

The porosity of the coconut shell seems to be comparatively low. This may be because of the reason that, the coconut shells are broken into small pieces in order to accommodate in the digester used for the study. This also resulted in the higher bulk density. Porosity of rubber seed outer shell is higher than the other two media and hence, it can be effectively utilised as media in the high rate bio reactor.

4.3.2 Start-up Characteristics and Media Compatibility

Stat up characteristics of the RPE 1 were identified by comparing the biogas production from the effluent treatments inoculated with 20 per cent and 50 per cent cow dung solution. Comparative assessment of the gas production from these treatments along with the media was also conducted.

The average daily gas production of RPE1 with various media did not vary much. Gas produced from RPE 1 with different media is shown in the Fig. 4.5. Treatments, T1 and T5 which were the treatments without any media, showed higher gas production. But the other treatments with exhibited lower gas production but cannot be regarded as due to the inhibition properties of the media.

Inhibition properties cannot be distinguished because the treatments with rubber seed inner shell as media exhibited hierarchy in gas production with 50 per cent inoculum (T8) did not showed any such property with 20 per cent inoculum (T4) so as also in the case of treatments T3 and T7 with rubber outer shell as media.

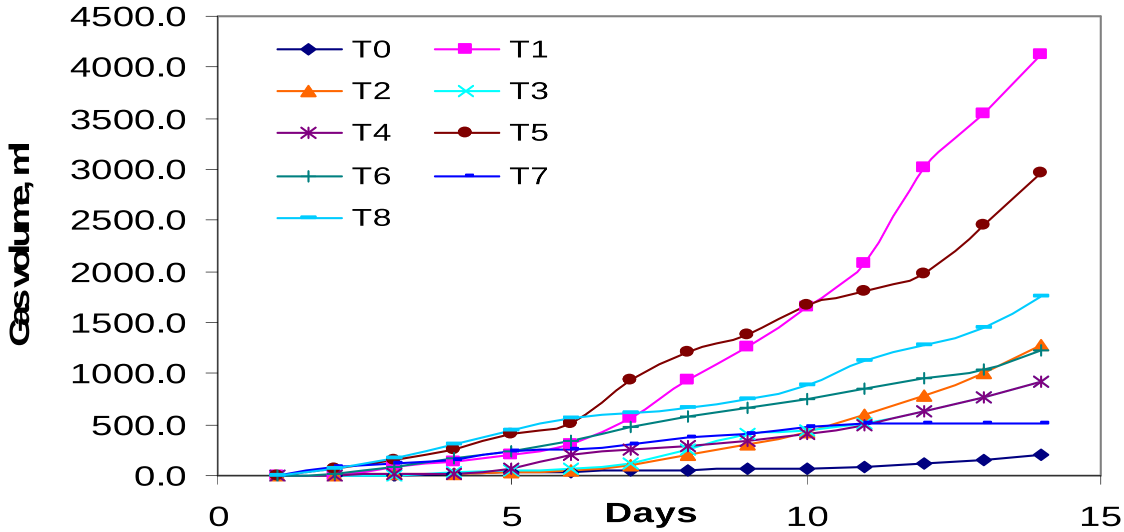

Fig. 4.5 Average cumulative gas production from RPE 1 with media

Treatments, T1 and T5 showed higher gas productions may be due to the presence of more amount of volatile acids than that with media. The volume of RPE 1 was reduced in the digesters with media due to the volume occupied by the media.

