

STUDIES ON VEGETABLE OILS AS FUEL IN CI ENGINES

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PROJECT REPORT

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KERALA, INDIA
2005

DECLARATION

We hereby declare that this project report entitled '**STUDIES ON VEGETABLE OILS AS FUEL IN CI ENGINES**' is a bonafide record of project work done by us 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.

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CERTIFICATE

Certified that this project report, entitled, '**STUDIES ON VEGETABLE OILS AS FUEL IN CI ENGINES**' is a record of project work done jointly by **George Mathew Neerackal, Joe Joe L. Bovas** and **Sareena K.V.** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associateship or fellowship to them.

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CONTENTS

Chapter No.	Title	Page No.
	LIST OF TABLES	
	LIST OF FIGURES	
	LIST OF PLATES	
	LIST OF ABBREVIATIONS USED	
I	INTRODUCTION	1
II	REVIEW OF LITERATURE	5
III	MATERIALS AND METHODS	19
IV	RESULTS AND DISCUSSION	28
V	SUMMARY AND CONCLUSION	59
	REFERENCES	
	ABSTRACT	

LIST OF TABLES

Table No.	Title	Page No.
3.1	Specification of diesel engine	27
4.1	Specific Gravity of fuels at 20 °C	28
4.2	Viscosity at 25°C, 60 °C and 90 °C	29
4.3	Comparison of various stages in Trans-esterification	35
4.4	Comparison of the reactant requirements and product yields in two Transesterification methods	38
4.5	Engine test with diesel as fuel	41
4.6	Engine test with POME, SOME and COME as fuel	42
4.7 Engine test	Engine test with B30 COME, B30 SOME and B30 POME as fuel	43
4.8	Engine test with B60 COME, B60 SOME and B60 POME as fuel	44
4.9	Engine test with C70 + P30 and C70 + S30 and as fuel	45
4.10	Engine test with and C50 + P50, C50 + S50 and P50 + S50 as fuel	46
4.11 Engine test	Engine test with 10 % and 20 % Coconut oil blended with diesel as fuel	47

LIST OF FIGURES

Fig. No.	Title	Page No.
4.1	Viscosities of diesel and vegetable oils at different temperatures.	31
4.2	Viscosities of diesel and biodiesels at different temperatures	31
4.3	Viscosities of diesel and B60 blends at different temperatures	32
4.4	Viscosities of diesel and B30 blends at different temperatures	34
4.5	Viscosities of diesel and various biodiesel-biodiesel blends at different temperatures	34
4.6	Smoke density at various loads using biodiesels in comparison with diesel	48
4.7	Smoke density at various loads using biodiesels-B60 blends Vs. diesel	48
4.8	Smoke density of diesel Vs. B30 blends at various loads	50
4.9	Smoke density at various loads –diesel Vs. biodiesel blends with 70% COME	50
4.10	Smoke density at various loads –diesel Vs. 50:50 biodiesel blends	51
4.11	Smoke density at various loads –diesel Vs. biodiesel from coconut oil and its various blends	51
4.12	Comparison of smoke density with diesel blended with coconut oil at different loads	52
4.13	Specific fuel consumption at various loads- diesel Vs. biodiesel	54
4.14	Specific fuel consumption at various loads- diesel Vs. B60 blends	54
4.15	Specific fuel consumption at various loads- diesel Vs B30 blends	55
4.16	Specific fuel consumption at various loads- diesel Vs. biodiesels with 70% COME	55
4.17	Specific fuel consumption at various loads- biodiesel Vs. biodiesel blends 50% each	56
4.18	Comparison of SFC of diesel with diesel blended with coconut oil at different loads	56
4.19	Specific fuel consumption at various loads- diesel Vs. coconut oil biodiesel and its various blends	58

LIST OF PLATES

Plate No.	Title	Page No.
1	Measurement of specific gravity with hydrometer	20
2	Experimental set up for viscosity measurement	20
3	Experimental set up for trans-esterification process	23
4	Engine test set up	26
5	Trans-esterification reactions	36
6	Separation of biodiesel from glycerol	37
7	Vegetable oils and the corresponding biodiesels	39

SYMBOLS AND ABBREVIATIONS

bhp	-	Brake horse power
BSFC	-	Brake specific fuel consumption
BTDC	-	Before top dead center
COME	-	Coconut oil methyl ester
cst	-	centistokes
Dept.	-	Department
°C	-	Degree Celsius
Fig.	-	Figure
HC	-	Hydro carbon
hp	-	Horse power
KCAET	-	Kelappaji College of Agricultural Engineering and Technology
POME	-	Palm oil methyl ester
SOME	-	Sunflower methyl ester

Chapter I

Introduction

INTRODUCTION

Transport and agriculture sectors of the country are highly dependent on petroleum fuels at present. The fossil fuels are expected to run out within the next few decades if the current rate of use prevails. The demand of diesel in India is increasing at a faster rate from 28.3 million tones in 1994-1995 to 40 million tones in 2002-2003 (Anonymous, 2003). Fossil fuels are so unevenly distributed that many countries of the world have to depend on others for their fuel requirement. For self-reliance in fuel it is imperative for India to harness all possible locally available sources of energy. Apart from their economic aspects, the environmental dimensions of fossil fuel use also favours alternate renewable fuels. As per the Kyoto protocol, countries including India have committed to reduce carbon emission. Bio-fuels are carbon neutral and nowadays there is a worldwide appreciation for such sources.

Vegetable oils present a very promising alternative to diesel oil since they are produced easily in rural areas where there is an acute need for modern forms of energy. Vegetable oils always had their advocates ever since the advent of internal combustion engines. The inventor of diesel engine, Rudolf Diesel, confidently predicted that plant based oils would be widely used to operate his engine. In fact, he used peanut oil for its demonstration (Srinivasa and Gopalakrishnan 1990). However, it is only in recent years that systematic efforts have been made to utilize vegetable oils as fuel in engines. Obviously only non-edible vegetable oils are being seriously considered, as edible oils are in great demand and are far expensive as fuels at present. This picture may change in future when energy farms become part and parcel of Indian agriculture.

Due to the wide variation in climate, soil conditions, competing use of land etc. different nations look upon different vegetable oils as potential fuels. For

example, Malaysia is considering the use of palm oil and its derivative as fuels for engines.

A number of oils are considered world wide for the use in engines. These include jatropha oil, soya bean oil, karanja oil, cottonseed oil, rice bran oil, rapeseed oil, sunflower oil etc. Vegetable oils can be directly used in diesel engines as they have a high cetane number and calorific values very close to diesel. However, the brake thermal efficiency is inferior to diesel. They also lead to problems of high smoke, hydrocarbons and carbon monoxide emissions. This is because, high viscosity and low volatility of vegetable oils lead to difficulty in atomizing the fuel and mixing it with air. Further, gum formation and piston sticking under long-term use (due to the presence of oxygen in their molecules) and the reactivity of unsaturated hydrocarbons chains are the problems with vegetable oils.

Several approaches have been tried by researchers to use vegetable oils directly in diesel engines. Some of them like preheating the oil, blending it with diesel, use of semi-adiabatic engine components, dual fuelling with gaseous and liquid fuels etc. have been found to be effective (Agarwal, 1998). Transesterification of vegetable oils is currently regarded as the most important means to process vegetable oils. The product from trans-esterification showed improved performance and reduced emissions. They are commercially referred as 'Biodiesels'. Biodiesel is a mixture of mono-alkyl esters of fatty acids derived from vegetable oils or animal fats. In simple terms, biodiesel is the product obtained when a vegetable oil or animal fat chemically reacts with an alcohol to produce fatty acid alkyl esters. A catalyst such as sodium or potassium hydroxide is required. Glycerol is produced as a byproduct. It has low viscosity compared to the parent vegetable oil and has physical properties better suited for diesel engines. The cetane number is also improved. The methyl esters of vegetable oils offer low smoke levels and high thermal efficiencies than pure vegetable oils. The methyl

esters of vegetable oils also lead to improved heat release rates. The power output was found to be superior to pure vegetable oils.

Biodiesel as an alternative fuel for diesel engines is receiving great attention worldwide. It is a renewable fuel and can be used either in pure form or in blends with diesel fuel in unmodified engines. They are also found to reduce exhaust pollutants to some extent. Another attraction is that it can be produced easily from common feedstocks. However, the relative simplicity of biodiesel production can disguise the importance of maintaining high quality standards for any fuel supplied to a modern diesel engine. It is essential to the growth of the biodiesel industry that all fuel produced and sold meet these quality standards.

In addition to the reduction in pollution, popularization of biodiesel gives many other benefits to the country. It provides a market for excess production of vegetable oils and animal fats. Production and use of biodiesel decreases the country's dependence on imported petroleum. However petroleum markets tend to be sensitive to small fluctuations in supply and additional sources of fuel can have a surprising impact on stabilizing fuel prices.

As the primary feedstock for biodiesel is biologically produced from oil or fat that can be grown season after season, biodiesel is renewable. As biodiesel is renewable it does not contribute to global warming due to its closed carbon cycle. And, since the carbon in the fuel is originally removed from the atmosphere by plants, there is no net increase in carbon dioxide levels. It should also be noted that the primary alcohol used to produce biodiesel is methanol. Methanol makes up about 10% of the feed stock input and since most methanol is currently produced from natural gas, biodiesel is not completely renewable. But the production of methanol from biomass by thermo-chemical gasification is technically possible.

