IMPACT OF AGE ON PERFORMANCE FOR BIODIESEL

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

ALTERNATE HYDRO ENERGY SYSTEMS

By

RAM DHANI CHAUHAN

ALTERNATE HYDRO ENERGY CENTRE
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE - 247 667 (INDIA)

JUNE, 2006

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this dissertation, entitled, **"IMPACT OF AGE ON PERFORMANCE FOR BIODIESEL"**, in partial fulfillment of the requirement for the award of the degree of **Master of Technology in "Alternate Hydro Energy Systems"**, submitted in Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee is an authentic record of my own work carried out during the period from July 2005 to June 2006 under the supervisions of **Dr. M.P. Sharma** (Senior Scientific Officer), **Dr. R.P. Saini** (Senior Scientific Officer), Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee.

I have not submitted the matter embodied in this dissertation for award of any other degree.

Date: June ,29,2006

Place: Roorkee

(R.D. CHAUHAN)

This is certified that the above statement made by the candidate is correct to the best of our knowledge.

(DR. M.P. SHARMA) 29/6/06
(Senior Scientific Officer)
Alternate Hydro Energy Centre
Indian Institute of Technology,
Roorkee – 247667 (U.A.)

(DR. R.P. SAINI)
(Senior Scientific Officer)
Alternate Hydro Energy Centre
Indian Institute of Technology,
Roorkee – 247667 (U.A.)

ACKNOWLEDGEMENT

It is my proud privilege to express my sincere gratitude to Dr. M.P. Sharma, Senior Scientific Officer, and Dr. R.P Saini, Senior Scientific Officer, Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee for their kind cooperation, invaluable guidance & constant inspiration throughout the dissertation work.

I also express my heartfelt gratitude to Shri Arun Kumar, Head, Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee for his motivation & full cooperation during the work of dissertation.

I also express my sincere regards and thanks to Dr. R.P. Saini, Senior Scientific Officer, PG Course Coordinator, Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee, for his continuous inspiration and necessary support regarding dissertation completion in due time.

I am also grateful to all faculty members and staff of Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee and all the members of Irrigation Department, Govt. of UP for their inspiration & full cooperation during the work of dissertation.

I extend my thanks to all classmates who have given their full cooperation and valuable suggestions for my dissertation work.

Last but not the least, I would like to express my humble respect and special thanks to my parents, wife and son, Aman & others who directly or indirectly helped me during completion of this dissertation work.

DATE: June 29,2006

(R.D. CHAUHAN)

ABSTRACT

Economic development in developing countries has led to huge increase in the energy demand. In India, the energy demand is increasing at a rate of 6.5% per annum. The crude oil demand of country is met by import of about 70%. Thus, the energy security has become key issue for our country. Biodiesel, as an eco-friendly and renewable fuel substitute for diesel has been getting the attention of researchers/scientists all over the world. The research has indicated that up to B20, there is no need of any engine modification and little work is available related to suitability and sustainability of biodiesel production from Jatropha as non-edible oil sources.

In present study, on the same pace of advancement of research, the effect of ageing on biodiesel from Jatropha oil for 5 months and subsequently its effect on engine performance have been evaluated. It was found that the increase in the viscosity of biodiesel was 25% & 38% for the samples stored at room temperature and kept in direct sunlight respectively followed by the significant growth in the acid value and peroxide value which is as per ASTM standard. The results of engine performance indicated that the brake specific fuel consumption (BSFC) for neat biodiesel was 13-15% higher at 2.165 kW load and 1500 rpm as compared to diesel fuel, while the brake thermal efficiency (BTE) of neat biodiesel (23.82%) was almost similar to diesel (24.15%). The BSFC upto B20 was about 4-5% lower than diesel, while BTE was somewhat higher than diesel. No significant change in fuel economy and efficiency was observed at B20 level

for five months aged sample in airtight container at room temperature. But 1-2% growth in BSFC was found at B20 level for five months aged sample stored in open atmosphere in direct sunlight. The engine performance with thermally aged biodiesel (at 100 ^{0}C for 10 hours) has been also evaluated and it was found that the BSFC for B20 blend of thermally aged biodiesel was higher by 17% and efficiency for this blend was lower by 2-3%.

So by this study, it can be concluded that 5-6 months aged biodiesel stored in airtight container at room temperature would not be show any underperformance in fuel economy and efficiency in diesel engine and direct contact of air and heat will promote the oxidation of biodiesel that will deteriorate its performance as fuel.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

GHG	Green House Gases
EU	European Union
US	United States
B20	Mixture of 20% (v/v) biodiesel + 80 % (v/v) Diesel
MT	Metric Ton
HSD	High Speed Diesel
Mha	Million Hectare
SVO	Straight Vegetable Oil
CI	Compression Ignition
COBD	Coconut Oil Biodiesel
RME	Rape Seed Oil Methyl Ester
BSFC	Brake Specific Fuel Consumption
MOEE	Mahua Oil Ethyle Ester
BTE	Brake thermal efficiency
DI	Direct Injection
HC	Hydro Carbon
JOME	Jatroph Oil Methyl Ester
FFA	Free Fatty Acid
TDC	Top Dead Centre
v/v	Volume by volume
w/w	Weight by weight
GCV	Gross Calorific Value
NCV	Net Calorific Value
AV	Acid Value
PV	Peroxide Value
DG	Diesel Generator Set

LIST OF SYMBOLS

Symbols	Description	Units
W_f	Fuel Consumed	g/h
P_b	Brake Power	kW
P_g	Load at generator end	kW
n_g	Efficiency of generator	%
F_v	Fuel consumed	g
D	Density of fuel	Kg/m^3

INTRODUCTION & LITERATURE SURVEY

1.1. GENERAL

Energy and environment are both vital for sustainable development. New initiatives for reduction of Green house gases (GHG) are being taken all over the world. The utilization of biodiesel can help in directly substituting fossils fuel consumption in certain proportion, thus, leading to the reduced reliance on crude oil import and improvement in environment. For the last four years, the use of blends of biodiesel (trans-esterified vegetable oil) with diesel to the extent of 5-10 % in European Union (EU) and the US has been rising with policy supports. The world usage of vegetable oil for biodiesel production has been estimated about 3 MT or just less than 3% of global vegetable oil production last years [1]. Major users are the Eu (mainly rapeseed oil) and the US (mainly soybean oil). The EU usage of vegetable oil for biodiesel has been rising at rate of about 30% annually in the last two years. The demand of diesel fuel for transport sector of India is growing at a high annual growth rate of 2.1% [2] on one hand and increasing imports & exhaustion of limited indigenous production has led to increased attention towards biodiesel on other hand. . The biodiesel is receiving great attention world wide as an alternative fuel for diesel engines as it has shown almost same engine performance with reduced emission compaed to diesel fuel. Biodiesel is no longer a fringe idea of a few scientists in a few countries but it has gained worldwide acceptance. India has been playing a lead role in biodiesel technology as evidence by the first successful trial run of Delhi-Amritsar Shatabdi express used on biodiesel (B5) on December 31, 2002.

Alternative fuels for diesel engines have attracted more and more attention in the auto fuel market due to depletion of fossil fuels in the world market stock and worsening of air pollution caused by fossil fuel based vehicles. As early as in 1900, vegetable oil had already been used directly for operating diesel engines. The carbon deposits and thickening of lubricating oil occur in the engine by use of vegetable oil as fuel mainly due to its high viscosity, low volatility and poly unsaturated character, as well as its gum formation characteristics due to oxidation and polymerization , and it has led to the discouraged use of raw vegetable oil. This has resulted into the efforts of improving the viscosity of vegetable oil by blending, Pyrolysis and emulsification etc. The alternative way to make best use of vegetable oil in the existing diesel engine is their derivatives called monoesters and transesterification is the best way to produce these ester from vegetable oils [3]. Transesterification is a reaction between a triglycerides and alcohol in the presence of catalyst to produce glycerol and esters. The molecular weight of typical ester molecule is roughly one third that of typical oil molecule and therefore, has very low viscosity. The introduction and commercialization of biodiesel in many countries around the world has been accompanied by the development of standards such as ASTM D6751 (ASTM-American society for testing and materials) and the European standard EN 14214.

In India, the total consumption of crude oil was bout 133 MT for the year 2004-05, but 75% of this production was met by import. The share of high-speed diesel was about 40% in the above production. The rate of energy consumption is increasing @ of 6.5% per annum while reserves for petroleum oil are decreasing day by day. In world production of crude oil, India's share of crude oil production is about 1% of total world production while in consumption, its share is about 3.1% of total world consumption [4]. The tendency over import of crude oil has been increased from 63% in 1971 to 75% in 2004-05. The demand of petroleum oil and its production in the country is given in Table1.1.

Table1.1: Crude Oil Consumption (MT) in India [5]

Sl.No	Year	Indigenous Production	Import	Total	Import as % of Total Demand	Import Value in (Crores)
1	1971	6.8	11.7	18.5	**63**	107
2	1981	10.5	16.2	26.7	**61**	3349
3	1991	33	20.7	53.7	**39**	6118
4	2001	32	57.9	89.9	**64**	30,695
5	2003-2004	33.4	90.4	123.8	**73**	81000
6	2004-2005	33.4	100	133.4	**75**	1,21,500

The above Table indicates that India imports heavy amount of crude oils for its domestic consumption and consequently pay heavy foreign exchange for it. The demand of high-speed diesel (HSD) is projected to grow from 39.81 MT in 2001-2002 to 52.32MT in 2006-2007 @ 5.6% per annum [5].