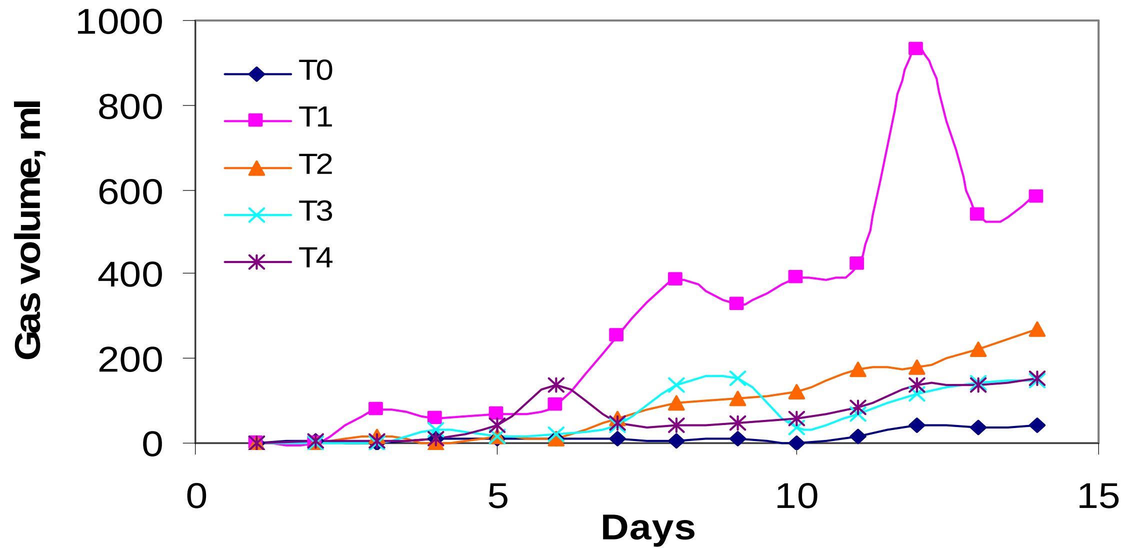

Fig. 4.6 Average daily gas production from RPE 1 with 20 per cent inoculum

From the Fig. 4.6, the inhibition properties of media at 20 per cent inoculum can be compared. The daily average gas production from these treatments cannot exhibit a remarkable difference. The Fig. 4.7 also clears the fact that the inhibition characteristics are least acceptable with different types of media.

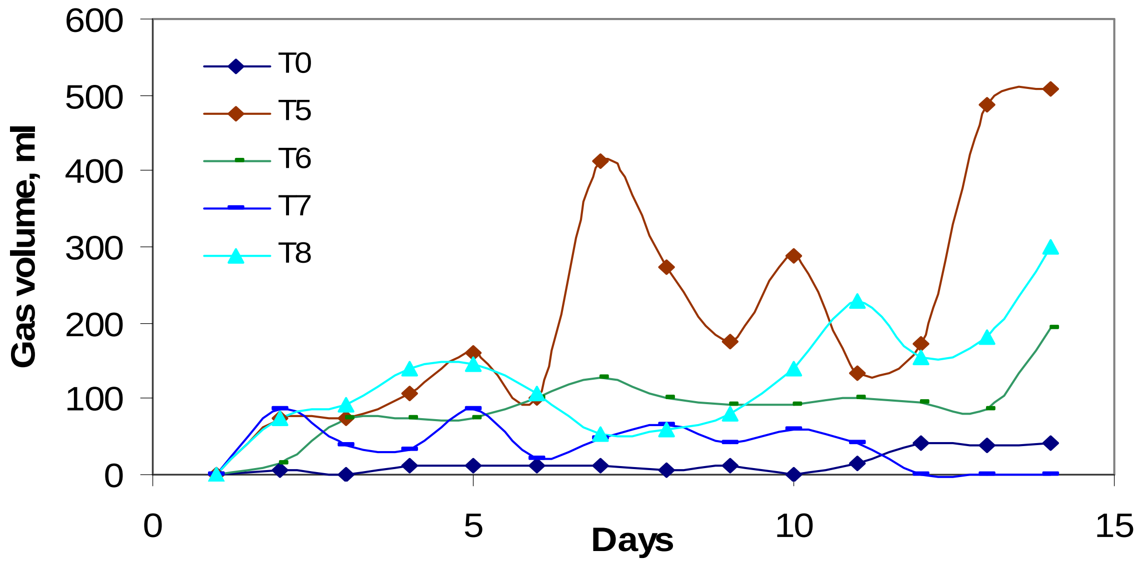

Fig. 4.7 Average daily gas production from RPE 1 with 50 per cent inoculum

On analyzing the start up characteristics of the RPE1 with 20 per cent and 50 per cent inoculum (Fig.v4.5), it shows that the start up characteristics are less affected with the amount of inoculum.

Thus the suitable material as media can be selected by considering the physical properties and the availability.

Summary and Conclusion

Chapter 5

SUMMARY AND CONCLUSION

Anaerobic digestion of biodegradable waste has the twin advantages of energy generation and pollution control in addition to the reduction of greenhouse gas emissions. It would replace the use of fossil fuels in various applications by utilizing methane generated from the waste. In spite of the fact that there is significant potential of energy generation from industrial wastewater in India, the technology is yet to be fully established.

Biomethanation of agro industrial effluents is often problematic due to its large volume and low strength. Rubber processing effluents (RPE) is an agent of environmental pollution, both air and water. There is much scope for biomethanation of RPE.

The study was aimed at assessing the pollution hazard caused by rubber processing units and investigating the potential of biogas production from the two rubber processing effluents. It also analyzed the suitability of different locally available media for the high rate bioreactors, thus producing biogas in the most economical way.

1. The investigation to identify the different type of effluents generated from the processing of rubber latex and understanding their respective characteristics shown its highly polluting nature and difficulties in the disposal of the effluents. The total solids (TS) content of the effluents were 40000 mg/l for the RPE1 and 45000 mg/l for the RPE2. The BOD values were 450 mg/l for the RPE1 and 1000 mg/l for the RPE2 and the COD values were 2260 mg/l for the RPE1 and 4479 mg/l for the RPE2. The pH values shown that both the effluents are acidic in nature and were obtained as 4.2 for the RPE1 and 2.8 for the RPE2.
2. The characteristics of rubber processing effluents reveal their wide variation from the standards prescribed by the Central Pollution Control Board (CPCB).
3. Six litres of RPE1 and twelve litres of RPE2 were generated during the conversion of rubber latex into sheet rubber and latex concentrate respectively.