The exhaust emissions from biodiesel are lower than that of regular diesel fuel. Biodiesel provides substantial reduction in carbon monoxide, unburned hydrocarbons, and particulate emissions from diesel engines. While the carbon

monoxide and unburned hydrocarbons from diesels are already low compared with gasoline engines, biodiesel reduces them further. Particulate emissions, especially the black soot portion, are greatly reduced with biodiesel. Unfortunately, many emission tests have shown a slight increase in the oxides of nitrogen (NO_x) with biodiesel (Srinivasa and Gopalakrishnan, 1990). This increase in NO_x can be eliminated with a small adjustment to the engine's injection timing while still retaining a particulate reduction.

Biodiesel has excellent lubricating properties. Even when added to regular diesel fuel in an amount equal to 1-2% (volume), it can convert fuel with poor lubricating properties, such as ultra-low-sulfur diesel fuel, into an acceptable fuel. Even though much research work has been done within and outside the country, biodiesel production and use are not popular in Kerala. The most important oil crop of Kerala is coconut. Even though there is only limited scope for its use as fuel at the current price levels, there are chances for wide fluctuations in coconut oil prices as experienced few years back. Decentralized energy production is at times vital for the development of rural societies. Apart from the use of pure biodiesels in engines, their blends with diesel also can be advantageous in several aspects. Notwithstanding the present adversaries of economics, academic interest to study our own home made diesel fuel prompts us to make a comparative study of different biodiesels with coconut oil.

Hence an investigation was taken up with the following specific objectives:

1. To study the relevant physical and chemical properties of the vegetable oils, the biodiesels and different blends prepared.
2. To study the trans-esterification procedures for preparation of methyl esters from three different vegetable oils viz. sunflower oil, palm oil and coconut oil.
3. To conduct engine tests with biodiesel, their blends with diesel and blends of different biodiesels.

Chapter II

Review of Literature

REVIEW OF LITERATURE

A review on the different aspects of vegetable oil used as fuel in diesel engines as well as preparation and use of biodiesels is made in this chapter.

2.1 Vegetable oil as fuel

Dunn and Perera (1985), made studies using rubber seed oils (RSO) to study the suitability of RSO as a diesel fuel substitute for engines used in plantation industry. It was found that viscosity of RSO was ten times greater than that of diesel at 40°C. RSO met the ASTM limits for total active sulphur, water and sediments. But failed to meet the limits for ash content, carbon residues, reflecting the crude nature of sample test.

Srinivasa and Gopalakrishnan (1991) conducted a study on the use of vegetable oils as fuel in diesel engines. The oils tested were rice bran oil and palm oil. Their study indicated that vegetable oils could be used in diesel engines without any major problems, brake thermal efficiency was found to be a slightly lower and the smoke density higher than with diesel oil.

Agarwal (1998) studied the use of vegetable oil in CI engines and found that the problems associated with the use of vegetable oil in diesel engines can be classified into two. There are operational problems and durability problems. According to him operational problems are related to startability, ignition, combustion and engine performance. The durability problems relate to deposit formation, carbonization of the injector tip, ring sticking, lubricant oil degradation/dilution etc. He reported that these problems could be handled broadly in two ways.

- a. Engine modification: The different engine modifications suggested were dual fueling, injector system modification and heated fuel lines.
- b. Fuel modification: The different fuel modification listed were blending, trans-esterification, cracking/pyrolysis and hydrogenation to reduce polymerization. Engine modifications are expensive in terms of money and

time owing to the large number of engines already in use. He remarked that the main problem in the use of vegetable oil is its high viscosity and could be solved to a great extent by the trans-esterification of vegetable oils to the corresponding esters.

Karaomanoglu *et al.* (2000) conducted a long term CI engine test with sunflower oil. The test was conducted at constant speed of 1500 rpm under part load conditions for 50 hours with a single cylinder, direct injection air-cooled diesel engine. The results indicated that sunflower oil could be proposed as a possible alternative for diesel oil.

Kumar *et al.* (2003) studied the various methods of using Jatropha oil and methanol in diesel engines. Their study found that brake thermal efficiency was better in duel fuel operation than by using jatropha oil alone. The smoke emission and nitric oxide emission were found to be lower with jatropha oil than diesel. It was further reduced in duel fuel operation and the blend with methanol. It was also found that the ignition delay was higher with jatropha oil and further increased with blend and duel fuel operation.

Geller *et al.* (2003) conducted a study to aid the development of chemical models for diesel fuel substitutes based on vegetable oils and their derivatives. They studied the atomization properties of pure short chain triglycerides using a previously developed model. They also analyzed the atomization of a simulated low molecular weight oil from a plant named Cuphea VS – 320. The atomization properties were compared with those of peanut oil and diesel fuel to provide reference. Their study suggested better performance with short chain oils and triglycerides than with traditional vegetable oils containing predominantly long chain triglycerides.

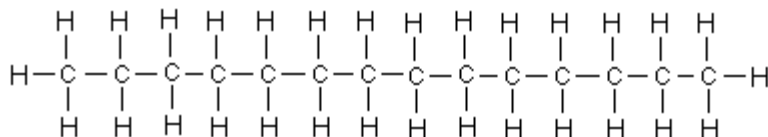
2.1.1 Diesel fuel quality requirements

Gerpen *et al.* (2004) conducted a study on the fuel requirements for diesel engine. According to them a fuel for diesel engine should satisfy the following requirements.

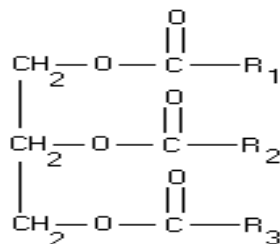
- a. Fuel should auto ignite at the temperatures and pressures present in the cylinder when the fuel is injected.
- b. The fuel must release energy when it burns.
- c. The fuel must not limit the operability of the engine at low temperatures.
- d. The fuel must not contribute to corrosion as many of the parts in the diesel fuel injection system are made of high-carbon steels and thus are prone to corrosion when in contact with water.
- e. The fuel must not contain sediment that could plug orifices or cause wear.
- f. The fuel should not cause excessive pollution.
- g. The fuel should be intrinsically safe.

2.1.2 Fuel chemistry

The ideal diesel fuel molecule is a saturated non-branched hydrocarbon molecule with carbon number fourteen (Srinivasa and Gopalakrishnan, 1991). The structure of a typical diesel oil is as shown below:



Vegetable oil molecules are triglycerides of fatty acids generally non-branched chains of different lengths and different degrees of saturations. They are liquids at ordinary temperature. They contain a large number of saturated as well as unsaturated fatty acid esters and have complex structures as below:



R_1 , R_2 and R_3 represent the hydrocarbon chains of the fatty acid groups of the triglyceride. In their free form, fatty acids have the configuration shown, where R_1 , R_2 , R_3 are hydrocarbon chains having carbon atoms ≥ 10 .

Dunn and Perera (1985) studied the fuel chemistry of rubber seed oil and compared it with that of diesel oil. They found that RSO is having a composition similar to that of linseed oil. It was found that the cetane rating of RSO is close to ASTM standards of No.2 diesel oil. RSO is extremely viscous and meet the ASTM standards of total and active sulphur, water and sediments. But it failed to meet the ASTM standards for ash content, carbon residue, reflecting the crude nature of the sample tested. It also had higher cloud and pour point.

Srinivasa and Gopalakrishnan (1991) studied the fuel chemistry of vegetable oils and found that the characteristics of the wide variety of vegetable oils fall within a narrow band and are close to those of diesel fuel. They found that vegetable oils showed about 10% less heating value than diesel oil due to the presence of oxygen molecules in their structure. He also stated that the high viscosity of the vegetable oils is due to its bulky structure and that it leads to some problems in pumping and atomization in the injection system of the diesel engine. Vegetable oils showed poor volatility characteristics, precluding their use in compression ignition engines. From their properties it was clear that vegetable oils are suitable as fuel only for compression ignition engines.

Agarwal (1998) conducted a study and found that vegetable oils are a mixture of organic composites ranging from simple straight chain compounds to complex structures of proteins and fat-soluble vitamins. Some inorganic heavy metals are also present. Vegetable oils may have perceptible amounts of nitrogen and sulphur, which may affect the emission spectra. Vegetable oils contain hydrocarbons of high aromaticity; most of them are not simple aromats containing hydrogen and carbon only but also belong to the turpentine class. His study showed that the chain length of fatty acids is inversely proportional to the thermal efficiency except at very small chain lengths. Proportion and location of double bonds also affected the cetane number. On volume basis, the heat content of

vegetable oils is almost comparable to diesel oil owing to greater densities. Heat value decreases with the increase in unsaturation as a result of fewer hydrogen atoms and decreases with increasing saponification number.

2.2 Processing of vegetable oils

Stumburg *et al.* (1996) investigated the use of conventional refinery technology to convert vegetable oils into a product resembling diesel fuel. They found that the use of medium severity refinery hydro-process yielded a product (super cetane) in the diesel boiling range with a high cetane value (55-90). Their study showed that the impact of the super cetane-diesel mixture on the emissions were similar to the impact by cetane enhancement by the use of nitrate additive.

Srinivasa and Gopalakrishnan (1991) conducted a study on vegetable oils such as karanji oil, rice bran oil and palm oil by subjecting it to thermal cracking, a process common in the petrochemical industry. In their study they found that the viscosity of the oil was reduced as the large molecule of the vegetable oil was split into smaller molecules by subjecting it to high temperature.