India has a unique situation in fuel consumption trend, as the national consumption of diesel is almost 7 times that of gasoline [6]. Projections show that the average annual rate of growth for all categories of vehicles will vary between 5% and 7% at the all-India level during period of 20-years from 2001 to 2021. In India, the vehicle population is growing at rate of over 5% per annum and today the vehicle population is approximately 40 million [7]. Oil provides energy for 95 % of transportation in India and the demand for transport fuel continue to rise. Hence diesel will continue to dominate the transport sector in the foreseeable future, and there are two reasons to search for alternative energy sources. The limited reserve coupled with emissions of GHG from the combustion of fossil fuel has led the search for alternative liquid biofuel resources. The biodiesel as an alternative fuel helps to overcome the problems. The production of biodiesel can be from edible oil, non-edible oil, animal fat and waste fried oil & greases. The possibility of production of biodiesel from edible oil resources in India is almost impossible, as primary need is to first meet the needs of edible oil that is already imported. India accounts for 9.3% of world's total oil seed production and contributes as the fourth largest edible oil producing country. Even then, about 43% of edible oil is imported for catering the domestic needs. The Table 1.2 gives the production and consumption of edible oil for country.

Table1. 2: Production and Consumption of Edible Oil (Lakh Tonnes)[8]

Sl . No	Oil Year	Production of Oil Seeds	Net Availability of Oil from Domestic Sources	Import of Edible oil	Consumption of Edible oil
1	1998-99	247.48	69.60	26.22	95.82
2	1999-2000	207.15	60.15	41.96	102.11
3	2000-2001	184.40	54.90	41.86	96,76
4	2001-2002	206.63	61.46	43.22	104.68
5	2002-2003	150.58	47.28	43.65	90.93
6	2002-2004	251.42	71.09	52.95	124.04
7	2004-2005	248.42	73.10	44.0	117.10

The above Table indicates that India imports about 50-60% edible oil of its domestic requirement. And therefore, it is not possible to divert the edible oil resources for biodiesel production in the country. So the non-edible oil resources like Jatropha and Pongamia etc. seems to be the only possibility for biodiesel production in the country.

According to Government of India survey, out of total land area; 60 Mha are classified are waste and degraded land. India has third largest road network in Asia having length about 3 million km which can be used for growing the jatropha and Karanj crops and oil can be converted into biodiesel. India has railway network of 63,140 km and land along the track can be easily used for cultivation of Jatropha curcas to check the soil erosion and to improve fertility in addition of oil production. The future demand for biodiesel in India is given in Table1.3.

Table1. 3: Biodiesel Demand in India [5]

Sl.No	Year	Diesel demand (MT)	5% blend MT)	Area (Mha)	10% blend (MT	Area (M ha)	20% blend (MT)	Area Mha)
1	2006-07	52.33	2.62	2.19	5.23	4.38	10.47	8.76
2	2011-12	66.40	3.35	2.79	6.69	5.58	13.38	11.19

The above Table indicates that by the year 2011-12, about 13.38 MT of diesel could be saved for future if B20 blend is utilized. This will ensure sustainable fuel availability with secured environmental conditions.

1.2. LITERATURE REVIEW

Vegetable oils are becoming more attractive because of their environmental benefits and their renewability. 100 years ago, Rudolph diesel tested vegetable oil as the fuel for his engine. There are more than 350 oil-bearing crops identified, among which some species like sunflower, safflower; soybean, cottonseed, rapeseed and peanut oils etc. are considered as potential alternative fuels as straight vegetable oils (SVO) for diesel engine [9,10]. The process of transesterification dates back as early as 1846 when Rochieder described glycerol preparation through ethanolysis of caster oil [8]. The methyl ester of vegetable oil was evaluated as a fuel in CI engine by Formo [9]. He observed that the performance of the esters of vegetable oil did not differ greatly from the diesel fuel. The brake power was nearly the same as with diesel fuel, while brake specific fuel consumption (BSFC) was higher than that of diesel fuel. Agrawal [10] prepared methyl as well as ethyl ester from linseed oil and tested in CI engine. He found that 20% blend of methyl ester and 15% blend of ethyl ester respectively with diesel gave an optimum performance. Rao and Krishnan [11] tested the biodiesel of Karanj oil, rice bran oil, soybean oil and neem oil and recommended the use of methyl ester as they exhibited better performance. Shahjee et .al [12] investigated the performance of stationary diesel engine with rubber seed oil methyl ester (RSOME) and coconut oil biodiesel (COBD) and found that at 100% load, COBD showed the highest BSFC of 323.8 gm / bhp - hour and was much higher (21%) than diesel oil (265.4 g/bhp-hour).

Haas [13] was also experimented the soap stock and soybean based biodiesel with diesel engine and found that the brake specific fuel consumption (BSFC) for soap stock biodiesel was similar to that for soybean oil biodiesel and

18% higher than for petroleum diesel. He also investigated for B20 blend of Biodiesel from soap stock and found that brake specific fuel consumption for B20 as well as for diesel was almost similar. Puhan et al. [14] prepared mahua oil ethyl ester from mahua oil and performance was evaluated with four-stroke direct injection natural aspirated diesel engine. The authors found that the brake thermal efficiency of mahua oil ethyl ester (MOEE) was comparable with diesel and observed that it was 26.36% for diesel and 26.42% for MOEE. Specific energy consumption (SEC) is an ideal variable because it is independent of fuel. Hence, it is easy to compare energy consumption rather than fuel consumption. SEC is defined as energy input required to develop unit power. At the maximum load, SEC is less in the case of MOEE compared to that diesel. This is due to the combined effect of low heating value and high density of MOEE.

Manyem et al. [15] Prepared neat biodiesel and oxidized biodiesel (Heating at 60^0C for 10 h) and evaluated the performance with turbocharged DI diesel engine. They found that oxidized and unoxidized neat biodiesel has 15.1% and 13.8% higher BSFCs than diesel fuel, respectively. They also found that the heating value of oxidized and unoxidized biodiesel was 14.7% and 12.7% lower respectively than that of No. 2. Diesel fuel. These results are similar to those of Mac Donald et al. [16] who fueled a caterpillar 3304 PCNA engine with low-sulfur diesel fuel and methyl esters of soybean oil. In their research, they found 13 to 14% increase in BSFCs compare to diesel. There was a 1.2% higher BSFC for the oxidized biodiesel than the unoxidized biodiesel. The heating value of oxidized biodiesel was 2.2% less than that of unoxidized biodiesel.

Thompson et al. [17] also found that the heat of combustion decreased as peroxide value of Biodiesel is increased. They found that the heating value of biodiesel decreased about 1.4% after 24 months storage. Arg et al. [18] did a field trial and concluded that the consumption of methyl ester of palm oil on the average was 12 km/l compared to 13 km /l for petroleum diesel on 1800 CC capacity cars. At a speed greater than 80-km/l, methyl ester of palm oil gave better fuel economy than conventional diesel. Another study [19] conducted on the use of palm oil methyl ester in Yammer TF80 and Isu zu 4FBI diesel engines showed that the specific fuel consumption for both engines were higher with palm oil biodiesel by approximately 15-20% as compared to conventional diesel and slightly lower thermal efficiency than conventional diesel. A numbers of works on the performances and emission of CI engines, fuelled with pure biodiesel and its blends with diesel oil have been carried out and are reported in the literature [20] and it indicates that even if based on different engine architectures, that may influence results generalization, the entire test showed a slight reduction of the performances (e.g. 5% decrease of the power over the entire speed range) and a significant increase in fuel consumption (+15%). The presence of oxygen in biodiesel led to more complete combustion processes, resulting in lower emission of CO, particulates and visible smokes. However, an increase in Nox emission with biodiesel has been measured, due to higher temperature generation during combustion.

C. Carraretta et al. [21] have also studied the performance of biodiesel with CI engine (6 cylinder, DI, diesel engine) and found that the increase of biodiesel percentage in the blend results in a slight decrease of both power and torque over entire speed range. In particular, with pure biodiesel there is a reduction by about 3% in power and about 5% in torque; a significant increase of BSFC over the entire speed range has been reported with biodiesel (about + 16%

average) due to its lower calorific value and greater density. The performance of CI engine with mahua methyl ester (MOME) was investigated by Puhan et al. [22] who found that the emission of reduction for Nox was about 4%. They also observed that about 11% reduction in smokes number, 30% reduction in CO emission, and 35% reduction in HC emission in MOME compared with diesel. The performance of diesel engine with biodiesel does not vary very much and it was found that the specific fuel consumption was higher (20%) than that of diesel engine and thermal efficiency is lower (13%) than that of diesel. Schumacher [23] tested on soybean methyl ester as a fuel in a Dodge truck and concluded that it can be used in diesel engine with either no difficulty. He reported that as the soybean methyl ester ratio in the mixture increased, the power; smoke intensity, CO and HC emissions decreased, and Nox emission and fuel consumption increased. Kumar et al. [24] did the research work for performance evaluation of CI engine with single cylinder diesel engine with Jatropha oil methyl ester (JOME) and found that the brake thermal efficiency of diesel engine with diesel was 30.3% while with JOME was 29%. They also found that part load thermal efficiency was found better at part loads for JOME than diesel. They also investigated that the maximum exhaust temperature with diesel and JOME was 402^0C and 415^0C respectively. Labeckas et al. [25] have studied the performances of direct injection diesel engine with rapeseed methyl ester (RME) and found that the brake specific fuel consumption at maximum torque (273.5g /kwh) and at rated power (281gm/kWh) for RME was higher by 18.7% and 23.2% relative to diesel fuel. The authors further revealed that at full load and rated rpm; B5 and B10 maintain their BSFC lower by 1.5% relative to diesel (228 g/kWh). The higher RME concentration in blends B20 and B35, as well as the use of neat

RME, suggest the BSFC is higher by 8.8%, 14% and 23.2% respectively. They also found that the brake thermal efficiency at rated rpm and rated load was about 37.5%, 38%, 37.8% and 35% for diesel, B5, B10 and neat Biodiesel respectively. They recommended B10 as the best blend of biodiesel for all speeds and all loads. At moderate rpm, the BSFC was lower by 3.5% for both the B5 and B10 blends, whereas at rated power, the B5 blend suggests slightly better (1.5%) fuel economy on the basis of test results, it was recommended that due to quite comparable cost and the real advantages in term of performance efficiency and environmentally friendly emissions, up to 10% bio fuel blends could be regarded as primary candidates to be put on stream for full scale usage in unmodified diesel engine.