4. The batch digestion study of the RPE1 proved that it is suitable for anaerobic digestion and biogas production. A maximum biogas production of 97.2 ml per litre of effluent mixture added was observed on the 40^{th} day whereas cow dung solution of 1.5 per cent TS shows a maximum biogas production of 101.0 ml per litre on the 28^{th} day.

5. The initial gas production within two to three days after the initial feeding in the case of RPE 1 was may be due to the liberation of volatile acids present in the effluent.

6. Batch digestion studies carried out with RPE 2 revealed that the biogas production from it was not promising as it produced only a small amount of biogas i.e. 112 ml from 60 days when the effluent is added without any neutralisation. This might be due to the high sulphur content of the effluent. Sulphate may be developed in the effluent during the addition of sulphuric acid to the ammoniated waste water produced from centrifuge plant to coagulate the rubber particles lost through the effluent.

7. When RPE 2 is neutralised with 20 per cent NaOH solution, the effluent produced a little higher amount of biogas but didn't give a considerable amount. The neutralised effluent mixture produced a peak volume of 24.05 ml of biogas per litre of the effluent on the 23^{rd} day whereas the control, cow dung solution, of 28000 mg/l TS produced 48.6 ml per litre of the solution on the 45^{th} day.

8. As the biogas production from the RPE 2 didn't give a significant result, it is not economical to use with a high rate reactor. Hence, further investigation with RPE 2 was not carried in the second phase.

9. The removal of sulphur is essential for using the RPE 2 in the high rate bioreactors. The neutralised effluent has shown a peak biogas production in the initial days and came down. This might be due to the presence of volatile acids in the effluents.

10. The study of RPE 1 with 20 per cent and 50 per cent inoculum did not vary much, so initial amount of inoculation will not affect the biogas generation.

11. The physical properties such as porosity and bulk density direct to select rubber seed outer shell as media due to its favourable physical characteristics. Remarkable change in the porosity will occur in the case of coconut shell if it is broken into bigger pieces than that was used in the experimental digester.
12. Biogas generation characteristics with media cannot suggest a remarkable inhibition property, so any media used for the study can be utilized in the high rate bioreactor as per the availability. Long term investigations are needed in order to assess the clogging and channelling problem.

References

REFERENCES

Acharya, C. N., 1985, Preparation of fuel gas and manure by anaerobic fermentation of organic materials. Indian Coun. Agric. Res., New Delhi. 58 pp.

Aivasidis, A. and Wndrwy, C., 1988, Recent Developments in Process and Reactor Design for Anaerobic Waste Water Treatment, Wat. Sci. Tech., 20 (1): 211–218.

APHA, 1989, Standard Methods for the Examination of Water and wastewater, American Public Health Association, Washington.

Bachmann, A., Beard, V. L. and McCarty, P. L., 1985, Performance Characteristics of the Anaerobic Baffled Reactor, Wat. Res., 19: 99-106.

Barry, M. and Colleran, E., 1982, Anaerobic digestion of silage effluent using an upflow fixed bed reactor, Agric. Wastes, 4(3): 231-239.

Chawla, O. P., 1986, Methane fermentation technology: Advances in Biogas Technology, Indian Council of Agricultural Research, New Delhi: 19-57.

Colberg, P. J., and Young L. Y., 1982, Biodegradation of lignin-derived molecules under anaerobic condition. Can. J. Microbial., 28 : 886-889.

Cho, J. K., Kim, Park S. C., and Chang, H. N., 1995, Biochemical methane potential and solid state anaerobic digestion of Korean food wastes, Bioresources Technology, 52 : 245-253.

Chua, H., Hu, W. F., Yu, P. H. F. and Cheung, M. W. L., 1997, Responses of an anaerobic fixed film reactor to hybrid shock loadings, Bioresources Technology, 61: 79-83.

Colleran, E., Mary Barry and Ann Wilkie, 1982, The application of the anaerobic filter design to biogas production from solid and liquid agricultural wastes In : Energy from biomass and Wastes VI, Institute of Gas Technology, Chicago : 443-481.

Deivanai, K. and Kasturi Bai, R., 1995, Batch biomethanation of Banana Trash and Coir Pith, Bioresource Technology 52: 93-94

Donovan, E. J., 1981, Treatment of high strength wastes by anaerobic filter, In: Energy conservation and use of renewable energies in the bio-industries, Pergamon Press: 179-198

El-Shafie, A. and Bloodgood, D. e., 1973, Anaerobic treatment in a multiple upflow filter system, J. Water Poll. Control Fed., 45: 2345-2357.