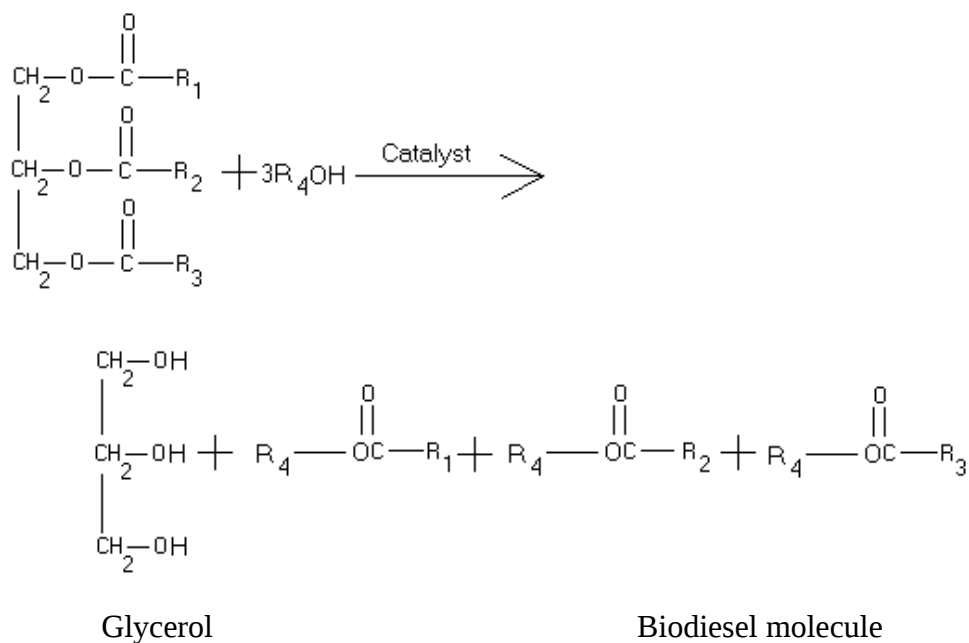
Agarwal (1996) studied the use of modified vegetable oils in diesel engines. He conducted experiments by blending with diesel and methanol at room temperature and higher temperatures. His studies showed that the viscosities of the vegetable oils could be reduced, improving the atomization at the injector nozzle.

Kumar *et al.* (2003) conducted studies using Jatropha oil and methanol by blending as well as dual fuel operation. A comparison of the results obtained from the use of jatropha oil with jatropha oil-methanol blend showed increase in brake thermal efficiency from 27.4% to 28.1%. A reduction in exhaust gas temperature, reduction in smoke density, lowering of Hydrocarbon and CO emissions and an increase in ignition delay were observed. The results of the dual fuel operation with methanol and jatropha oil showed a significant increase in the brake thermal efficiency from 27.4% to 28.7%, a good reduction in smoke levels at maximum power output, increased hydrocarbon and CO emissions, reduction in NO level

from 736 to 713 ppm, higher ignition delay, peak pressure, maximum rate of pressure rise and combustion rate.

2.2.1 Transesterification

All vegetable oils and animal fats consist primarily of triglyceride molecules. Transesterification is the process of reacting triglycerides with an excess of alcohol in the presence of a catalyst (KOH, NaOH, NaOCH₃, etc.) to produce glycerol and fatty esters. The transesterified triglycerides are commonly known as biodiesel. Biodiesel is defined as the mono-alkyl esters of fatty acids derived from vegetable oils or animal fats. In simple terms, biodiesel is the product obtained when a vegetable oil or animal fat is chemically reacted with an alcohol to produce fatty acid alkyl esters. A Catalyst such as sodium or potassium hydroxide is required for the reaction (Gerpen *et al.*, 2004). The chemical reaction with methanol is shown below.



Srinivasa and Gopalakrishnan (1991) studied the production of methyl esters of vegetable oil. They produced methyl esters from peanut oil, soybean oil, babassu oil, palm oil, and sunflower oil.

Gupta (1994) considering the limitations and capabilities of a common Indian farmer and his requirements, developed a simple inexpensive and less time consuming procedure to prepare biodiesel. The main steps involved are (a) heating the oil, (b) adding alkaline alcohol to oil, and stirring the mixture, (c) settling and separation of glycerol, (d) washing of biodiesel with water and removal of water. It requires not only less time but also less heating and the whole process is completed in about 5 hours. And the process does not require any special equipment.

Cvengros and Povazanee (1996) studied the production and treatment of rape seed oil methyl esters as an alternative fuel for diesel engine. Four percent NaOH in methanol was used as the catalyst. It was found that the final treatment of methyl ester with phosphoric acid and ammonia provides for an exchange of ashy soap forms in methyl ester for ashless forms, thus rendering methyl ester non-corrosive.

Agarwal (1998) conducted a study on the production of methyl and ethyl esters of linseed oil, which showed viscosity, heat content, and density close to that of diesel oil. Esterification brought about a modification in the molecular structure of the linseed oil, thus converting it into biodiesel.

Ma *et al.* (1998) studied the effects of catalyst, free fatty acids and water on the trans-esterification of beef tallow and the reaction timing was investigated. They found that sodium hydroxide was more effective than sodium methoxide as a catalyst and the presence of water was more detrimental than the presence of free fatty acids. In their study the best results were obtained when the water content of the beef tallow was kept below 0.06% and the free fatty acid content below 0.5%. They reported that the production of beef tallow methyl esters were completed in 15 minutes

Canzkei and Gerpen (2003) studied the trans-esterification of low cost feed stock such as used frying oils via acid catalysis. They investigated the molar ratio of alcohol, reaction temperature, catalyst amount, reaction time, water content and free fatty acid to determine the best strategy for producing biodiesel. Food grade soybean oil was used to make esters using excess methanol and sulfuric acid as

catalyst. To compare the effect of alcohol they made biodiesel using alcohols like methanol, ethanol, 2-propanol and n-butanol. It was found that acid catalysis can provide high conversion rates but much longer time was required. It was also found that acid catalysis requires the concentration of water to be less than 0.5%.

Moreno *et al.* (1999) conducted a study in the production of methyl ester from sunflower oil. It was found that the sunflower methyl ester (SME) had a small amount of water and methanol, which probably indicated a better process of esterification and later purification. The lower acidity of the SME was related to a good process of separation by the catalyzer.

Cvengros *et al.* (2004) studied the production of methyl esters from used frying oils and fats. They found that if the acidity number is below 3.0 mg KOH/g and water content below 0.1%, then they could process them to methyl esters using standard techniques of alkali-catalyzed trans-esterification with methanol. Vacuum distillation of free fatty acids in a film evaporator was found as an effective method for simultaneously decreasing the free fatty acid content.

Gerpen *et al.* (2004) conducted a study on the different approaches available for transesterification reaction to occur quickly enough to be practical. The different options suggested by him are given below.

a. Base catalysts such as NaOH, KOH and sodium methoxide

Base catalysts are used essentially for all vegetable oil biodiesel production. The initial free fatty acid content and the water content are generally low. Tallows and greases with free fatty acid content greater than about 1 % must be pretreated to either remove the FFA or convert the FFA to esters before beginning the base catalyzed reaction. Otherwise, the base catalyst will react with the free fatty acids to form soap and water. The soap formation reaction was very fast and goes to completion before any esterification begins. Base catalyzed reactions are reported to be relatively fast, with residence times from about 5 minutes to about 1 hour, depending on temperature, concentration, mixing and alcohol: triglyceride ratio.

b. Acid Catalysts such as H₂SO₄, H₃PO₄ and CaCO₃ :

Acid catalyst systems were characterized by slow reaction rates and high alcohol: tryglyceride requirements (20:1 and more). Generally, acid catalyzed reactions were used to convert FFA to esters, or soaps to esters as a pretreatment step for high FFA feedstocks. Residence times from 10 minutes to about 2 hours are reported.

c. Lipase Enzymes

Gerpen *et al.* (2004) reported that the lipase enzymes are dependant on source. Lipase catalyzed reactions have the advantage of producing only esters and pure glycerol. The enzyme reactions are highly specific and chemically clean. As the alcohol can be inhibitory to the enzyme, a typical strategy is to feed the alcohol into the reactor in three steps of 1:1 mole ratio each. The reactions were very slow, with a three step sequence requiring from 4 to 40 hours, or more. The reaction conditions were modest, from 35 to 45°C. The non-catalyst options were designed to overcome the reaction initiation lag time caused by the extremely low solubility of the alcohol in the TG phase. One approach was the use of a co-solvent, tetrahydrofuran (THF), to solubilise the methanol. The result was a fast reaction, on the order of 5 to 10 minutes, and no catalyst residues in either the ester or the glycerol phase. The THF co-solvent was chosen, in part, because it had a boiling point very close to that of methanol. This system required a rather low operating temperature, 30°C.

d. Non-catalyst options such as supercritical processes, and co-solvent systems

Another non-catalytic approach is the use of a high (42:1) alcohol to oil ratio. Under supercritical conditions (350 to 400 °C and > 80 atm) the reaction is complete in about 4 minutes.

Kumar *et.al* (2003) studied the trans-esterification process of jatropha oil using methanol as the alcohol and NaOH as the catalyst and compared it with

diesel. The study showed that the combustion duration and ignition delay were increased.