Graboski et al. [27] operated a diesel engine using methyl ester biodiesel that was produced from soybean soap stock by Haas et al. [13]. It was found that B20 blend of biodiesel addition decreased particulate matters (PM) emission approximately 30% and slightly increased Nox (2.8%) while B100 decreased PM to 59% and increased Nox to (10.6%). Higher exhaust temperature from biodiesel-fuelled engine may indicate higher Nox [27]. However some researchers reported lower Nox emission [28] in biodiesel fuelled engines. The reported reason for lower emission is that increasing oxygen content in the blend shorten the ignition delay and reduces the amount of premixed fuel and peak burning temperature, which means a reduction in Nox emission. Kalligerous et al. [29] suggested that the Nox emission were reduced in all cases for biodiesel-fuelled engine. The reason for the decrease in Nox emission was that the Cetane number of biodiesel was higher than that for marine biodiesel fuel and this is usually associated with lower Nox emission [15]. Increasing Cetane number reduces the size of premixed combustion by reducing the ignition delay. This results in lower Nox formation rates since the combustion pressure rises more slowly, giving more time for cooling through the heat transfer and dilution and leading to lower localized gas temperature [30]. Research work has been done on the intercorrelation of aromatic content with other fuel properties [31], proving that aromatic and polyaromatic hydrocarbons are responsible for high Nox emissions. This is probably due to the higher flame temperature associated with aromatic compounds. By reducing the aromatic, the flame temperature will drop, leading to a lower Nox production rate. As a result, the addition of biodiesel, which does not contain the above classes of compound so, reduces the Nox emission from the engine.

As stated elsewhere, transesterification is the better alternative way of modifying the vegetable oils to monoesters [3]. Chemically, 3:1 molar ratio of alcohol to triglycerides is required to complete transesterification process. However in practices, higher alcohol to oil molar ratio is generally employed to achieve biodiesel of low viscosity and high conversion [32 & 33]. Physiochemical properties of methanol include molecular weight (32.04), boiling temperature (64.7^{0}C) and specific gravity (0.792). As the molecular weight of MeOH is low compared to other alcohol, less amount of methanol is required for reaction on mole basis. Since boiling temperature is also low compared to other alcohol, less energy required for reaction. Alkali catalyzed transesterification is much faster than acid catalyzed transesterification and is most often used commercially [30]. Further, the Trans- methylation occur approximately 4000 times faster in the presence of alkaline catalyst than acid catalyst [34]. The main advantages of using biodiesel are its renewability, better quality exhaust gas emission, biodegradability; it does not contribute to a rise in the level of carbon dioxide in the atmosphere [35, 36& 37]. Meher et al. (38) also concluded that the free fatty acid (FFA) Value of oil should be lower than 3% for alkali based biodiesel production. The addition of more sodium hydroxides catalyst compensates for higher acidity, but the resulting soap formation causes an increase in viscosity or formation of gels that interferes in the reaction as well as with separation of glycerol. Ma et al. [39] were investigated the effect of free fatty acids and water on transesterification of beef tallow with methanol and concluded that the water content of beef tallow should be kept below 0.06% w/w and free fatty acid content of beef tallow should be kept below 0.5% w/w in order to get the best conversion. Water content has been reported as more critical variable in the transesterification process than FFAs. The maximum content of free fatty acid (0.5% w/w) was confirmed by the results of Bradshow and Meuly [40]. Feuge et. al. [41] also advocated that, for an alkali-catalyzed transesterification, the triglycerides and alcohol must be substantially anhydrous because water makes the reaction partially change to sponification, which produces soap. The soap lowers the yield of esters and renders the separation of ester and glycerol and the water washing becomes difficult. Keim [42] has suggested the acid catalyzed transesterification for higher presence of water and FFA. A molar ratio of 6:1 was used for beef tallow transesterification with methanol by Ali [43] and they reported that about 80% (by tallow weight) of ester was recovered. Jackson et al. [44] studied the transesterification reaction with lipase as enzyme catalyst for Methanolysis of corn oil inflowing supercritical carbon dioxides with an ester conversion of > 98%(w/w).

1.3. FORMULATION OF PROBLEM

Some research work has been done for production of biodiesel, its performance evaluation in CI engines and effect of ageing on biodiesel. However very little work has been reported on the performance of CI engine on the blends of jatropha biodiesel and diesel as well as effect of aged biodiesel on the engine performance. In view of the above and the thrust of Government of India using jatropha biodiesel, the present study was selected. The proposed study has the following objectives:

(i) To study the fuel properties of oil and biodiesel of jatropha.

(ii) To evaluate the performance of a CI engine on the different blends of biodiesel with diesel

(iii) To study the effect of aged biodiesel on the engine performance.

The whole work has been grouped into six chapters. The first chapter gives the crude oil consumption and edible oil production of country, biodiesel demand for country, literature survey and objective of work. Second chapter gives an idea of available resources for biodiesel production, composition of triglycerides, available standard for biodiesel, and diesel engine performance. The third chapter gives an idea about biodiesel production from Jatropha seeds, fuel properties measurement of biodiesel and study of ageing on certain fuel properties like viscosity, acid value and peroxide values. The fourth chapter gives details about performance evaluation of engine with neat biodiesel as well as aged biodiesel. In the chapter five, all the experimental results have been discussed thoroughly. Conclusion and recommendation of this work is given in sixth chapter.

CHAPTER-2

VEGETABLE OIL RESOURCES FOR BIODIESEL PRODUCTION

2.0. GENERAL

Basically, straight vegetable oils (SVO) are either edible like coconut, sesame, rapeseed, mustard, linseed, peanut and olive oil etc. or non-edible like pongamia, jatropha, neem etc, which are not consumed by animals and men. These plants are annual/perennial and there are at least 150 species of trees & shrubs of non-edible plants in the country. In Indian context, about 60 Mha of waste land &Road/Railway track side space can be used to grow non-edible plants .The seeds of which will yield oil and biomass residue for various usage. This sector will also encourage crushing, oil expellers, and biodiesel producers type industries to produce raw and finished goods. This is one of the factors that may contribute to the concept of " Sustainable Rural Areas" where environment and people are interdependent.

2.1. VEGETABLE OIL RESOURCES

Vegetable oils and triglycerides present in the oils are considered as viable alternative to diesel. The high viscosity of oil, which can be improved by possible treatments like dilution with suitable solvents, emulsification, pyrolysis and transesterification. The later process converts SVO, which is 90-95% triglycerides, to esters of glycerols and fatty acids. The nature of fatty acids plays an important role in determining the physio-chemical properties of Biodiesel. The basic constituent of vegetable oils is triglycerides. The chemical structure of triglycerides molecule is given below:

CH_2OOCR1

|

CHOO CR2

|

CH_2OOCR3

Where R1, R2 & R3, hydrocarbon may be same or different. Vegetable oils comprise of 90 to 98% triglycerides and small amounts of mono- and di-glycerides. Triglycerides are the esters of three fatty acids with one glycerol molecule and contain substantial amounts of oxygen in its structure. Fatty acids vary in their carbon chain length and in the number of double bonds. The structures of common fatty acids are given in Table 2.1[45]. Table 2.2 summarizes the fatty acid composition of some vegetable oils [46,47]. The fatty acids commonly found in vegetable oils are stearic, palmitic, oleic, linoleic and linolenic. Vegetable oils contain free fatty acids (FFA) 1 to 5%, phospholipids, phosphatides, carotenes, tocopherols, sulphur compounds and traces of water [45]. The Table 2.2 indicates that the Jatropha oil contains about 25% saturated and more than 60% unsaturated fatty acids. The quantity of single saturated and double saturated fatty acids is almost the same. The unsaturation in the oil causes the oxidation of oil, which deteriorates the physical, and chemical properties of oil. Higher saturation in the oil will reduce the pour and cloud points of the oil.

Table 2. 1: Chemical Structure of Common Fatty Acids [45]

Sl. No	Fatty Acid	IUPAC Name	Structure*	Formula
1	Lauric	Dodecanoic	12:0	$C_{12}H_{24}O_2$
2	Myristic	Tetradecanoic	14:0	$C_{14}H_{28}O_2$
3	Palmitic	Hexadecanoic	16:0	$C_{16}H_{32}O_2$
4	Stearic	Octadecanoic	18:0	$C_{18}H_{36}O_2$
5	Arachidic	Eicosanoic	20:0	$C_{20}H_{40}O_2$
6	Behenic	Docosanoic	22:0	$C_{22}H_{44}O_2$
7	Lignoceric	Tetracosenoic	24:0	$C_{24}H_{48}O_2$
8	Oleic	Cis-9-octadecanoic	18:1	$C_{18}H_{34}O_2$
9	Linoleic	Cis-9,cis-12-octadecadiecnoic	18:2	$C_{18}H_{32}O_2$
10	Linolenic	Cis-9,cis-12,cis15-octadecatrienoic	18:3	$C_{18}H_{30}O_2$
11	Erucic	Cis-13-decosanoic	22:1	$C_{22}H_{42}O_2$

*- XX: Y, XX shows the no. of carbon atom in fatty acid chain with y no. of double bond

Table2.2: Fatty Acid Composition (w/w)% of Oil [46,47]