El-Shini, S. A., El-Housseini, M, Ali, B. E. and El-Shinnawi, M. M., 1992, biogas generation from food processing wastes, Resour. Conser. Recyc., 6: 315-327.

Gollakota, K. G. and Meher, K. K., 1988, effect of particle size, Temperature, Loading rate and stirring on Biogas Production from castor cake (oil expeller). Biol. Wastes, 24: 243-249.

Guiot, S. R. and Van den Berg, L., 1984, Performance and biomass retention of an upflow anaerobic reactor combining a sludge blanket and a filter, Biotech. Lett.., 6: 161-164.

Hamdi, M. and Garcia, J. C., 1993, Anaerobic digestion of olive mill waste waters after detoxification by prior culture of *Aspergillus niger*, Process Biochemical., 32: 155-159.

Hashimoto, A.G., 1982, Methane from Cattle Wastes: Effects of temperature, Hydraulic Retention Time and Influent substrate Concentration on kinetic parameters, Biotechnology and Bioenergy, XXIV: 2039-2052.

Heijnen, J. J., Mulder, A., Enger, W. and Hoeks, F., 1989, Review on the application of anaerobic fluidized bed reactors in wastewater treatment, The Chemical Engg. J, 41: B37-50.

Hill, D. T. and Bolte, J. P., 1992, Bioretentive properties of synthetic media for anaerobic digestion of animal wastes, Trans. ASAE, 35: 2711-2715.

Hills, D. J., 1979, Effect of C:N ratio on anaerobic digestion of diary manure, Agricultural Wastes, 1: 247-320.

Hills, D. J., 1980, Methane gas production from dairy manure at high solid concentration, Trans. ASAE, 23:122-126.

Hofson, P. N., Bousfield, S. and Summers, R., 1981, Methane production from Agricultural and Domestic Wastes, Applied Sciences Publishers, Barking England.

Hudson, J. W., Pohland, F. G. and Pendergrass, R. P., 1978, Anaerobic Packed column treatment of Shell fish processing waste waters, Proc., 33rd Purdue International Waste Conference: 560-574.

James, S. P., 2000, Development of a High Rate Anaerobic Reactor for Biomethanation of Cassava Starch Factory Effluent, PhD Thesis, Department of Bioenergy, College of Agricultural Engineering, TNAU, Coimbatore.

James, S. P. and Kamaraj, S., 2002, Immobilised cell anaerobic bioreactors for energy production from agro-industrial waste waters – An introduction, Bioenergy News, 6 (3): 10-15.

James, S. P. and Kamaraj, S., 2003, Hybrid Anaerobic Reactor for Energy Production from Cassava Starch Factory Effluent, Bio Energy News, September 2003: 10-12.

James, S. P. and Kamaraj, S., 2004, Preliminary Investigation on the Use of Coconut Shells as media for Cell immobilization in Anaerobic Bioreactors SESI Journal 14(2): 35-40.

Jewell, W. J., Switzenbaum, M. S. and Morris, J. W., 1981, Municipal Waste water treatment wih the anaerobic attached microbial film Expanded bed process Journal, Water Pollution Control Federation, 53(3): 482-490.

Kalyazhni, S. V. and Devlyatshina, M. A., 1997, Batch Anaerobic Digestion of Glucose and its Mathematical Modelling, I. Kinetic Investigation, Bioresources Technology, 59: 73-80.

Kamaraj, S., Sudhakar, S., Krishnaveni, S., Sankaranaryanan, M. and Swaminathan, K. R., 1984, Dynamic studies on Indian Rural Biogas Digesters, World Bioenergy Conference, Gothenberg, Sweden.

Kennedy, K. J. and Van den Berg, L., 1982, Anaerobic digestion of piggery waste using stationary fixed film reactor, Agricultural Wastes, 4(2): 151-158.

Landine, R. C., Brown, G. J., Cocci, A. A. and Viraraghavan, T., 1983, Anaerobic Treatment of High Strength High Solids Potato Wastes, Agricultural Wastes, 7: 111-123

Lane, A. G., 1984, Laboratary Scale Anaerobic Digestion of Fruit and Vegetable Solid Waste, Biomass, 5: 245-259.

Lettinga, G., 1984, The Prospects of Anaerobic Waste water treatment, In: Anaerobic Digestion and Carbohydrate hydrolysis of waste, Elsevier applied Science Publishers, New York, 262-273.

Mahadevaswamy, M. and Venkataraman, L. V., 1990, Integrated utilization of fruit processing wastes for biogas and fish production, Biological Wastes, 32: 243-251.

Mathur, A. N. and Rathore, N. S., 1992, Biogas production, Management and utilization, Himanshu Publishers, New Delhi.

Mosey, F. F., 1978, Anaerobic filtration: A biological treatment process for warm industrial effluents, Water Pollution Control, 77: 370-378.