Canzkei and Gerpen (2003) constructed a pilot plant to produce biodiesel from high free fatty acid feedstocks. The constructed plant had a capacity of 190 liters and uses acid catalyzed pretreatment followed by an alkaline catalyzed transesterification. They also estimated the fuel cost using different feedstock.

Puhan *et.al* (2005) studied the production of methyl ester from mahua oil and studied its physical and chemical properties. The cetane number of mahua methyl ester was found to be 51 while the cetane number of diesel is 46. The specific gravity was almost equal to that of diesel. The flash point and fire point were 127 and 136 respectively, which are also higher than that of diesel.

2.3 Engine tests

Several workers used vegetable oils as well as their derivatives in diesel engines. Srinivasa and Gopalakrishnan (1991) reported that Rudolf Diesel used peanut oil in his engine.

Dunn and Perera (1985) conducted an engine test using rubber seed oil. The engine tested was a single cylinder, four stroke, air-cooled, naturally aspirated petter (model AC 1) engine giving 4.9 kW at 3600 rpm. Tests were carried out at different loads with engine running on diesel oil, rubber seed oil (RSO), and blends of rubber seed oil with diesel at constant speed setting of 2600 rpm. The blends used were having 25%, 50% and 75% of RSO by volume. The results showed that RSO and its blends with diesel behaved in the same manner as that of diesel, the specific fuel consumption was higher in the case of RSO and its blends with diesel, the thermal efficiency was slightly higher in the case of RSO, the carbon deposits were higher and there was no significant increase in exhaust temperature.

Elsbett *et al.* (1985) developed a new DI diesel engine to use vegetable oil directly without processing it. According to them as the per liter, vegetable oil has almost the same heat value as gasoline, it has the important advantage to be suitable

for diesel engine which are superior to other engines in a ratio of 40 to 27. They concluded that this fact resulted in lower fuel consumption in engines.

Srinivasa and Gopalakrishnan (1991) conducted engine test using methyl esters of karanja oil, rice bran oil, neem oil and palm oil on a single cylinder, four stroke, water cooled, direct injection Kirloskar A V1 engine. The engine was tested at loads of 20, 40, 60, 80, 100, 110 percent of the rated output at 1500 rpm. It was found that methyl esters of vegetable oils showed shorter ignition delays and longer combustion duration than diesel oil, but the smoke emission was found to be a little higher than with diesel

Stumburg *et al.* (1996) conducted an engine test using hydro-processed vegetable oil. The engine used for the test was a Ricardo single cylinder engine. Six fuels were tested using the EPA 13-mode test procedure. The results showed a reduction in the exhaust gases particulates, as a result of the improvements in the ignition quality.

Laforgia and Ardito (1995) studied the performance and emissions of biodiesel fueled 4 cylinder SOFIM 2500 IDI engine. They concluded that bio-diesel could substitute diesel fuel substantially by neither altering the engine performance nor modifying the engine itself, the injection timing must be advanced 30% from the setting provided by the manufacturer in order to obtain best smoke results.

Agarwal (1998) conducted engine test using linseed oil methyl ester and found that there was a reduction in the smoke density and a reduction in the polymerization of vegetable oil was also seen.

Moreno *et al.* (1999) studied the use of sunflower methyl ester for automobile diesel engines. Engine test were conducted with sunflower oil methyl ester and its blends with diesel. The engine used was Isuzu model 16640, 4 cylinders, indirect mechanical injection, turbo charger without inter cooler. Their studies showed that sunflower oil methyl esters whose contents were in the range 25 to 50 % were most suitable. The HC and CO emissions decreased considerably and NO_x emissions were slightly below that of diesel fuels.

Karaomanoglu *et al.* (2000) conducted a long term engine test using sunflower oil for 50 hours. The engine used for the test was a four stroke, single cylinder direct injection, air cooled diesel engine with a bore to stroke ratio of 108:110. The results indicated that sunflower oil could be proposed as a possible candidate for diesel fuel.

Gupta (2001) reported comparable performance of an unmodified, direct injection, 3.67 kW diesel engine with biodiesel of rice bran oil, cotton seed oil, linseed oil and rape seed oil. The effects of different injection timings and injection pressures on brake thermal efficiency were also studied. It was reported that as compared to fuel injection pressure, the fuel injection timings had more pronounced effect on brake thermal efficiency. Optimum values of fuel injection timing and pressure were found to be 25° BTDC and 25 MPa respectively for all biodiesels studied except for rice bran oil biodiesel and unwashed linseed oil biodiesel for which the optimal value of fuel injection timings were below the range studied.

Herchel *et al.* (2001) studied the effects of pure coconut oil and coconut oil-diesel fuel blends on the performance and emissions of a direct injection diesel engine. Operation of the test engine with pure coconut oil and coconut oil - diesel fuel blends for a wide range of engine load conditions were shown to be successful even without engine modifications. It was also shown that increasing the amount of coconut oil in the coconut-diesel fuel blend resulted in lower smoke and NO_x emissions. However, this resulted in an increase in the BSFC. This was attributed to the lower heating value of neat coconut fuel compared to diesel fuel.

Munoz *et al.* (2001) studied the emissions of an automobile diesel engine fueled with sunflower methyl ester and their blends with diesel fuel. The engine used was Isuzu model 16640, 4 cylinders, indirect mechanical injection, turbo charger without inter cooler. The test was carried out without any engine modification but the injection timing was delayed by 3° and then the emissions were measured. According to their studies the hydrocarbon emission was lower, NO_x emissions were totally dependent on the engine operation conditions of speed and load and the CO emission were lower than that of diesel fuel. Delaying the

injection timing by 3 ° caused higher HC emissions and slight decrease in NO_x emissions. The CO emission increased in all operating conditions.

Kumar *et al.* (2003) conducted engine tests using jetropha methyl ester, jetropha oil and jetropha oil methanol blend. For the test they used a 4 stroke, single cylinder, water-cooled diesel engine developing 3.7 kW at 1500 rpm. A high-speed digital acquisition system in conjunction with a piezoelectric transducer was used to measure the cylinder pressure. An infrared exhaust analyzer was used to measure HC and CO. For measuring NO_x a Rosemount analytical, model 951A analyzer was used. Smoke levels were obtained using a Bosch system and the injection timing was optimized at 27° before TDC and the cooling water temperature at the outlet maintained at 70 °C. The results showed a significant increase in brake thermal efficiency, a reduction in smoke density and reduced NO emissions.

Raheman and Phadatare (2003) studied the performance of esterified karanja oil and its blends with diesel fuel. The reduction in exhaust emissions together with increase in torque, brake power, brake thermal efficiency and reduction in brake specific fuel consumption were observed for B20 and B40 blends of karanja biodiesel.

Raymond *et al.* (2004) conducted studies on carbon balance implications of coconut biodiesel utilization in the Philippine automotive transport sector. Different scenarios for the use of agricultural residues as fuel for heat or power generation were analyzed. Reduction in net CO₂ emissions were estimated at 77–104 g/MJ of diesel displaced by biodiesel. The predicted reductions in CO₂ emissions were found to be much greater than values reported in recent studies on biodiesel derived from other vegetable oils. However, agricultural productivity constraints suggest that by 2010, the maximum level of biodiesel substitution for the entire country was only 8%.

Puhan *et al.* (2005) conducted engine test using Mahua oil methyl ester on a Kirloskar, single cylinder, four stroke, constant speed, water cooled, direct injection vertical engine and was coupled to a swinging field separating exciting type DC

generator and loaded by electrical resistance bank. An iron –constantan thermocouple, measured the exhaust gas temperature and a mercury thermometer measured the cooling water temperature. The results showed a higher specific fuel consumption, but it was found that the nitrogen oxides were lowered by 4%, the heating value was 12% less than diesel, the smoke density reduced by 12% and the CO and HC emissions extremely low.

Usta (2005) conducted studies using tobacco seed oil methyl ester in a four cycle, four-cylinder turbocharged indirect injection diesel engine. The effects of tobacco seed oil methyl ester-diesel blends were examined at both full and partial loads. Among the blends it was found that B82.5 provided the maximum increase in the torque, power and thermal efficiency. The power obtained was 3.13% and the peak thermal efficiency 2.02% higher than that obtained with diesel fuel. The experimental results thus showed that tobacco seed oil methyl ester can be partially substituted for the diesel fuel at most operating conditions.

Chapter III

Materials and Methods

MATERIALS AND METHODS

The methodology adopted for conducting the experimental investigation involves three sections viz. study of fuel properties, study of transesterification process and engine tests.

3.1 Study of physical properties of vegetable oils and their methyl esters

The physical properties such as specific gravity and viscosity were analyzed.

3.1.1 Specific gravity

The hydrometer method for determining specific gravity was used as this is suitable for with transparent oils. The experimental setup is shown in Plate 1.

100 to 200 ml of the oil to be examined was poured into a tall cylinder deep enough to accommodate the hydrometer and wide enough to allow it to float freely in the oil. When the oil was free from air bubbles, the hydrometer was carefully inserted, and allowed to reach equilibrium. Then it was depressed by about two scale divisions and released by imparting a slight spinning motion to bring it to rest away from the walls of the cylinder. When equilibrium was re-established, the specific gravity on the scale was read. The correct reading is that point on the hydrometer scale at which it is cut by the surface of the oil and it should, if possible, be estimated to the fourth place of decimals.