Sl No	Fatty Acids / Oil Type	Myristic	Palmitic	Stearic	Oleic	Linoleic	Linolenic
1	Corn	1-2	8-12	2-5	19-49	36-42	-
2	Cottonseed	0-2	20-25	1-2	23-35	40-50	-
3	Peanut	-	8-9	2-3	50-65	20-30	-
4	Rapeseed	-	4.3	1.3	60	21.1	13.2
5	Soybean	-	6-10	20-30	2-5	50-60	5-11
6	Sunflower	-	6	3.5	17	73	0
7	Tallow	3-6	24-32	20-25	37-43	2-3	-
8	Linseed		4-7	2-4	25-40	35-40	25-60
9	Yellow grease	1.3	17.3	12.4	54.7	8	-
10	Jatropha	0.1	14-15	4-10	34-46	29-45	0.3
11	Rice bran	0.6	11.7-17	1.7-2.5	39-43	26-35	-
12	Sal	-	4.5-8.6	34-44	34-44	2.7	-
13	Mahua	-	16-28	20-25	45-51	9-4	-
14	Neem	-	13-16	14-24	49-61	2-15	-
15	Pongamia	-	3.7-7.9	2.4-8.9	44-71	10-18	-

2.1.1. Fuel Properties of Vegetable Oils

The fuel properties of vegetable oils as listed in Table 2.3 [45,48] indicates that the kinematic viscosity of vegetable oils varies in the range of 30 to 40 cSt at 38°C. The High viscosity of these oils is due to their large molecular weight and chemical structure. Vegetable oils have high molecular weights in the range of 600 to 900, which are three or more times higher than diesel fuel. The flashpoint of vegetable oils is very high (above 200°C). The higher heating values of these oils are in the range from 39 to 40 MJ/kg that are low compared to diesel fuels (about 45 MJ/kg). The presence of chemically bound oxygen in vegetable oils lowers their heating values by about 13%. The Cetane numbers are in the range of 32 to 40. The Iodine value ranges from 0 to 200 depending upon unsaturation. The cloud and pour points of vegetable oils are higher than that of diesel.

Table2.3: Fuel Properties of Vegetable Oil [45,48]

Vegetable Oils	Kinematic Viscosity (cSt at 38^{0}C)	Cetane Number	Heating Values (MJ/kg)	Cloud Point (^{0}C)	Pour Point (^{0}C)	Flash Point ^{0}C	Specific Gravity at 15^{0}C
Corn	34.9	37.6	39.5	-1.1	-40.0	277	0.9095
Cottonseed	33.5	41.8	39.5	1.7	-15.0	234	0.9148
Linseed	27.2	34.6	39.3	1.7	-15.0	241	0.9236
Peanut	39.6	41.8	39.8	12.8	-6.7	271	0.9026
Rapeseed	37.0	37.6	39.7	-3.9	-31.7	246	0.9115
Safflower	31.3	41.3	39.5	18.3	-6.7	260	0.9144
Sesame	35.5	40.2	39.3	-3.9	9.4	260	0.9133
Soybean	32.6	37.9	39.6	-3.9	-12.2	254	0.9138
Sunflower	33.9	37.1	39.6	7.2	-15.0	274	0.9161
Palm	39.6	42.0	39.5	31.0	-	267	0.9180
Jatropha	55 at 30 ^{0}c	40-45	39-40	-	-	240	0.912
Diesel	1.3-4.1	40-55	42	-15 to -5	-33 to -15	60-80	0.82-0.86

The above table indicates that the viscosity of vegetable oils is in the range of 40-50 cSt which is almost 20-25 times higher than diesel. The vegetable oils have higher the flash point and lower calorific value than diesel.

2.1.2 Performance of Straight Vegetable Oils (SVO) as Substitute of Diesel

It is found that the use of vegetable oils as diesel fuels in conventional diesel engines leads to a number of problems related to the type and grade of oil and local climatic conditions [49,50]. The injection, atomization and combustion characteristics of vegetable oils in diesel engines are quite different from those of hydrocarbon-based diesel fuels. The high viscosity of vegetable oils interferes with injection process and leads to poor fuel atomization. The inefficient mixing of oil with air contributes to incomplete combustion. The high flash point attributes to its lower volatility characteristics. This leads to more soot deposit formation, carbonization of injector tips, piston ring sticking and lubricating oil dilution and degradation. The combination of high viscosity and low volatility of vegetable oils causes poor cold engine start up, misfire and ignition delay. Oxidative and thermal polymerization of vegetable oils cause a deposition on the injectors forming a film that will continue to trap fuel and interfere with combustion. In the long-term operation, vegetable oils normally develop gumming, injector coking and piston ring sticking. Therefore, the engine must be more or less modified according to the conditions of use and the oil involved. The modified engines built by Elsbett in Germany and Malaysia and Diesel Morten und Geraetebau GMBH (DMS) in Germany and in the USA showed a satisfactory performance when fuelled with vegetable oils of different compositions and grades.

2 .1.3 Derivatives of Triglycerides as Diesel Fuel

SVO occupy a prominent position in the development of alternative fuels, although they have many problems associated with its direct use in diesel engine. These are coking and trumpet formation on injectors, carbon deposits, and oil ring sticking, thickening or gelling of lubricating oil. Following methods can minimize the problems in the use of SVO:

(i) Pyrolysis

(ii) Microemulsification

(iii) Dilution

(iv) Transesterification

2.1.3.1 Pyrolysis

Pyrolysis refers to a chemical change caused by the application of thermal energy in the absence of air or nitrogen spurge was studied by many workers. The Pyrolysis of triglycerides is done to obtain lighter products suitable for diesel engines. These studies include the effect of temperature on the type of products obtained, the use of catalysts, to obtain paraffins and olefins similar to those present in hydrocarbon-based diesel fuels and the characterization of the thermal decomposition products. Thermal decomposition of triglycerides produces the compounds of classes like alkanes, alkenes, alkadienes, aromatics and carboxylic acids. Different types of vegetable oils produce large differences in the composition of the thermally decomposed oil. Generally the formation of alkanes, alkenes, alkadienes, aromatics and carboxylic acids is caused by the Pyrolysis of triglycerides. The Mechanisms for the thermal decomposition of triglycerides is complex due to chemical structure and complexity of possible reactions of mixed triglycerides. The liquid fractions of the thermally decomposed vegetable oil are likely to approach diesel fuel. The pyrolysed soybean oil contains 79% carbon and 11.88% hydrogen [51]. It has low viscosity and a high Cetane number compared to pure vegetable oils. The Cetane number of pyrolysed soyabean oil is enhanced to 43 from 38 and the viscosity is reduced to 10.2 cSt from 32.6 cSt at 38°C [51,52], but it exceeds the specified value of 7.5 cSt. The pyrolysed vegetable oils possess acceptable amounts of sulpher, water and sediment and give acceptable copper corrosion values but unacceptable ash, carbon residue and pour point. Engine testing on pyrolysed oil has been limited to short-term tests. And encouraging results of performance evaluation on Pyrolysis products are lacking in the literature, perhaps due to unsatisfactory results.

2.1.3.2 Microemulsification

Microemulsions are isotropic and clear, thermodynamically stable dispersions of oil, water, surfactant, and often a small amount of amphiphilic molecule called co surfactant [52,53]. The droplet diameters in Microemulsions range from 100 to 1000 Å. A microemulsions can be made of vegetable oils with an ester and dispersant (cosolvent), or of vegetable oils, an alcohol and a surfactant, with or without diesel fuels. Microemulsions, because of their alcohol content have lower volumetric heating values than diesel fuels, but the alcohols have high latent heat of vaporization and tend to cool the combustion chamber, which would reduce nozzle coking. A microemulsions of methanol with vegetable oils can perform nearly same as diesel fuel. The use of 2-octanol as an effective amphiphilic in the micellar solubilization of methanol in triolein and soybean oil has been demonstrated [49]. The reported engine tests on a microemulsions consisting of soyabean oil : methanol : 2-octanol : Cetane improver (52.7:13.3:33.3:1) indicate the accumulation of carbon around the orifice of the injector nozzle and heavy deposits on exhaust valves.

2.1.3.3 Dilution

Dilution of vegetable oils with diesel, solvent or eathnol can be accomplished eg. the dilution of sunflower oil with diesel fuels in the ratio of 1:3 (v/v) was studied and engine tests was carried out by Ziejewski et al. [50]. The viscosity of this blend was found as 4.88 cSt at 40°C. They concluded that the blend could not be recommended for long-term use in the direct injection diesel engines, because of severe injector nozzle coking and sticking. A comparable blend with high oleic safflower oil was also tested and it gave satisfactory results, but its use in the long term is not applicable as it leads to thickening of lubricant. A 1:1 blend of soyabean oil and stoddard solvent (48% paraffins and 52% naphthenes) had viscosity of 5.12 cSt at 38°C. This fuel produced heavy carbon deposit on the tulips of the intake valves and showed considerable top ring wear.

2.1.3.4 Transesterification

The plant oils usually contain free fatty acids, phospholipids, sterols, water, odorants and other impurities, due to which, the oil cannot be directly used as fuel. To overcome these problems, the oil requires some sort of chemical modification as stated above. Among these methods, the transesterification is the key and an important step to produce the cleaner and environmentally safe fuel from vegetable oils. Biodiesel is defined as the monoalkyl esters of long chain fatty acids derived from renewable feed stocks, such as vegetable oil or animal fats, for use in compression ignition engine. The mixture% (v/v) of biodiesel and diesel is denoted as BXX, where XX shows the volume percentage of Biodiesel in diesel. Complete biodiesel is represented by B100. Biodiesel, which is considered as a possible substitute of conventional diesel fuel, is commonly, composed of fatty acid methyl / ethyl esters that can be prepared from triglycerides in vegetable oils by transesterification with methanol / ethanol respectively. The resulting biodiesel is quite similar to conventional diesel fuel in its main fuel characteristics. Transesterification or alcoholysis is the displacement of alcohol from an ester by another in a process similar to hydrolysis, except the alcohol is used instead of water. This process has been widely used to reduce the high viscosity of triglycerides. The transesterification reaction is represented by the general equation as:

$$\text{Triglyceride} + R^1OH \rightleftharpoons \text{Diglyceride} + RCOOR^1$$

$$\text{Diglyceride} + R^1OH \rightleftharpoons \text{Monoglyceride} + RCOOR^1$$

$$\text{Monoglyceride} + R^1OH \rightleftharpoons \text{Glycerol} + RCOOR^1$$

The catalysts used in transesterification may be base type, acid type and enzyme based. The transesterification can be performed without catalyst that is known as supercritical method. The merits and demerits of above stated type of transesterification are compared in the given Table 2.4.