Meuller, J. A. and Mancini, J. L., 1977, Anaerobic filter kinetics and application Procedure, 30th Industrial Waste water Conference Purdue University: 423-456.

Narasimhamoorthy, G. S, and Purushothaman, A., 1986, Biogas generation from Bagasse, Industrial Chemical Engineer, 28(3): 54-56.

Newell, P. J., 1981, The Use of High Rate Contact Reactor for Energy Production and Waste Treatment from Intensive Livestock Units, In: Energy Conservation and Use of Renewable Energies in the Bio industries, Pergamon Press Oxford: 397-407.

Nordstedt, R. A. and Thomas, M. V., 1985 a, Start-up characteristics of anaerobic fixed bed reactors, Trans. ASAE, 28 (4): 1242-1247, 1252.

Nordstedt, R. A. and Thomas, M. V., 1985 b, Wood block media for anaerobic fixed bed reactors, Trans. ASAE, 28 (6): 1990-1996.

Pascik, I., 1990, Modified Polyurethane Carriers for Biochemical Waste Water Treatment, Wat. Science Technology, 22(1/2): 33-42.

Robinson, R. W., Akin, D. E., Nordestedt, R. A., Thomas, M. V. and Aldrich, H. C., 1984, Light and Electron Microscopic Examination of Methane Producing Biofilms from Anaerobic Fixed Bed Reactors, Applied Environmental Microbiology, 48: 127-136.

Sarada, R. and Joseph, R., 1994, Studies on factors influencing methane production from tomato processing waste, Bioresource Technology, 47: 55-57.

Sharma, S. and Madan, M., 1992, Optimal Utilisation of Seri-culture Waste, Resour. Conser. Recyc., 7: 295-304.

Sharma, S. R. R. and Bandyopadhyay, M., 1991, Treatment of pulp and paper mill effluent by upflow anaerobic filter, Indian Journal of Environmental Health, 33(4): 456-463.

Singh, L., Maurya, M. S., Saira, M. and Alam, S. I., 1993, Production of biogas from Night soil, Effects of loading and Temperature, Bioresource Technology, 45: 59-61.

Singh, R. B., 1974, Biogas plant: Generating Methane from Organic Wastes, Gobargas Research station, Ajtmal, Etawah, India: 24-36.

Smith, R. E., Reed, M. J. and Kiker, J. T., 1997, Two phase anaerobic digestion of swine wastes, Trans. ASAE, 20(6): 1123-1128.

Sorlini, C., Ranalli, G. and Merlo, S., 1990, Microbiological aspects of anaerobic digestion of swine slurry in upflow fixed bed digesters with different packing materials, Biological Wastes, 31: 231-239.

Unni, B. G., Pillai, K. R. and Singh, H. D., 1987, Production of biogas from sugarcane pressmud, Laboratory scale and Pilot plants studies, Energy Management, 11(1): 23-32.

Viswnath, P. and Krishna Nand, 1994, Anaerobic Digestion of Silk Industry Wastes, Bioresource technology, 49: 273-276.

Young, J. C. and McCartie, P. L., 1969, The anaerobic filter for waste treatments Journal Water Pollution Control federation, 41(5): 160-173.

Appendices

APPENDIX – I
Batch Digestion Study of RPE 1

Days	Average Daily Gas Production		Average Cumulative Gas Production	
	Control	RPE 1	Control	RPE 1
1	10.69	85.51	10.69	85.51
2	90.86	240.51	101.55	326.02
3	69.48	513.09	171.03	839.11
4	48.10	293.96	219.13	1133.07
5	48.10	160.34	267.23	1293.41
6	101.55	85.51	368.78	1378.92
7	85.51	48.10	454.30	1427.03
8	133.62	58.79	587.91	1485.82
9	197.75	42.76	785.67	1528.57
10	85.51	48.10	871.18	1576.68
11	106.89	69.48	978.07	1646.16
12	42.76	16.03	1020.83	1662.19
13	32.07	16.03	1052.90	1678.23
14	144.31	10.69	1197.21	1688.91
15	187.06	10.69	1384.27	1699.60
16	309.99	133.62	1694.26	1833.22
17	390.16	0.00	2084.42	1833.22
18	395.51	0.00	2479.93	1833.22
19	422.23	0.00	2902.15	1833.22
20	358.09	0.00	3260.25	1833.22
21	497.05	0.00	3757.30	1833.22
22	459.64	0.00	4216.94	1833.22
23	566.53	0.00	4783.48	1833.22
24	652.05	32.07	5435.53	1865.29
25	662.74	37.41	6098.26	1902.70
26	855.15	48.10	6953.41	1950.80
27	887.21	69.48	7840.63	2020.28
28	1010.14	240.51	8850.77	2260.79
29	919.28	213.79	9770.05	2474.58
30	897.90	358.09	10667.95	2832.67
31	881.87	309.99	11549.82	3142.66
32	913.94	384.82	12463.76	3527.48
33	897.90	411.54	13361.67	3939.02
34	732.22	336.71	14093.89	4275.73
35	502.40	432.92	14596.28	4708.65
36	486.36	694.81	15082.65	5403.46
37	518.43	582.57	15601.08	5986.03
38	550.50	534.47	16151.58	6520.49
39	646.70	812.39	16798.29	7332.88
40	363.44	972.73	17161.72	8305.61