3.1.2 Viscosity

The viscosity of diesel, vegetable oil, biodiesel and the blends were observed at different temperatures viz. 25 °C, 60 °C and 90 °C. Redwood No.1 Viscometer was used for the study (Plate 2). Redwood apparatus measures viscosity in empirical units and not in absolute units such as centistokes. It was possible to convert Redwood viscometer readings to absolute units. The method is primarily applicable for viscosity determination of those oils which flows in a newtonian

manner (i.e. if it possesses a linear relationship between shearing stress and rate of shear under the test condition).

The procedure followed is given below:

- (a) The oil cup was cleaned with a suitable solvent (carbon tetrachloride) and dried thoroughly using soft tissue paper. The jet hole was cleaned with a fine thread.
- (b) The viscometer was set up, using the circular spirit level to ensure its level. The bath was filled with water, to a level not less than 10mm below the rim of the oil cup at the test temperature.
- (c) The viscometer bath was treated to a few degrees above the desired test temperature. The prepared sample was poured in to the oil cup through a filter of metal gauze. The temperature of the bath was adjusted until the sample in the cup is maintained at test temperature stirring the contents of the bath and cup during the process. The sample was stirred during the preliminary period by means of ball valve, closing the bottom of the jet by suitable means. But the sample was not stirred during the actual determination when the temperature of sample became quite steady at the desired value. The liquid level was adjusted by allowing the sample to flow out until the surface of the sample touches, the filling point. Then the oil cup was placed in position and the oil cup thermometer was swung towards the closed end of the curved slot in the cover. The clean, dry, standard 50ml flask was placed centrally below the jet with the top of the neck a few millimeters from bottom of the jet. The flask was not insulated in any way. The ball valve was lifted simultaneously starting the time recorder. The valve was suspended from the clip supporting the oil cup thermometer by means of the hook in the wire stem. The time recorder was stopped at the

instant the sample reached the graduation mark of the flask and the final reading of the oil cup thermometer was noted.

- (d) Determinations were rejected if the temperature of the sample in the oil cup varied during the run by more than 0.1°C for temperatures of 60°C or below, by more than 0.3°C for 93°C, and by more than 8.50°C at 121°C.

3.2 Transesterification

It is the process by which triglycerides of fatty acids found in common vegetable oils are converted into simple esters of fatty acids.



Simple alcohols are used for trans-esterification and this process is usually carried out with a basic catalyst (NaOH, KOH) in the complete absence of water. The bonding of alcohol and organic acid with elimination of water produces ester.

3.2.1 Transesterification process

In the esterification process, the alcohol combines with the triglycerides to form glycerol and ester. An excess alcohol is required to force the reaction to completion. Although other alcohols may be used, methanol is the most common and separation of glycerol, a byproduct, occurs most readily with it. The glycerol is removed by density separation. Soap can be a substantial byproduct in the presence of water. This decreases the overall yield of ester, which is not a problem if the presence of water is below one percent. Different researchers have tried transesterification of vegetable oils with slightly varying procedures.

Trans-esterification of different vegetable oils carried out in a 3000ml beaker. An electric heater was used to heat the oil. Temperatures were recorded with a digital thermometer. The experimental setup is shown in Plate3.

Procedure 1:

The procedure proposed by Gupta (2001) is applicable to oils with free fatty acids (FFA) less than 4%. The process is completed in four steps as below:

- (a) The oil is heated to 60⁰ and the temperature is maintained.
- (b) Alkaline alcohol is prepared by dissolving 10g of NaOH in 200ml of methanol for every kilogram of oil.
- (c) The alkaline methanol is mixed with oil maintained at 60⁰ and stirred well for 20 minutes. The mixture is then transferred to a separated from the top.
- (d) The biodiesel obtained is washed with warm water to remove NaOH and dissolved soap.

Procedure 2:

Kumar *et.al* (2003) used another procedure to prepare biodiesel. This also involves making the triglycerides of the oil to react with methyl alcohol in the presence of a catalyst (NaOH/KOH) to produce glycerol and fatty acid esters. Specified amount of oil (1000ml), methanol (450ml), and NaOH (10g) is taken in a round-bottomed flask. The contents were stirred till ester formation began. The mixture was heated to 70⁰C and held at that temperature without stirring for one hour, and then it was allowed to cool overnight without stirring. The reaction formed two layers, the bottom layer being glycerol and the top layer ester.

3.2.1 Preparation of blends

Biodiesel-diesel blends, biodiesel-biodiesel blends and diesel blended with coconut oil were prepared for the study. Pure biodiesels (methyl esters) of coconut oil (COME), sun flower oil (SOME) and palm oil (POME) were prepared. Biodiesel-diesel blends used were as given below:

B 70x: 70 % biodiesel and 30 % diesel

B 60x: 60 % biodiesel and 40 % diesel

B 30x: 30 % biodiesel and 70 % diesel

Where 'x' can be COME, SOME or POME as the case may be.

Biodiesel- biodiesel blends used were:

C50 + S50	:	50 % Coconut oil biodiesel and 50% sun flower oil biodiesel
C70 + S30	:	70 % Coconut oil biodiesel and 30% sun flower oil biodiesel
C30 + P70	:	30 % Coconut oil biodiesel and 70% palm oil biodiesel
C50 + P50	:	50 % Coconut oil biodiesel and 50% palm oil biodiesel
C70 + P30	:	70 % Coconut oil biodiesel and 30% palm oil biodiesel
P50 + S50	:	50 % palm oil biodiesel and 50% sun flower oil biodiesel

3.3 Engine Test

The engine performances of prepared biodiesel, biodiesel-diesel blends and biodiesel-biodiesel blends were studied in comparison with diesel fuel. The compression ignition engine used for the study was a single cylinder, four stroke, constant speed, water cooled, vertical engine and the specifications are given in Table 3.1. The bhp was measured using rope dynamometer and smoke density using a Hastridge smoke meter. The test set up is shown in Plate 4.

The engine was started on normal diesel fuel and warmed up. The warm up period ended when the liquid cooling water temperature was stabilized. The engine performance was tested at no load, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100 and 110 percentage of the rated load. The torque was measured using a brake dynamometer and the bhp was calculated using the formulae

$$\text{bhp} = [(W - S) \pi D N] / 4500$$

where,

W = weight added (kg)

S = spring balance reading(kg);

D = diameter of the brake drum (m)

N = rpm

Table. 3.1 Specification of diesel engine

Sl. No.	Parameters	Specification
1	Bore	80 mm
2	Stroke	110mm
3	Swept volume	553 cm ³
4	Clearance volume	36.87 cm ³
5	Compression ratio	16.5:1
6	Rated output	3.7 kW at 1500 rpm
7	Rated speed	1500 rpm
8	Injection pressure	240 bar
9	Fuel injection timing	24 BTDC
10	Lubricating oil	SAE 40
11	Connecting rod length	235 mm
12	Valve diameter	33.7 mm
13	Maximum valve lift	10.2 mm

Chapter IV

Results and Discussion

RESULTS AND DISCUSSION

The results of the experimental investigations carried out to study the fuel properties of vegetable oils, their methyl esters, biodiesel-diesel blends, biodiesel-biodiesel blends, trans-esterification process and engine tests are outlined in this chapter.

4.1 Fuel properties of vegetable oils, their methyl esters and blends

The fuel properties such as specific gravity and kinematic viscosity were investigated and are discussed below.

4.1.1 Specific gravity

Specific gravity of vegetable oil, their methyl esters and their different blends are shown in Table 4.1. It was found that coconut oil had the highest specific gravity among the vegetable oils, and was 9.78% higher than that of diesel. The lowest specific gravity was observed for palm oil, which was 7.3% higher than that of diesel. Among the biodiesels sunflower oil methyl ester (SOME) had the highest specific gravity and was found to be 4.65% higher than diesel oil.

Table 4.1 Specific Gravity of fuels at 20°C

Sl. No.	FUEL	Specific gravity	Sl. No.	FUEL	Specific gravity
1	Diesel	0.838	10	B60 POME	0.857
2	SOME	0.877	11	C50 + P50	0.871
3	B30 SOME	0.858	12	C50 + S50	0.875
4	B60 SOME	0.865	13	P50 + S50	0.873
5	COME	0.873	14	C70 + P30	0.872
6	B30 COME	0.854	15	C70 + S30	0.874
7	B60 COME	0.865	16	PO	0.900
8	POME	0.875	17	CO	0.920
9	B30 POME	0.851	18	SO	0.913

Among the biodiesel-diesel blends it was seen that B60 blend of coconut oil methyl ester (COME) and SOME had the highest specific gravity and was 3.22% higher than diesel. Among the biodiesel-biodiesel blends it was found that the blends prepared by mixing 70% COME and 30% SOME had the highest viscosity and was 4.42% higher than diesel. By comparing the specific gravity of biodiesels with diesel it was found that COME was close to that of diesel and was 0.342% less than SOME.

4.1.2 Viscosity

The viscosities of diesel fuel, vegetable oil biodiesel, biodiesel-diesel blends and biodiesel-biodiesel blends measured at 25 °C, 60 °C, and 90 °C are shown in Table 4.2.