Table2.4: Process Comparison for Biodiesel Production [54,55]

Sl.No	Variables	Alkali Catalyst	Lipase	Super critical Method	Acid Catalyst
1	Reaction temp.(^{0}c)	60-70	30-40	239-385	55-80
2	Fatty acid	Sponified product	Methyl ester	Ester	Ester
3	Water	Interference	No influence	No influence	Interference
4	Glycerol recovery	Difficult	Easy	Good	Normal
5	Purification of methyl ester	Repeated washing	None	Good	Repeated washing
6	Molar ratio of alcohol	6:1	-	42:1	30:1
7	Time	1-6 (hours)	-	240 seconds	>20 (hours)

The above Table summarizes the superiority of the supercritical methanol process over common catalyzed method. The merit is that this process is free of catalyst, simpler purification and higher yield of methyl ester in least time. But the demerit of this is its higher consumption of alcohol. The time required to complete the transesterification reaction is considerably smaller in alkali-based transesterification than acid catalyst based reaction.

2.2 FACTORS AFFECTING TRANSESTERIFICATION REACTION

Followings are the variables affecting the reactions:

(i) Effect of free fatty acid and moisture

(ii) Catalyst type and concentration

(iii) Molar ratio of alcohol to oil and type of alcohol

(iv) Effect of reaction time and temperature

(vi) Mixing intensity

2.3 STANDARD FOR BIODIESEL

The countries like Germany, Italy, France, the Czech Republic and USA etc. have developed their own biodiesel standard. However, Indian standard under the name IS: 15607 is also being developed. All over the world, the ASTM standard is usually followed. The ASTM and other standards are given in the Table 2.5, which shows that the limiting values for viscosity, flash point and acid value in ASTM standard is slightly higher than DIN standard. The limiting value for carbon residue is almost same for the entire above standard. Among the general parameters for biodiesel, the viscosity controls the characteristics of the injection from the diesel injector. The viscosity of fatty acid methyl esters can go very high levels and hence it is important to control it within an acceptable level to avoid negative impacts on fuel injector system performance. Therefore, the viscosity specifications proposed are nearly same as that of the diesel fuel.

Table 2.5: General Parameters of the Quality of Biodiesel [56]

Parameters	Austria (ON)	Czech republic (CSN)	France (journal official)	Germany (DIN)	Italy (UNI)	USA (ASTM
Density at 15 °C g/cm^3	0.85–0.89	0.87–0.89	0.87–0.89	0.875–0.89	0.86–0.90	0.88
Viscosity at 40°C mm^2/s	3.5–5.0	3.5–5.0	3.5–5.0	3.5–5.0	3.5–5.0	1.9–6.
Flash point (°C)	100	110	100	110	100	130
CFPP (°C)	0/−5	−5	–	0–10/−20	–	–
Pour point (°C)	–	–	−10	–	0/−5	-15 to 10
Cetane number	≥49	≥48	≥49	≥49	–	≥47
Neutralization number (mgKOH/g)	≤0.8	≤0.5	≤0.5	≤0.5	≤0.5	≤0.8
Carbon residue (%)	0.05	0.05	–	0.05	–	0.05

2.4 FUEL PROPERTIES OF BIODIESEL FROM DIFFERENT FEEDSTOCKS

The biodiesel can be produce from different type of feedstocks, which may be vegetable oil, non vegetable oil, animal fat and fried oil etc. The fuel properties of esters depend on available fatty acid composition. The different fuel parameters of esters based on different feedstocks are given in the Table 2. 6.

Table2. 6: Fuel Properties of Fatty Acid Methyl Esters (FAME) and Diesel [48,49&56]

SL.No.	Source Name	Cetane No.	GCV (MJ/kg)	Kinematic Viscosity at 40 ^{0}c (mm^2/Sec)	Cloud Point ^{0}c	Pour Point	Flash Point ^{0}c
1	Raped seed	54.4	40.44	6.7	-2	-9	84
2	Soyabean	46.2	39.80	4.08	2	-1	171
3	Sunflower	46.6	39.80	4.22	0	-4	-
4	Tallow	62.0	39.94	4.11	12	9	96
5	Jatropha	52	39.62	4-5.5	-	-	191
6	Diesel	40-55	44.50	1.3-4.1	-15 to 5	-33 to -15	60-80

The above Table indicates that the calorific value of esters produced from different feedstocks is almost same. The calorific value of esters is about 12% lower than diesel on kg basis and about 8% lower on per liter basis combustion.

The cetane number of biodiesel is higher than diesel, which is responsible for reduced ignition delay. The viscosity is slightly higher than diesel viscosity. The flash point of biodiesel is also higher than diesel fuel, which results in safe transportation.

2.5 ADVANTAGES OF BIODIESEL

Followings are the advantages of biodiesel:

(i) Biodiesel is biodegradable.

(ii) It is nontoxic

(iii) It is renewable. With a much higher flash point than it is for petro-diesel (biodiesel have a flash point of about 160 ^{0}c), biodiesel is classified as a nonflammable liquid by the occupational safety and health administration.

(iv) Biodiesel is the only alternative fuel that runs in any conventional unmodified diesel engine.

(v) Biodiesel can be used alone or mixed in any ratio with petroleum diesel fuel. The most common blend however is a mix of 20% biodiesel with 80% petroleum diesel (B20).

(vi) Biodiesel has about 11% oxygen by weight and contains no sulpher. The lifecycle production and use of biodiesel produces approximately 80% less carbon dioxide emission, and almost 100% less sulpher dioxide.

(vii) The use of biodiesel can extend the life of diesel engines because it is more lubricating than petroleum diesel fuel, while fuel consumption, auto ignition, power output, and engine torque are relatively unaffected by biodiesel.

2.6 DISADVANTAGES OF BIODIESEL

Biodiesel has also some disadvantages that are given as:

(i) Lower calorific value than diesel fuel.

(ii) Higher pour and cloud point than diesel.

(iii) Prone to oxidation due to unsaturation.

(iv) Higher Nox emission than diesel.

(v) Corrosive nature against copper and brass.

(vi) Non- compatible with plastic and rubber material

(vii) Low volatility

(viii) Lower shelf life

2.7 FREE FATTY ACIDS (FFA)

Free fatty acids in a fat (or fat extracted from a sample) can be determined by volumetric titration. The FFA value is then expressed as % of a fatty acid common to the product being tested. Frequently, values are expressed as % oleic acid for tallow or soybean oils. For coconut oils or other oils that contain high levels of shorter chain fatty acids, FFA may be expressed as % lauric acid. FFA is an indication of hydrolytic rancidity, but other lipid oxidation processes can also produce acids. It may also be useful to know the composition of the free fatty acids present in a sample to identify their source and understand the cause of their formation. Unlike peroxide value and free fatty acid analysis, which give an idea of how good or bad oil is at a particular time, the OSI (Oxidative Stability Index) analysis has predictive value for oxidative indication of lipid. OSI can be used to compare various oils to predict their respective shelf lives. The OSI analysis can also be used to evaluate the effectiveness of antioxidants or determine how much longer frying oil can be used before it goes bad.

2.8 COMPARISON OF EMISSIONS FOR BIODIESEL AND DIESEL

The literature has reported that the engine operation on biodiesel mixed with diesel gave lower emission than diesel fuel expect in case of Nox. It has been observed that in case of NOx, there is increase in 2% with B20 use and 10% with B100 use. The comparison of emission of biodiesel compared to diesel is given in Table2.7.

Table 2.7: Emission Comparison of Biodiesel and Diesel [57]

SI.No.	EmissionType	B100	B20
1	Hydrocarbon (HC)	-67%	-20%
2	CO	-48%	-12%
3	Particulate matter (PM)	-47%	-2%
4	Nox	+10%	+2%
5	SO_2	-100%	-20%
6	PAH	-80%	-13%

The above Table comparison shows that all emissions associated with biodiesel use are lower than diesel except Nox. The higher of Nox emission could be reduced either by slight retard of injection timing (1 to 5 degree) or by use of catalytic converter. The life cycle analysis of biodiesel shows that the reduction in CO_2 emission is about 16% with B20 and 72% with B100 use for per liter combustion basis [24,25].

2.9 DIESEL ENGINE PERFORMANCE WITH BIODIESEL

Biodiesel has shown its good performance with diesel engine. B20 use in diesel engine provides almost same fuel economy as it is observed with diesel fuel. Due to high lubricity in nature, it provides less wear and tear in engine component. Many studies on the performances and emission of compression ignition engines, fuelled with pure biodiesel and blends with diesel oil have been performed and are reported in the literature [19,20], which indicates that Even if based on different engine architectures, that may influence results *generalization*, the entire test showed a slight reduction of the performances (e.g. 5% decrease of the power over the entire speed range) and a significant increase of fuel consumption (+15%). The presence of oxygen in biodiesel leads to more complete combustion processes, resulting in lower emission of CO, particulates and visible smokes. However, an increase in Nox emission has been measured, due to higher temperature.