Days	Average Daily Gas Production		Average Cumulative Gas Production	
	Control	RPE 1	Control	RPE 1
41	593.26	416.88	17754.98	8722.50
42	438.26	464.99	18193.25	9187.48
43	347.40	358.09	18540.65	9545.57
44	288.61	416.88	18829.26	9962.46
45	203.10	523.78	19032.36	10486.24
46	171.03	555.85	19203.39	11042.08
47	171.03	534.47	19374.42	11576.55
48	122.93	630.67	19497.34	12207.22
49	122.93	523.78	19620.27	12731.00
50	74.83	742.91	19695.10	13473.90
51	117.58	716.19	19812.68	14190.09
52	192.41	603.95	20005.09	14794.04
53	96.20	769.63	20101.29	15563.67
54	122.93	582.57	20224.22	16146.24
55	149.65	737.56	20373.87	16883.80
56	165.68	641.36	20539.55	17525.16
57	128.27	550.50	20667.83	18075.66
58	69.48	753.60	20737.31	18829.26
59	90.86	523.78	20828.17	19353.04
60	96.20	475.68	20924.37	19828.71
61	138.96	764.29	21063.33	20593.00
62	149.65	700.15	21212.98	21293.15
63	155.00	513.09	21367.98	21806.24
64	155.00	721.53	21522.97	22527.77
65	176.37	406.19	21699.35	22933.96
66	117.58	400.85	21816.93	23334.81
67	203.10	475.68	22020.03	23810.49
68	58.79	379.47	22078.82	24189.96
69	208.44	315.34	22287.26	24505.30
70	101.55	390.16	22388.81	24895.46
71	106.89	347.40	22495.70	25242.86
72	96.20	283.27	22591.91	25526.13
73	69.48	213.79	22661.39	25739.91
74	112.24	245.85	22773.62	25985.77
75	128.27	395.51	22901.90	26381.27
76	101.55	315.34	23003.45	26696.61
77	74.83	219.13	23078.27	26915.74
78	74.83	342.06	23153.10	27257.80
79	80.17	272.58	23233.27	27530.38
80	80.17	277.92	23313.44	27808.30

81	64.14	288.61	23377.57	28096.91
82	64.14	251.20	23441.71	28348.11
83	69.48	352.75	23511.19	28700.86
84	80.17	245.85	23591.36	28946.71
85	69.48	203.10	23660.84	29149.81
86	69.48	326.02	23730.32	29475.84
87	58.79	309.99	23789.11	29785.83
88	69.48	261.89	23858.59	30047.72
89	21.38	219.13	23879.97	30266.85
90	48.10	288.61	23928.07	30555.46
91	42.76	283.27	23970.83	30838.73
92	16.03	229.82	23986.86	31068.55
93	26.72	235.17	24013.59	31303.71
94	26.72	299.30	24040.31	31603.01
95	37.41	240.51	24077.72	31843.52
96	32.07	277.92	24109.79	32121.45
97	42.76	261.89	24152.55	32383.34
98	10.69	309.99	24163.24	32693.33
99	42.76	358.09	24206.00	33051.42
100	10.69	336.71	24216.68	33388.13
101	16.03	454.30	24232.72	33842.43
102	53.45	411.54	24286.17	34253.97
103	106.89	486.36	24393.06	34740.33
104	122.93	470.33	24515.99	35210.66
105	80.17	705.50	24596.16	35916.16
106	48.10	625.33	24644.26	36541.49
107	48.10	379.47	24692.36	36920.96
108	42.76	609.29	24735.12	37530.25
109	42.76	587.91	24777.87	38118.16
110	53.45	513.09	24831.32	38631.25
111	48.10	470.33	24879.42	39101.58
112	53.45	684.12	24932.87	39785.70
113	53.45	529.12	24986.32	40314.82
114	42.76	475.68	25029.07	40790.50
115	48.10	481.02	25077.18	41271.52
116	42.76	470.33	25119.93	41741.85
117	37.41	411.54	25157.35	42153.39
118	26.72	411.54	25184.07	42564.93
119	26.72	342.06	25210.79	42906.98
120	69.48	342.06	25280.27	43249.04
121	32.07	267.23	25312.34	43516.28
122	48.10	256.54	25360.44	43772.82
123	53.45	261.89	25413.89	44034.71
124	21.38	192.41	25435.27	44227.12
125	53.45	213.79	25488.72	44440.90
126	26.72	224.48	25515.44	44665.38
127	64.14	219.13	25579.57	44884.51
128	58.79	251.20	25638.37	45135.71
129	53.45	224.48	25691.81	45360.19
130	42.76	267.23	25734.57	45627.42
131	53.45	171.03	25788.02	45798.45
132	21.38	112.24	25809.40	45910.69
133	64.14	138.96	25873.53	46049.65
134	21.38	106.89	25894.91	46156.54
135	32.07	133.62	25926.98	46290.16