Table 4.2 Viscosity at 25°C, 60 °C and 90 °C

Sl. No.	Fuel	Viscosity, cst		
		25 °C	60 °C	90 °C
1	Diesel	5.192	4.045	3.455
2	SOME	7.001	4.783	4.661
3	B30 SOME	5.674	4.140	3.667
4	B60 SOME	6.149	4.332	3.767
5	COME	5.709	4.169	3.559
6	B30 COME	5.451	4.050	3.551
7	B60 COME	5.650	4.269	3.794
8	POME	6.229	4.969	3.972
9	B30 POME	6.476	4.474	3.807
10	B60 POME	5.948	4.617	3.903
11	C50 + P50	6.292	4.400	3.843
12	C50 + S50	6.228	4.359	3.792
13	P50 + S50	6.608	4.462	3.855
14	C70 + P30	6.235	4.394	3.593
15	C70 + S30	6.150	4.230	3.703
16	CO	31.66	10.660	7.329
17	PO	43.24	17.039	10.01
18	SO	33.38	13.132	8.298

A comparison of viscosities of vegetable oils with diesel at 25 °C, 60 °C, and 90 °C is depicted in Fig, 4.1. It was found that the lowest viscosity among the vegetable oils was for coconut oil and was 5.1 times greater than the viscosity of diesel at 25 °C, 1.6 times at 60 °C and was only 1.1 times at 90 °C. It was seen that the viscosity of vegetable oils reduces at an exponential rate as the temperature increases, unlike diesel.

Fig. 4.2 gives the comparison of the viscosities of biodiesel with diesel at 25 °C, 60 °C, and 90 °C. The lowest viscosity was seen with COME and was only 0.52 cst higher than diesel oil at 25 °C. The difference became less significant at higher temperatures and was just 0.1 cst higher than diesel oil at 90 °C. It was clear that the rate of decrease in the viscosity was higher than diesel oil with the increase in temperature. The highest viscosity was found with SOME and was 1.81 cst higher than diesel at 25 °C, 0.73 cst higher at 60 °C and 1.2 cst higher at 90 °C. The rate of decrease in viscosity of SOME from 60 °C to 90 °C was very low and was only 0.12 cst while POME showed a decrease of 1 cst and COME showed a decrease of 0.61 cst. SOME showed the maximum decrease in viscosity of 2.22 cst from 25 °C to 60 °C when compared to other biodiesels.

Fig. 4.3 shows the comparison of viscosities of biodiesel blends with 40% diesel (B60) with diesel oil at 25 °C, 60 °C and 90 °C. It was found that by blending COME with 40% diesel the viscosity was reduced by 0.06 cst at 25 °C, increased by 0.1 cst at 60 °C and 0.23 cst at 90 °C. In the case of B60 SOME and B60 POME it was found that viscosity decreased with temperature compared to that of other methyl esters. The lowest viscosity at 25 °C was found with B60 COME and was found to be 0.46 cst higher than diesel oil while at 60 °C and 90 °C the lowest viscosity was found with B60 SOME. At 60 °C the viscosity of B60 SOME was 0.22 cst higher than that of diesel oil and at 90 °C the viscosity was 0.3 cst higher than diesel oil.

Fig. 4.4 shows the comparison of viscosity of B30 (biodiesel blended with 70% diesel) with diesel. The lowest viscosity was found with B30 COME and was 0.26 cst higher than that viscosity of diesel at 25 °C, the viscosity was equal to that

of diesel at 60 °C and was 0.09 cst higher than that of diesel at 90 °C. The highest viscosity was found with B30 POME and was higher than the viscosity of diesel oil by 1.28 cst at 25 °C, 0.42 cst at 60 °C and 0.34 cst at 90 °C. While comparing the viscosity of B30 COME and B30 SOME, B30 SOME had a higher viscosity than B30 COME by 0.22 cst at 25 °C, 0.09 cst at 60 °C and 0.12 cst at 90 °C.

Fig. 4.5 shows the viscosities of biodiesel-biodiesel blends with diesel. It was found that the viscosity of the blend obtained by blending 70% COME and 30% SOME (C70-S30) had higher viscosity and was 0.96 cst higher than diesel oil at 25 °C. It was found that the viscosity of C70-S30 had a viscosity higher than COME by 0.4 cst and lower than SOME by 0.85 cst at 25 °C. The viscosity of C70-S30 blend had a viscosity higher than diesel by 0.18 cst at 60 °C. At 90 °C the viscosity of C70-P30 was found to have the lowest viscosity and was 0.13 cst higher than diesel and 0.11 cst lower than C70-S30.

4.2 Trans-esterification

Trans-esterification was carried out using two procedures, Procedure: 1 (proposed by Gupta, 1994) and Procedure: 2 (procedure followed by Kumar *et al.*, 2003). The yield of biodiesel, separation time, physical nature of glycerol obtained and changes occurring during trans-esterification were studied for both procedures. Based on these observations the procedures were standardized for coconut oil, sunflower oil and palm oil. Table 4.3 depicts the comparison of the two procedures with respect to reaction time, separation time and the number of washes required. The pH of the wash water was observed with a pH paper and washing was stopped when it became neutral. It was found that while washing SOME, better results were obtained when the first wash was done with slightly acidic water with a pH in the range 5.5 to 6. The remaining washes were done using distilled water. It was also observed that use of hot water reduced the number of washes.

Table 4.3 Comparison of various stages in Trans-esterification

Sl. No.	Name of oil	Reaction time, min.		Separation time, min.		No. of washes required
		Procedure		Procedure		
		1	2	1	2	
1	Coconut oil	10	70	20	0	5
2	Palm oil	11	75	600	0	7
3	Sunflower Oil	15	79	600	0	10

The methodology outlined in section 3.2 was followed in Procedure 1. Sodium hydroxide (10g/l) was added to the required amount of methanol and stirred. It was observed that the mixing of NaOH with methanol is an exothermic process. It was also found that gases evolved during the process has to be safely disposed as it is dangerous to inhale them. The alkaline methanol was added to the heated oil at 62 °C. It was noticed that the temperatures fell down to 51 to 54 °C for different oils. The heating was continued and it was found that the reaction started as the mixture reached 59°C indicated by a colour change from the original colour to light green and then to reddish brown (Plate. 5 a to 5 d) at the end. This indicated the end of the reaction. The typical fruity smell of the ester was felt at the end of the reaction. Then the mixture was kept for separation. It was found that separation was very quick in the case of coconut oil and was very slow in the case of sunflower oil. In the case of coconut oil separation was complete in 10 minutes. The use of a separating funnel for separation of glycerol from biodiesel was found advantageous (Plate 6). The reaction mixture was transferred to the separating funnel as soon as the reaction was complete as the glycerol phase can be easily separated when it is in the free flowing state. As time passed, it ceased to flow freely creating problems in removing it. In the case of palm oil, the separation of glycerol was difficult as the glycerol phase became semi-solid with a porous structure. As it contained biodiesel in the pore space, squeezing the mass was often

required to recover it. In the case of sunflower oil trans-esterification the glycerol obtained was jelly like.

In the second procedure (section 3.2) as followed by Kumar *et al.*(2003), alkaline methanol prepared at first was mixed with the oil and was stirred well till the esterification began which was indicated by a fruity smell. Then mixture was then heated to 70°C. While heating it was observed that, two distinct layers (a bottom dark reddish brown layer and a top pale yellow layer) were formed. At 70 °C, the two layers mixed and formed a single layer with light reddish brown colour. Then the mixture temperature was maintained at 70°C for one hour. After one hour it was found that there appeared two similar layers again, the top layer with biodiesel and bottom layer with glycerol. It was found that the glycerol obtained by this method never turned solid and remained in semi solid state.

Table 4.4 shows the salient aspects viz. quantities of alcohol, NaOH and yield per liter of oil for both procedures. It was found that procedure 1 was preferable when more biodiesel yield with less cost is desired if time is not a constraint. Procedure-1 was found to be more convenient, less complicated, low cost and could be used even on farm level. Vegetable oils and their corresponding methyl esters are shown in Plate 7.

Table 4.4. Comparison of the reactant requirements and product yields in two Transesterification methods

Oil used	Volume of oil, ml	Volume of NaOH used, g	Volume of methanol, ml		Amount of biodiesel obtained / kg of oil, ml	
			Procedure		Procedure	
			1	2	1	2
Coconut Oil	1000	10	200	450	970	950
Sunflower Oil	1000	10	200	450	955	930
Palm Oil	1000	10	200	450	976	953

4.3 Engine Test

The results of the engine tests done as per the procedures outlined in section 3.3 are briefly described in this chapter.

4.3.1 General performance

In general the engine ran smooth with all the biodiesels compared to the diesel fuel. There was a considerable reduction in sound while using biodiesel from coconut and its blends. Table 4.5 show the results of the engine tests using diesel and Table 4.6 shows the corresponding results with POME. SOME and COME as fuels. Table 4.7 shows the engine test results using B30 blends of biodiesels with diesel viz. COME, POME and SOME respectively as fuels. Table 4.8 gives the engine test results using B60 blends of COME, POME and SOME respectively as fuels. The engine test results using (C70 + P30) and (C70 + S30) biodiesel blends as fuel are shown in Tables 4.9 respectively. Table 4.10 shows the engine test results with C 50 + S 50, C50 + P50 and S50 + P50 respectively as fuels. Table 4.11 gives the engine test results using diesel blended with 10% and 20% coconut oil respectively.

4.3.2 Smoke density

Fig. 4.6 depicts the smoke densities of COME, SOME and POME in comparison with diesel oil. It was found that COME showed the lowest smoke densities at all loads. The highest smoke density while using COME was at 110% load and was 56.9%. It was found that the smoke density while using POME was also lower than that while using diesel oil up to 90% load and after which it shot up. The smoke density while using SOME was found to be almost same as that of diesel oil.