In the view of above, it seems that biodiesel blends with diesel will perform well as compared to diesel. The fuel properties of diesel and biodiesel are almost similar and the comparison given in Table 2.8, which indicates that the Cetane number, flash point and lubricity value are higher than diesel fuel while the calorific value is lower than diesel. The viscosity of biodiesel is also higher than diesel. The higher cetane would result in shortening the delay period that would provide the better combustion of fuel. The presence of oxygen in biodiesel would facilitate the lower emission due to better combustion.

Table 2.8: Fuel Properties of Diesel and Biodiesel [58]

Sl.No	Fuel properties	Diesel	Biodiesel
1	Fuel standard	ASTM D 975	ASTM D 6751
2	Fuel composition	C10-C21 HC	C12-C22 FAME
3	Lower heating value (MJ/kg)	42.52	37.12
4	Kinematic viscosity at 40 ^{0}c(cSt)	1.3-4.1	1.9-6.0
5	Density (kg/m $^{3)}$ at 15 ^{0}c	848	878
6	Water, ppm, by wt.	161	0.05% max
7	Carbon, wt.%	87	77
8	Hydrogen, wt%	13	12
9	Oxygen, wt%	0	11
10	Sulfur, wt%	0.05 max.	0
11	Boiling point, ^{0}c	188 to 343	182 to 338
12	Flash point, ^{0}c	60 to 80	100 to 170
13	Cloud point, ^{0}c	-15 to 5	-3 to 12
14	Pour point, ^{0}c	-35 to -15	-15 to 16
15	Cetane number	40 to 55	48 to 60
16	Auto ignition temperature, ^{0}c	316	-
17	Stoichiometric air/fuel ratio, w/w	15	13.8
18	BOCLE scuff, gm	3600	>7000

2.9.1 Affecting Parameters for Diesel Engine Performance

A diesel engine takes air inside combustion chamber, compresses it and then injects fuel into the compressed air. The heat of the compressed air burns the fuel spontaneously. A diesel engine compresses air at a ratio of 14:1 to as high as 25:1. The higher compression ratio of the diesel engine leads to better efficiency. When a gas is compressed, its temperature rises, a diesel engine uses this property to ignite the fuel. Air is drawn into the cylinder of a diesel engine and compressed by the rising piston at a much highe compression ratio than for a spark-ignition engine, up to 25:1. The air temperature reaches 700–900 ^{0}c, at the top of the piston stroke, diesel fuel is injected into the combustion chamber at high pressure, through an atomising nozzle, mixing with the hot, highlycompressed air. The resulting mixture ignites and burns very rapidly. This contained combustion causes the gas in the chamber to heat up rapidly, which increases its pressure, which in turn forces the piston downwards. The connecting rod transmits this motion to the crank shaft, which is forced to turn, delivering rotary power at the output end of the crankshaft.The following parameters that will affect the performance of diesel engine are discussed as:

2.9.1.1 Viscosity of the fuel

The viscosity of the fuel should be low for better atomization in side the combustion chamber. For finer size of fuel droplet, the available overall surface area of all fuel droplets will be higher than coarse size of fuel droplets. The higher surface area will facilitate more heat transfer due to radiation and convection from combustion chamber. The higher amount of heat available to fuel droplets will result into smaller delay period. For finer atomization, the delay period is order of 0.0008 second while for coarse atomization; it would be in order of 0.005 second and shorter delay period is required for better combustion.

2.9.1.2 Delay period

When fuel is injected into the turbulent compressed air, inside combustion chamber, it does not ignite immediately. There is a time period called the ignition delay, during which fuel heats up, vaporizes, mixes with air and undergoes chemical precombustion reactions that produce the radicals necessary for spontaneous ignition or auto ignition. In other wards, ignition delay is a set of process that includes the heating, vaporization and mixing process known as "physical delay " and the pre-reaction known as the "chemical delay". The ideal engine should have an extremely short delay period and rapid air motion in the cylinder. The factor that influence the length of delay periods are:

(I) Temperature of air charge

(II) Pressure of charge

(III) Atomization of fuel

(IV) Timing of injection

(V) Engine speed.

(VI) Cetane number

Both advancing and retarding of injection increases the delay angle. The minimum delay is occurred at about 11.5^0 before top dead center (TDC). Delay period always decreases with increase in engine speed. This is caused by increase air turbulence. Direct control of burning during second stage is almost impossible. The indirect control consists in reducing the amount of fuel entering during delay period and this is obtained by reducing the delay period. At higher speed, delay period reduces due to less loss of heat and more crank angle in a given time. During ignition lag, particle of fuel receives heat from air, their surface temperature is increased towards the ignition point. Oxygen then combines with some of the surface hydrocarbons molecules to form unstable peroxides and these decompose at once with evolution of great heat. With this heat, the flame of combustion expands in whole combustion chamber.

2.9.1.3 Easier release of energy

The heating value of fuel will depend on the composition of fuel. A fuel with low energy content per liter will cause the engine to produce less power. Fuel with more unsaturation tends to have slightly lower energy contents. Tests have shown that the actual efficiency at which the energy in the fuel is converted to power is the same for biodiesel and petroleum-based diesel fuel. Therefore, the brake specific fuel consumption (BSFC), the parameter most often used by engine manufacturers to characterize the fuel economy will be at least 12.5% higher for biodiesel. The BSFC is similar to efficiency in that it measures how much fuel may be required to do a certain quantity of work. However, it does not contain information about the amount of energy that may be available from the fuel, so it cannot be used to make comparisons between engines burning different fuels. The prefix "brake" designates that the power is measured directly at the engine's output shaft. The thermal efficiency of a fuel is usually defined as the ratio of the power produced by the engine to the energy in the fuel consumed, as indicated by the net calorific value (NCV) of the fuel.

2.9.1.4 Higher volumetric energy content

The density of the fuel is not itself an important parameter for the diesel engine but it is generally related to the fuel's energy content. As a first approximation, all hydrocarbon diesel fuels have about the same energy content on per kg basis. The differences between Fuels relate mostly to their density. More dense fuels provide greater energy per liter and since fuel is sold volumetrically, the higher the density, the greater the energy potential. As mentioned earlier, since biodiesel has a higher density than diesel fuel (0.87-0.88 g/cm^3 compared with 0.84-0.85 g/cm^3 for No. 2 diesel fuel and 0.81 – 0.815 g/cm^3 for No. 1 diesel). Biodiesel's 12% lower energy content per kg becomes only 8% less on a liter basis.

2.9.1.5. Engine speed

At higher engine speed, the turbulence created in the compressed air would be more. That would facilitate for higher heat transfer and better mixing of fuel with air. The same would be resulted into shorter delay period and less heat loss to body of cylinder.

2.9.1.6. Cetane number

One of the most important properties of a diesel fuel is its readiness to autoignite at the temperatures and pressures present in the cylinder when the fuel is injected. Cetane number is used to rate the performance of diesel fuel. It is defined as percentage of cetane in a cetane-methylnaphthalene mixture with the same ignition performance. A higher cetane number indicates greater fuel efficiency. Fuels with a high cetane number will have short ignition delays and a small amount of premixed combustion since little time is available to prepare the fuel for combustion.

CHAPTER-3

STUDY OF FUEL PROPERTIES OF BIODIESEL

3.0 GENERAL

In order to determine the fuel properties of biodiesel, the biodiesel was produced from jatropha oil using transesterification process. The production processes for biodiesel and fuel properties estimation have been discussed in this chapter.

3.1. OIL EXTRACTION AND BIODIESEL PRODUCTION

3.1.1. Seed Collection

The seeds of jatropha were collected from biofuels board of uttranchal. The Bio Fuel Board is located in Dehradoon district of Uttranchal state. Their seed godown was located in Sahaspur market that was about 30 km. away from Dehradoon. The board is acting as a nodal agency for Uttranchal state for popularizing the technology of biodiesel. The board has done the plantation of jatropha in the many parts of state. The weight of single dry seed of jatropha is about 750 mg and it contains oil by 25-30%(w/w). The kernel forms about 60% of the seed. The deoiled seed cake has a crude protein content of between 53-60% and favourable amino acid profile. The oil contains about 21% saturated and 79% unsaturated fatty acids contents. The color of seed was like white patch in light dark. The chemical composition of seed of Jatropha is given in the Table 3.1, which shows that seed has about 38% fat that would be responsible for oil extraction. The seed also contains moisture of about 6% that would facilitate the formation of FFA. A photograph of Jatropha seeds is shown in Fig 3.1.

Table 3.1: Chemical Composition of Jatropha Seed

Sl.No.	Constituents	%(w/w)
1	Protein	18
2	Carbohydrate	17.05
3	Fat	38
4	Moisture	6.2
5	Fiber	15.5
6	Ash	5.3

Fig 3.1: Jatropha Seeds

3.1.2. Seed Expelling

The Jatropha seeds were expelled by locally available expeller generally used for expelling mustard seeds in the market. The seeds were expelled three times in the expeller. During the expelling, small quantity of water (about 250 ml for 15 kg) was mixed. Major part of this poured water has evaporated in the form of steam. The oil yield was obtained as 15-20%, though yield was less and it may be due to very old seed. The expelled oil was left for 24 hours for settling. After settling, the oil was poured into another container. The deoiled cake can not directly use for animal feed due to its toxicity. The best solution to use the deoiled cake for biogas generation in the digester and the digested slurry would be good bio-fertilizer for agricultural field. After this, the complete oil was filtered. The filtered oil was heated in vacuum evaporator to remove the moisture. Then, the oil was kept in airtight container. Precaution was taken that the oil should not come in direct contact of air and sunlight. The colour of oil was light brown like mustard oil. This oil was further used for production of biodiesel, which was needed for ageing study and performance evaluation of engine. Some fuel properties like kinematic viscosity, density, calorific value and acid value were determined in the laboratory. The oil should keep in the moisture less container since the water in the oil would increase the amount of FFA. The higher FFA would create major problem like soap formation during triglycerides conversion. A photograph of jatropha oil is shown in the Fig.3.2. The fatty acid composition of oil comprises of Palmitic (13.5%), Stearic (6.4%), Oleic (45.99%), Linoleic (28.6%), Linolenic (15.9%) and others (11.5%).