APPENDIX – II
Batch Digestion Study of RPE 2

Days	Average Daily Gas Production			Average Cumulative Gas Production		
	Control	Neutralised RPE 2	Non Neutralised RPE2	Control	Neutralised RPE2	Non Neutralised RPE2
1	0.00	224.48	0.00	0.00	224.48	0.00
2	0.00	133.62	0.00	0.00	358.09	0.00
3	0.00	176.37	5.34	0.00	534.47	5.34
4	0.00	53.45	0.00	0.00	587.91	5.34
5	0.00	0.00	0.00	0.00	587.91	5.34
6	0.00	0.00	0.00	0.00	587.91	5.34
7	0.00	0.00	5.34	0.00	587.91	10.69
8	0.00	0.00	0.00	0.00	587.91	10.69
9	0.00	0.00	0.00	0.00	587.91	10.69
10	0.00	0.00	0.00	0.00	587.91	10.69
11	0.00	0.00	0.00	0.00	587.91	10.69
12	0.00	0.00	0.00	0.00	587.91	10.69
13	0.00	0.00	0.00	0.00	587.91	10.69
14	0.00	0.00	0.00	0.00	587.91	10.69
15	42.76	0.00	0.00	42.76	587.91	10.69
16	5.34	10.69	5.34	48.10	598.60	16.03
17	10.69	21.38	10.69	58.79	619.98	26.72
18	48.10	0.00	0.00	106.89	619.98	26.72
19	26.72	16.03	5.34	133.62	636.02	32.07
20	32.07	37.41	5.34	165.68	673.43	37.41
21	58.79	58.79	16.03	224.48	732.22	53.45
22	42.76	21.38	10.69	267.23	753.60	64.14
23	42.76	32.07	5.34	309.99	785.67	69.48
24	74.83	21.38	0.00	384.82	807.04	69.48
25	0.00	0.00	0.00	384.82	807.04	69.48
26	5.34	21.38	0.00	390.16	828.42	69.48
27	16.03	32.07	0.00	406.19	860.49	69.48
28	48.10	58.79	0.00	454.30	919.28	69.48
29	181.72	90.86	0.00	636.02	1010.14	69.48
30	187.06	74.83	0.00	823.08	1084.97	69.48
31	358.09	117.58	0.00	1181.17	1202.55	69.48
32	326.02	85.51	0.00	1507.20	1288.06	69.48
33	422.23	240.51	10.69	1929.42	1528.57	80.17
34	384.82	149.65	5.34	2314.24	1678.23	85.51
35	390.16	144.31	5.34	2704.40	1822.53	90.86
36	363.44	128.27	0.00	3067.84	1950.80	90.86
37	443.61	90.86	5.34	3511.45	2041.66	96.20
38	422.23	90.86	5.34	3933.67	2132.52	101.55
39	427.57	144.31	0.00	4361.25	2276.83	101.55
40	422.23	117.58	0.00	4783.48	2394.41	101.55
41	454.30	96.20	10.69	5237.77	2490.61	112.24
42	459.64	96.20	0.00	5697.41	2586.82	112.24

43	459.64	80.17	0.00	6157.06	2666.99	112.24
44	486.36	85.51	0.00	6643.42	2752.50	112.24
45	486.36	48.10	0.00	7129.79	2800.61	112.24
46	416.88	64.14	0.00	7546.67	2864.74	112.24
47	432.92	48.10	0.00	7979.59	2912.84	112.24
48	347.40	48.10	0.00	8326.99	2960.95	112.24
49	358.09	64.14	0.00	8685.08	3025.08	112.24
50	384.82	21.38	0.00	9069.90	3046.46	112.24
51	374.13	58.79	0.00	9444.03	3105.25	112.24
52	352.75	69.48	0.00	9796.77	3174.73	112.24
53	272.58	48.10	0.00	10069.35	3222.83	112.24
54	256.54	64.14	0.00	10325.90	3286.97	112.24
55	240.51	42.76	0.00	10566.41	3329.73	112.24
56	197.75	26.72	0.00	10764.16	3356.45	112.24
57	518.43	101.55	0.00	11282.59	3458.00	112.24