Fig. 4.7 illustrates the smoke densities while using B60 POME, B60 SOME, and B60 COME in comparison with diesel. It was found that at no load and 10% load the smoke densities of biodiesel- diesel blends were higher than those with diesel oil. At higher loads the smoke density of biodiesel – diesel blends showed

lower smoke densities than diesel oil with the lowest with B60-COME and the highest with B60 SOME.

Fig. 4.8 compares smoke density of B30 SOME, B30 POME, and B30 COME with diesel. It was found that the smoke densities at B30 blends were lower than that of diesel fuel but were very close to diesel. B30 COME gave the lowest smoke density.

Smoke densities of biodiesel-diesel blends prepared by mixing 70% of COME with 30% of POME and SOME respectively against diesel oil is depicted in Fig.4.9. C70 + S30 showed the lowest smoke density when compared with diesel. C70 + P30 also showed lower smoke density than diesel, but slightly higher than C70 + S30. The lowest smoke density of C70 + S30 which was just 8.7% higher than while using COME and 21.3% lesser than while using SOME. The blend C70 + P30 also showed remarkable reduction in smoke density, The smoke density of C70 + P30 at 100% load was 63.2% which was 18.7% higher than while using diesel fuel and was 34.9 % lesser than that while used POME.

Fig. 4.10 shows the comparison of smoke densities while using biodiesel-biodiesel blends formed by mixing 50%-50% blends of different biodiesels. It was found that the blend prepared by mixing 50% COME and 50% POME showed the lowest smoke density. The smoke density of (C50 + P50) of 100% load was 43.4% and was found to be 1.1% lower than while using COME, 54.7% lower than while using POME, 19.8% lower than C70 + P30 and 9.8% lower than while using C70 + S30. The blend with 50% POME and 50% SOME showed a smoke density lower than C50 + S50 upto 30% load and slightly higher from 40% load to 90% load after which it showed a remarkable increase.

A comparison of COME along with its various blends in contrast to diesel is illustrated in Fig. 4.11. In general it was observed that as the proportion of COME increased in the blend, the smoke density decreased.

The test results when diesel was blended with 10% and 20% coconut oil are depicted in Fig. 4.12 It was found that diesel blended with coconut oil showed lower smoke density than diesel upto 20% load and higher beyond 20 % load.

4.3.2 Specific fuel consumption

The SFC of POME, SOME, and COME against diesel oil is illustrated in Fig. 4.13. It was found that at 100% load, COME and POME showed the highest SFC of 323.4 g/bhp/hr and was 30.36 % higher than diesel oil. SOME showed SFC at 292.6 g/bhp/hr and was 18.43% higher than diesel oil.

Fig. 4.14 shows the SFC of B60 POME, B60 SOME, and B60 COME in contrast with diesel oil. It was found that SFC of all the 3 blends were almost similar, with B60 COME having the highest SFC of 334.3 g/bhp/hr, i.e.29.46 % higher than diesel oil and B60 SOME showed the lowest SFC of 302.340 g/bhp/hr, 17.09 %higher than diesel oil at 100% load.

A comparison of SFC of B30 POME and B30 COME with diesel is depicted in Fig. 4.15. It was found that the SFC was highest with B30 POME whereas B30 COME showed the lowest SFC at 100% load. B30 POME had a SFC of 314.7 g/bhp/hr, which was 21.88 % higher than diesel oil. B30 COME showed SFC of 288.7 g/bhp/hr, which was 11.79% higher that of diesel oil at 100% load.

Fig. 4.16 depicts the SFC of biodiesel – biodiesel blends (C70+P30, C70+S30) with diesel oil. It was found that the blend C70+P30 showed the highest SFC of 332.2 g/bhp/hr, which was 1.29 times higher than diesel oil while C70+S30 showed the lowest SFC of 321.7 g/bhp/hr, which was also higher than diesel oil at 100% load.

SFC of biodiesel-biodiesel blends (C50+P50, C50+S50 and P50+S50) against diesel fuel is illustrated in Fig.4.17. It was found that C50+S50 showed the highest SFC of 332.805 g/bhp/hr which was 28.89 % higher than diesel oil whereas C50+P50 showed the lowest SFC at 257.968 g/bhp/hr, slightly lower than that of diesel at 100% load.

Fig. 4.18 illustrates the comparative SFC of COME and its various blends with diesel oil. It was found that the SFC of C50+S50 had the highest and was 1.29 times than that of diesel at 100% load. C50+P50 showed the lowest SFC at 100% load, but was also higher than diesel.

The test results with diesel oil with diesel blended with coconut oil is depicted in Fig, 4.19. It was found that diesel blended with coconut oil showed slightly higher specific fuel consumptions than with diesel alone. It was seen that diesel blended with 20% coconut oil had the lowest SFC at 100% load. It was found that the SFC is 287.5 g/bhp/hr, 1.11 times higher than that when diesel alone is used.

Table 4.6. Engine test with POME, SOME and COME as fuel

Sl. No.	Load Kg	Bhp	POME		SOME		COME	
			SFC g/bhp/hr	Smoke density %	SFC g/bhp/hr	Smoke density %	SFC g/bhp/hr	Smoke density %
1	0	-	-	18.7	-	33.8	-	27.0
2	10	0.5	1429.22	41.8	1475.327	48.9	1389.390	31.6
3	20	1.0	726.476	45.0	805.614	56.4	831.649	32.4
4	30	1.5	506.146	42.7	561.130	56.0	614.068	38.0
5	40	2.0	383.492	48.1	454.928	62.1	490.144	30.9
6	50	2.5	367.347	50.7	406.232	64.7	415.165	28.3
7	60	3.0	400.000	61.9	365.544	61.5	372.149	31.3
8	70	3.5	362.611	62.6	337.849	66.5	352.411	36.7
9	80	4.0	358.117	65.6	328.738	69.6	332.079	39.0
10	90	4.5	342.801	74.3	315.184	71.9	313.044	39.2
11	100	5.0	325.413	98.1	307.270	74.5	323.833	44.5
12	110	5.5	316.429	100	292.577	76.3	323.383	56.9

Table 4.7. Engine test with B30 COME, B30 SOME and B30 COME as fuel

Sl. No.	Load Kg	Bhp	B30 COME		B30 POME		B30 SOME	
			SFC g/bhp/hr	Smoke density %	SFC g/bhp/hr	Smoke density %	SFC g/bhp/hr	Smoke density %
1	0	-	-	58.7	-	38.8	-	43.8
2	10	0.5	1428.625	50.0	1363.107	43.5	1537.18	51.0
3	20	1.0	762.500	54.3	840.490	53.7	730.124	71.2
4	30	1.5	579.638	61.7	645.113	66.2	587.910	69.4
5	40	2.0	444.278	59.0	488.734	61.6	474.535	57.4
6	50	2.5	370.187	54.9	420.245	58.6	395.558	58.1
7	60	3.0	339.001	48.9	374.809	58.2	375.028	61.6
8	70	3.5	315.065	43.9	343.257	60.3	341.386	64.8
9	80	4.0	303.076	49.2	323.909	70.1	325.776	69.8
10	90	4.5	307.056	59.9	326.857	78.2	316.799	81.7
11	100	5.0	288.670	67.7	314.702	92.5	306.054	86.4
12	110	5.5	304.291	95.5	322.018	94.6	334.546	97.5

Table 4.8. Engine test with B60 COME, B60 SOME and B60 COME as fuel

Sl. No.	Load Kg	Bhp	B60 COME		B60 POME		B60 SOME	
			SFC g/bhp/hr	Smoke density %	SFC g/bhp/hr	Smoke density %	SFC g/bhp/hr	Smoke density %
1	0	-	-	59.2	-	45.2	-	53.0
2	10	0.5	1237.925	58.3	1334.141	47.7	1226.950	49.0
3	20	1.0	749.278	51.3	866.629	69.3	745.333	60.6
4	30	1.5	591.622	53.9	606.368	71.4	582.328	71.6
5	40	2.0	471.532	54.9	485.858	60.8	460.379	71.9
6	50	2.5	396.941	45.4	396.300	62.3	385.754	62.0
7	60	3.0	368.608	51.7	354.988	63.4	356.211	68.6
8	70	3.5	348.771	44.3	338.252	64.0	335.868	70.6
9	80	4.0	335.127	49.8	317.277	65.4	314.292	72.6
10	90	4.5	327.652	65.6	313.346	73.0	300.608	85.1
11	100	5.0	334.299	69.5	314.977	86.4	302.340	98.9
12	110	5.5	350.143	83.3	301.260	90.9	340.868	99.7

Table 4.10. Engine test with and C50 + P50, C50 + S50 and P50 + S50 as fuel

Sl. No.	Load Kg	bhp	C50 + P50		C50 + S50		P50 + S50	
			SFC g/bhp/hr	Smoke density %	SFC g/bhp/hr	Smoke density %	SFC g/bhp/hr	Smoke density %
1	0	-	-	46.8	-	42.9	-	36.3
2	10	0.5	1534.426	56.8	1345.866	40.0	1359.931	36.4
3	20	1.0	896.398	63.7	827.641	57.3	812.303	50.6
4	30	1.5	627.748	58.9	601.030	55.2	603.978	48.4
5	40	2.0	505.416	46.1	491.727	45.2	458.535	47.3
6	50	2.5	430.714	41.4	426.540	44.3	385.975	45.9
7	60	3.0	394.713	43.2	383.7719	47.7	335.125	47.7
8	70	3.5	370.354	48.6	367.047	48.8	352.135	45.7
9	80	4.0	333.433	45.1	336.826	53.8	327.922	49.8
10	90	4.5	279.727	45.8	341.797	62.0	321.547	51.1
11	100	5.0	257.968	43.4	332.805	78.6	317.615	64.3
12	110	5.5	247.981	48.4	349.011	97.1	344.228	96.1