Fig. 3.2: Jatropha oil

3.1.3. Procedure for Biodiesel Production from Jatropha Oil

An available laboratory-scale biodiesel reactor of one-liter capacity was used for production of biodiesel from Jatropha curcus oil by alkali-catalyzed trans-esterification method. Methanol (CH_3OH) was chosen as the alcohol used for trans-esterification of Jatropha curcus oil because of its low cost and low viscosity of obtained ester [38]. NaOH was chosen since it is cheaper and reacts much faster than acid catalyst [32]. The FFA of oil was measured by volumetric titration and found that it was more than 3.5%, it is therefore, two step-transesterification process was adopted. In the first step, Jatropha oil was heated upto 35-40^{0}C and 8% (v/v) methanol and 1 ml H_2SO_4 per liter of oil was mixed. The whole mixture was stirred for 1 hour at above temperature. And after that, heater was switched off and stirrer was run for another one hour. Mixture was settled in separating funnel for two hours. The first step process is known as esterification of oil. In the second step, 12% (v/v) methanol and 3 to 3.5 gm NaOH per liter of oil was mixed thoroughly such that NaOH should not be in separate stage so that it could react with oil separately to form soap. The esterified oil was heated upto 55-60^{0}C and sodium methoxide solution was poured into esterified oil. The stirrer was run for 1.5-2 hours and then mixture was taken to separating funnel and left it for two hours settling in funnel. Thereafter, the lower layer of glycerin (brown in color) was drained off by gravity separation. A photograph of separated layer of glycerin and biodiesel is shown in Fig.3.3

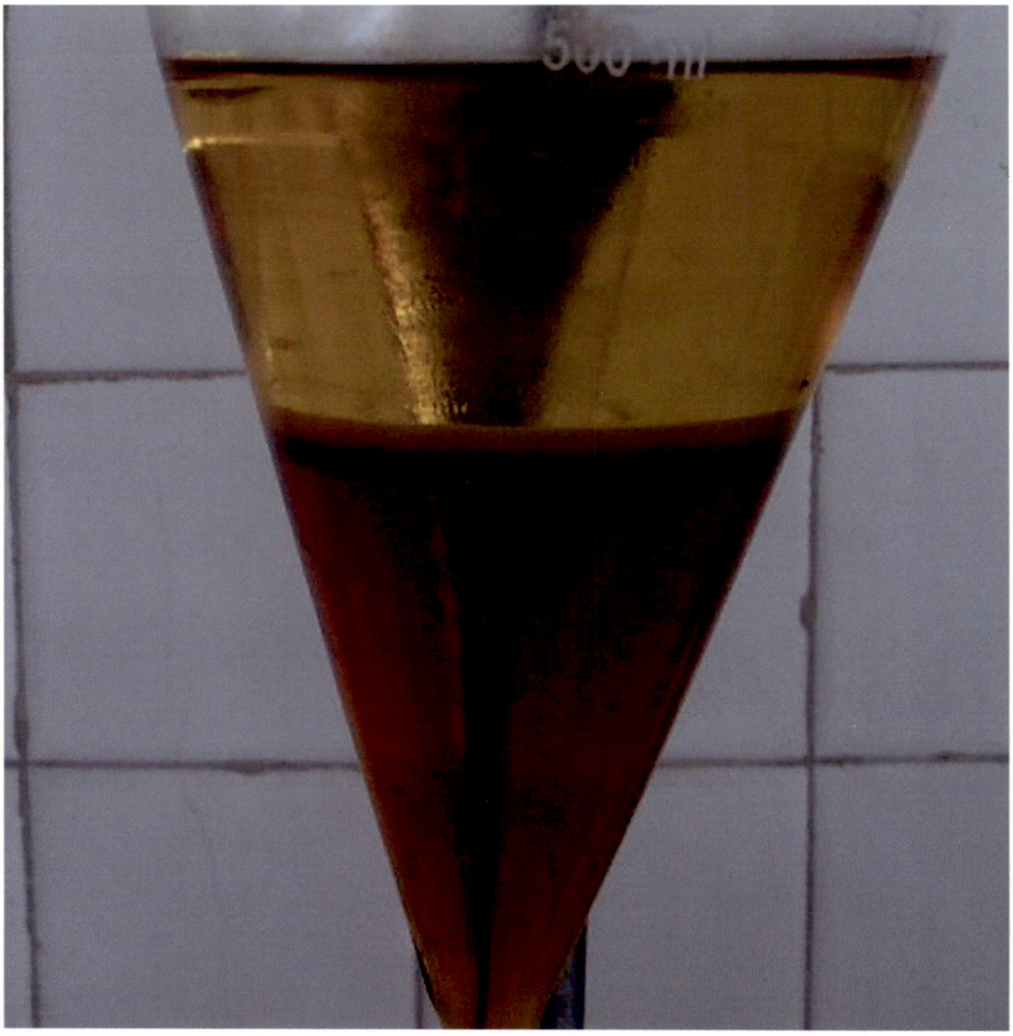

Fig. 3.3: Separated Layers of Biodiesel and Glycerin

3.1.4. Washing and Drying of Biodiesel

The washing of biodiesel was done with worm water. In the first washing' emulsion was formed of milky color and two separate layers was created within 30 minutes. If it does not separate within 20-30 minutes then, it indicates that the conversion of triglycerides has not been taken place completely into esters. The photograph of un-separated emulsion is shown in the Fig. 3.4. If the emulsion becomes separated in the above time period, then it is indicative of full conversion of triglycerides into esters. The lower layer of water was milky color and upper layer of biodiesel in yellow color. The photograph for separated emulsion is given in the Fig.3.5. The same process was repeated (generally3-4 times) until lower layer appeared liked transparent water (PH of 7). The photograph of biodiesel after third washing is given in the Fig 3.6.. After this, the haze present in the biodiesel was removed by heating at 30-40 ^{0}C for half hour. After then, biodiesel becomes fully transparent with light yellow color. If after heating, the haze does not remove from it, then, it is indication of partial washing and the same washing procedure should be repeated further for two to three times. After that, the present haze should be removed by heating at 30-40 ^{0}C for half hour. The moisture present in the biodiesel was removed by heating it in vacuum evaporator for one hour. The produced biodiesel should not be kept in the container made of copper, brass and non-fluorinated plastic. It should be kept in steel, aluminum or glass made container. The photograph of pure biodiesel is shown in Fig. 3.7. A flow chart for the complete procedure for the production of biodiesel from Jatropha seed is shown in the Fig. 3.8.