APPENDIX – III
Media Study on RPE 1

Days	Average Daily Gas Production of RPE 1								
	T0	T1	T2	T3	T4	T5	T6	T7	T8
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	5.34	0.00	0.00	0.00	5.34	74.83	16.03	85.51	74.83
3	0.00	80.17	16.03	0.00	5.34	74.83	74.83	37.41	90.86
4	10.69	58.79	0.00	32.07	10.69	106.89	74.83	32.07	138.96
5	10.69	69.48	16.03	16.03	42.76	160.34	74.83	85.51	144.31
6	10.69	90.86	10.69	21.38	138.96	101.55	101.55	21.38	106.89
7	10.69	256.54	58.79	42.76	48.10	411.54	128.27	48.10	53.45
8	5.34	384.82	96.20	138.96	42.76	272.58	101.55	64.14	58.79
9	10.69	326.02	106.89	155.00	48.10	176.37	90.86	42.76	80.17
10	0.00	390.16	122.93	37.41	58.79	288.61	90.86	58.79	138.96
11	16.03	422.23	176.37	69.48	85.51	133.62	101.55	42.76	229.82
12	42.76	929.97	181.72	117.58	138.96	171.03	96.20	0.00	155.00
13	37.41	539.81	224.48	144.31	138.96	486.36	85.51	0.00	181.72
14	42.76	582.57	267.23	149.65	155.00	507.74	192.41	0.00	299.30

Days	Average Cumulative Gas Production of RPE 1								
	T0	T1	T2	T3	T4	T5	T6	T7	T8
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	5.34	0.00	0.00	0.00	5.34	74.83	16.03	85.51	74.83
3	5.34	80.17	16.03	0.00	10.69	149.65	90.86	122.93	165.68
4	16.03	138.96	16.03	32.07	21.38	256.54	165.68	155.00	304.65
5	26.72	208.44	32.07	48.10	64.14	416.88	240.51	240.51	448.95
6	37.41	299.30	42.76	69.48	203.10	518.43	342.06	261.89	555.85
7	48.10	555.85	101.55	112.24	251.20	929.97	470.33	309.99	609.29
8	53.45	940.66	197.75	251.20	293.96	1202.55	571.88	374.13	668.08
9	64.14	1266.69	304.65	406.19	342.06	1378.92	662.74	416.88	748.25
10	64.14	1656.85	427.57	443.61	400.85	1667.54	753.60	475.68	887.21
11	80.17	2079.08	603.95	513.09	486.36	1801.15	855.15	518.43	1117.04
12	122.93	3009.05	785.67	630.67	625.33	1972.18	951.35	518.43	1272.03
13	160.34	3548.86	1010.14	774.98	764.29	2458.55	1036.87	518.43	1453.75
14	203.10	4131.43	1277.38	924.63	919.28	2966.29	1229.27	518.43	1753.05

ENERGY PRODUCTION FROM RUBBER PROCESSING EFFLUENTS THROUGH BIOMETHANATION

By

HARI B. KRISHNAN
MUHAMMED RANEEF S.
SURYA A. S.

ABSTRACT OF THE PROJECT REPORT

Submitted in partial fulfillment
of the requirement for the degree of

Bachelor of Technology
in
Agricultural Engineering

Faculty of Agricultural Engineering and Technology
Kerala Agricultural University

Department of Farm Power, Machinery, and Energy
KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
TAVANUR – 679 573, MALAPPURAM DISTRICT
KERALA, INDIA
2008

ABSTRACT

The generation and disposal of large quantities of biodegradable wastes such as Rubber Processing Effluents (RPE) without adequate treatment result in significant environmental pollution. Some of the waste streams are treated by conventional means like aeration, which is energy intensive and expensive. In this context, anaerobic digestion offers potential energy savings and is a more stable process for medium and high strength organic effluents. Apart from treating the wastewater, the methane produced from the anaerobic system can be recovered which results in saving the global environment by reducing the use of fossil fuels. The study was aimed at assessing the pollution hazard caused by rubber processing units, understanding the biomethanation characteristics of RPE and to evaluate the performance of locally available agricultural wastes viz. coconut shell, rubber seed shell etc. as packing media in high rate anaerobic bioreactors.

Two types of effluent were identified, one which is generated during the production of rubber sheet (RPE 1) and other one from the centrifuge plants (RPE 2). It was revealed that the RPE had a low pH and high BOD and COD. This reveals the extend of variation of characteristics from the standards. The batch digestion studies proved that RPE1 is suitable for biomethanation whereas RPE 2 is not suitable. The specific gas production of RPE1 found to be 6665.3 ml/l. Batch digestion studies with different media viz. coconut shell, rubber seed inner shell, and rubber seed outer shell reveals that any media can be used in the high rate bioreactor considering the physical characteristics and availability. Also, the amount of inoculum added to start the biomethanation did not showed any remarkable changes in the gas production. The pollution caused by RPE can be effectively reduced by anaerobic treatment with the added advantage of energy production. This can be further used to ensure better management of energy in the processing plants.