Table 4.5. Engine test with diesel as fuel

Sl. No.	Load, kg	bhp	Specific fuel consumption g/bhp/hr	Smoke density %
1	0	-	-	43.8
2	10	0.5	1316.86	44.2
3	20	1.0	668.124	58.5
4	30	1.5	468.843	59.5
5	40	2.0	393.794	61.2
6	50	2.5	356.042	68.1
7	60	3.0	330.159	68.5
8	70	3.5	297.246	70.4
9	80	4.0	292.044	73.8
10	90	4.5	273.684	75.4
11	100	5.0	258.207	85.2
12	110	5.5	244.976	99.3

Table 4.9. Engine test with C70 + P30 and C70 + S30 and as fuel

Sl. No.	Load (Kg)	Bhp	C70+P30		C70+S30	
			SFC (g/bhp/hr)	Smoke density (%)	SFC (g/bhp/hr)	Smoke density (%)
1	0	-	-	34.8	-	27.1
2	10	0.5	1501.65	44.2	1381.212	27.6
3	20	1.0	930.685	49.8	874.729	45.9
4	30	1.5	644.931	40.4	620.592	40.9
5	40	2.0	501.790	37.8	501.019	32.3
6	50	2.5	450.065	36.2	443.624	33.2
7	60	3.0	383.437	37.3	390.034	33.8
8	70	3.5	373.870	40.1	367.527	36.8
9	80	4.0	364.684	45.1	336.154	37.6
10	90	4.5	340.127	54.1	328.726	44.2
11	100	5.0	332.191	63.2	321.718	53.2
12	110	5.5	358.070	95.4	333.765	84.8

Table 4.11. Engine test with 10 and 20 % Coconut oil blended with diesel as fuel

Sl. No.	Load, Kg	Bhp	10 % coconut oil		20% coconut oil	
			SFC g/bhp/hr	Smoke density %	SFC g/bhp/hr	Smoke density %
1	0	-	-	59.3	-	45
2	10	0.5	1343.41	57.8	1277.88	41.1
3	20	1.0	753.24	59.5	724.23	53.0
4	30	1.5	588.26	70.1	568.46	60.3
5	40	2.0	463.89	70.9	457.48	68.4
6	50	2.5	380.60	64.2	401.38	68.0
7	60	3.0	360.00	65.2	371.64	62.0
8	70	3.5	333.34	76.1	333.38	68.6
9	80	4.0	329.52	81.6	320.3326	77.7
10	90	4.5	304.29	83.8	310.4261	86
11	100	5.0	305.35	95.8	287.4627	91.1
12	110	5.5	320.87	98.9	323.68	98.3

Chapter V

Summary and Conclusions

SUMMARY AND CONCLUSION

Bioenergy options to replace fossil fuels have attracted worldwide attention as they are renewable and environment friendly. Transport and agricultural sectors depend heavily on diesel engines and hence the search for a renewable diesel fuel alternative is often directed towards vegetable oils. A number of oils are being considered worldwide which include edible oils such as sunflower oil, palm oil, soybean oil, rape seed oil etc. as well as non edible oils like jatropha oil, karanja oil, cotton seed oil, rice bran oil, mahua seed oil, tobacco seed oil etc. To overcome the adverse fuel properties of vegetable oils such as high viscosity and lower cetane number, efforts for fuel modifications were taken up by several workers. As a result, the trans-esterification of vegetable oils has been emerged as the most promising technology. Coconut is the major oil crop of Kerala and much study is not seen done in the case of coconut oil. Even though the use of coconut oil as fuel is not attractive under the present economic scenario, factors like fluctuation in diesel and coconut oil prices, pollution hazards, advantages of a home made fuel, decentralized energy production and academic interests prompted an investigation on the use of coconut oil in comparison with other vegetable oils viz. sun flower oil and palm oil as fuel in compression ignition engines.

The investigation included a study of the fuel properties of the three vegetable oils, their methyl esters (biodiesels), biodiesel blends with diesel and blends of different methyl esters. Two different methods were examined for trans-esterification of vegetable oils. Engine tests were then undertaken with the different fuels and fuel blends to study their performances with respect to smoke density and specific fuel consumptions at varying loads.

The salient results of the study could be outlined as below:

1. The specific gravity was highest for coconut oil among the vegetable oils followed by sunflower oil and palm oil. Among biodiesels, sunflower oil methyl ester exhibited the highest specific gravity while coconut oil methyl ester had the lowest.

2. The study of viscosities of vegetable oils showed that the viscosities decreased at a faster rate with the increase in temperature from 25 to 60°C and there after at a slow rate. Palm oil was the most viscous followed by sunflower oil and coconut oil at the three different temperatures. Among biodiesels coconut oil methyl ester showed the lowest viscosity of 5.71 cst (at 25°C) and was very close to diesel (5.19 cst).
3. By blending biodiesels with 40% diesel the viscosity reduced by 12% in sunflower oil methyl ester, 1% in coconut oil methyl ester and 4.49% in palm oil methyl ester at 25°C. The reduction was not that significant in the case of coconut oil methyl ester blends as its viscosity was comparable to diesel. Among biodiesel - biodiesel blends, the blend of coconut oil methyl ester with sunflower oil methyl ester in the ratio 1:1 showed the lowest viscosity of 6.23 cst at 25°C.
4. Among the two methods of trans-esterification studied, the procedure proposed by Gupta, 1994 was superior as it was less expensive, simple in operation and gave higher yield than the method proposed by Kumar *et al.* (2003).
5. There was a considerable reduction in the smoke density while using biodiesel in C I engines when compared to diesel. Coconut oil methyl ester showed the lowest smoke density compared to other methyl esters at all loads. All proportions of coconut oil methyl ester with diesel exhibited considerable reduction in smoke densities compared to diesel at all loads except at no load which confirmed the pollution reduction ability of coconut oil biodiesel.
6. The 1: 1 blend of coconut oil methyl ester with palm oil methyl showed a smoke density of 43.4% at 100% load, which was very close to that from coconut oil methyl ester.

7. The specific fuel consumptions were higher for biodiesels than diesel. Coconut oil methyl ester and palm oil methyl ester showed the highest specific fuel consumption of 323.4 g/bhp/hr at 100 % rated load and was 30.36% higher than diesel.
8. The 1:1 blend of coconut oil and palm oil in the ratio showed a specific fuel consumption of 257.968 g/bhp/hr, which was 0.239 g/bhp/hr less than diesel.
9. Engine tests with straight coconut oil - diesel blends with 10 % and 20 % coconut oil showed that the smoke densities were lesser than diesel only upto 20 % load. The smoke densities were higher than diesel at higher loads.

The salient results of the study indicated that coconut oil biodiesel is a better fuel than diesel for CI engines, except for its high specific fuel consumption. Blending coconut oil biodiesel even at low proportions (30 %) resulted in a considerable reduction in pollution caused by diesel engines. Even if the current economics of coconut oil biodiesel use preclude the wide use of coconut oil biodiesel, its potential as an anti pollutant additive for diesel is noteworthy.

References

Abstract

ABSTRACT

Bioenergy options to replace fossil fuels have attracted worldwide attention as they are renewable and environment friendly. The search for a renewable diesel fuel alternative is often directed towards vegetable oils and the trans-esterification of vegetable oils has been emerged as the most promising technology. Coconut is the major oil crop of Kerala and an investigation on the use of coconut oil in comparison with other vegetable oils as fuel in compression ignition engines was carried out which included a study of the fuel properties of the vegetable oils, their methyl esters (biodiesels) and different blends. Two different methods were examined for trans-esterification of vegetable oils. Engine tests were then undertaken with the different fuels and fuel blends. It was observed that the fuel properties viz. specific gravity and viscosity were unsuitable for use of straight vegetable oils where as their methyl esters exhibited comparable viscosities with diesel fuel. Among the two methods of trans-esterification studied, the procedure proposed by Gupta, 1994 was superior over the method proposed by Kumar *et al.* (2003). There was a considerable reduction in the smoke density while using biodiesel in CI engines when compared to diesel. Coconut oil methyl ester showed the lowest smoke density compared to other methyl esters at all loads. All proportions of coconut oil methyl ester with diesel exhibited considerable reduction in smoke densities compared to diesel at all loads except at no load which confirmed the pollution reduction ability of coconut oil biodiesel. The 1: 1 blend of coconut oil methyl ester with palm oil methyl showed a smoke density very close to that from coconut oil methyl ester. The specific fuel consumptions of biodiesels and their blends were higher than diesel at all loads. Coconut oil methyl ester and palm oil methyl ester showed the highest specific fuel consumptions. Engine tests with straight coconut oil - diesel showed that the smoke densities were higher than diesel at loads higher than 20 %. The study indicated that coconut oil biodiesel is a better fuel than diesel for CI engines, except for its high specific fuel consumption. Blending coconut oil biodiesel with diesel resulted in a considerable reduction in pollution and hence its potential as an anti pollutant additive for diesel is noteworthy.