Fig.3.4: Unseparated Emulsion of Biodiesel and Water

Fig 3.5: Biodiesel After First Washing

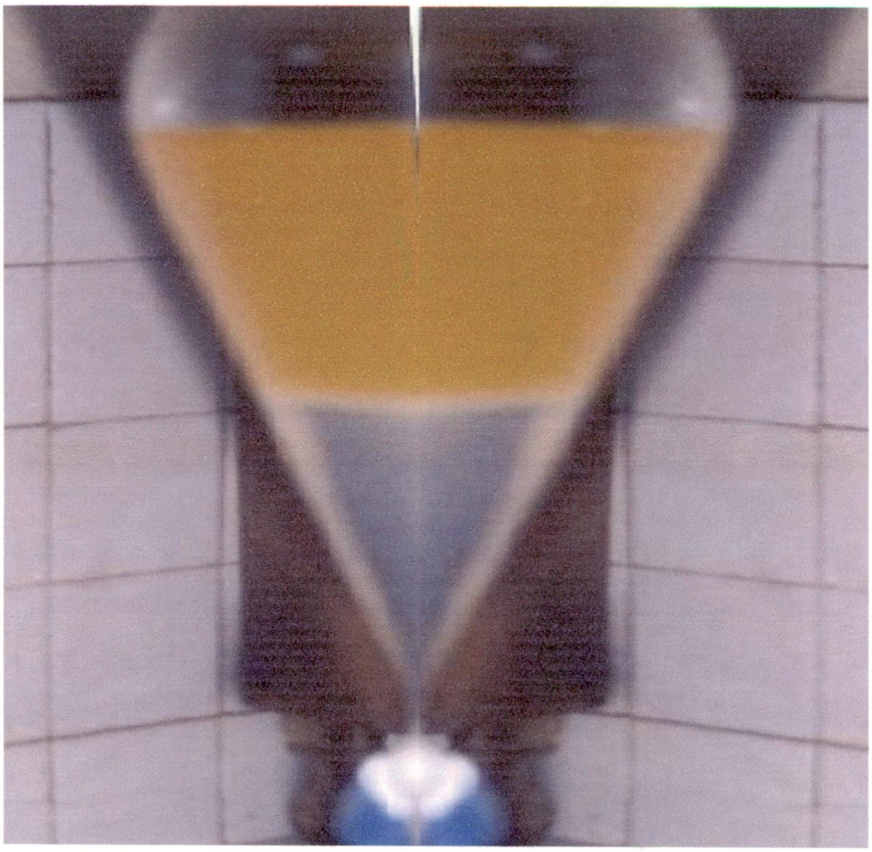

Fig. 3.6: Biodiesel After Third Washing

Fig. 3.7: Biodiesel After Drying

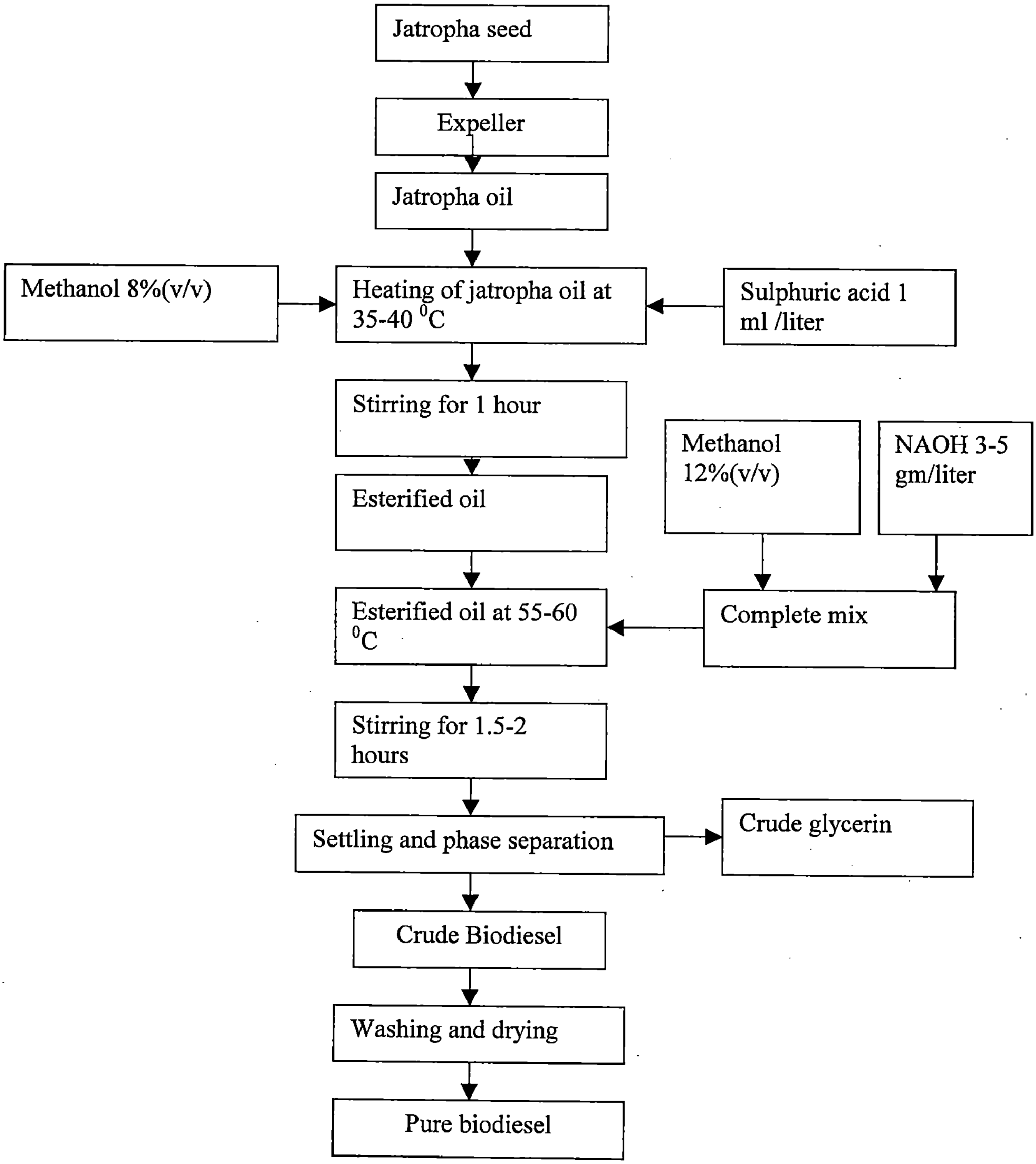

Fig 3.8: Process Flow Chart for Transesterfication

3.2 MEASUREMENT OF BIODIESEL FUEL PROPERTIES

The different fuel properties of biodiesel produced from Jatropha oil were measured using standard methods in the laboratory. The following properties were determined;

3.2.1 Density Measurement

The density of jatropha oil and its biodiesel was measured. The value of density for Jatropha oil and its biodiesel at 15 ^{0}C was found about 912 kg /m ^{3} and 889 kg /m ^{3} respectively.

3.2.2 Viscosity Measurement

Viscosity of a fluid is a measure of its resistance to flow. The ratio of absolute viscosity to density for any fluid is called Kinematic viscosity. The unit of Kinematic viscosity in C.G.S system is centistokes (cSt). The Kinematic viscosity of biodiesel was measured by Redwood viscosity no. 1. Though, it does not give a direct measurement of viscosity in an absolute unit but it enables the viscosities of oil to be compared by measuring the time of efflux of 50-ml. The value of kinematic viscosity at 40 ^{0}C for biodiesel was found to be 5.5 mm ^{2} / s and kinematic viscosity at 30 ^{0}C for jatropha oil was found to be 55 mm ^{2}/ s.

3.2.3 Calorific Value Measurement

The Gross calorific value (GCV) of biodiesel was measured by Bomb calorimeter. The GCV for both Jatropha oil and its biodiesel was found as 39.2 and 39.83 MJ/kg respectively. From Table 2.8, the availability of hydrogen in the biodiesel is about 12% (w/w). The calculation of net calorific value (NCV) has been done on the basis of formula given as:

NCV (MJ/kg) =GCV (MJ/kg) –(mass of steam x 2442.3)/1000

Mass of steam= 9 x wt% of hydrogen in the fuel

The NCV for biodiesel was evaluated as about 37.19 MJ/kg.

3.2.4 Flash Point Measurement

The flash point is defined as the "lowest temperature corrected to a barometric pressure of 101.3 kPa (760 mm Hg), at which application of an ignition source causes the vapors of a specimen to ignite under the specified conditions of test." The flash point of biodiesel was measured by Pensky-Martens apparatus. The value of flash point for biodiesel was observed as 184 ^0C and for jatropha oil was observed as 240 ^0C.

3.2.5 Acid Value (AV) Measurement

Acid number – "The quantity of base, expressed as milligrams of potassium hydroxide per gram of sample, required to titrate a sample to a specified end point." The acid number is a direct measure of free fatty acids in B100. The free fatty acids can lead to corrosion and may be a symptom of water in the fuel. The AV for biodiesel was determined by standard procedure and value was found as 0.31 mg KOH / g. The AV for jatropha oil was found about 7.5 mg KOH / g.

3.2.6 Peroxide Value (PV) Measurement

Lipid oxidation, which is also called auto-oxidation, occurs in lipid materials by way of free radical mechanism. After an induction period, hydroperoxide is formed. Ultimately these peroxides breakdowns, and secondary products, e.g., aldehydes, ketones, organic acids and hydrocarbons are formed. The extent of oxidation that has taken place in a sample of lipid or lipid fat can be expressed in terms of peroxide value. Peroxides produced by oxidation of the oil are measured using the technique based on their ability to liberate iodine from potassium iodide. Peroxide value was determined by measuring iodine released from potassium iodide. The peroxide value for biodiesel was found as 15 meq peroxide/kg of sample.

All the fuel properties of Jatropha oil , (JOME) and diesel and comparison with ASTM standard are given in the Table 3.2 which shows that some properties like flash point, viscosity and density of oil as well as its biodiesel are higher than diesel. The density of jatropha oil is about 8% higher than diesel. The viscosity of jatropha oil is more than twenty times higher than the viscosity of diesel. The higher value of viscosity and density of biodiesel than diesel may be due to its higher molecular weight. Since the biodiesel contains the fatty acid methyl ester (FAME) in the range of C_{12} - C_{22}, while diesel contains mostly hydrocarbon in the range of C_{10} - C_{21}. The positive deviation in density of biodiesel is about 6% than diesel and it is almost similar to the maximum limiting value of biodiesel as prescribed in ASTM standard. In the case of viscosity, increment of about 111% was observed with compared to diesel fuel and still, it was within the limit of viscosity value prescribed by ASTM standard. The reason for this high viscosity may be same as indicated in the case of density. The flash point of biodiesel is more than twice of value of diesel and it may be due to lower volatility of biodiesel than diesel. The net calorific value of biodiesel is lower by 13.5% than diesel and almost similar as per ASTM standard for biodiesel. The reason for calorific value may be due to lower %(w/w) of carbon in biodiesel than diesel. From the Table 2.8, it is clear that the carbon %(w/w) in diesel is 87% and in biodiesel, it is 77%. The acid value of biodiesel is much higher than diesel and still, it is lower than the limit prescribed by ASTM standard. The main reason for acid value is the non-conversion of FFA into esters and presence of moisture in the biodiesel. The peroxide value for fresh biodiesel was observed as within the acceptable limit as per reported in [59,60].

3.3. STUDY OF AGEING EFFECT

Two type of sample were taken for ageing study. The first sample of biodiesel was kept in airtight glass bottle at room temperature and was designated as (SA). The second sample of biodiesel was kept in the open glass bottle exposed to sunlight for the daytime and designated as (SB). The ageing effect on properties like viscosity, acid value and peroxide value of biodiesel was evaluated in the first week of every month (from January to June) and the results are given as:

3.3.1 Variation of Viscosity with Time

From the results of Table 3.3, it is seen that Viscosity of biodiesel tends to increase over time. The significant difference between the viscosity values of sample (SA) and sample (SB) was found. The variation in the kinematic viscosity at 40 ^{0}c with time for both the samples is given in the Table3.3, which shows that there is a faster growth in sample SB than in sample SA.

3.3.2 Variation of Acid Value with Time

The variation of acid values for both the sample was measured by volumetric titration method using standard procedure. The results obtained for acid values for both the samples of biodiesel is given in the Table 3.4 which shows that the variation for acid value for sample SB is much faster than sample SB.

3.3.3 Variation of Peroxide Value with Time

The variation in peroxide value for both the sample was measured by volumetric titration method using standard procedure. The results obtained for peroxide values for both the samples of biodiesel are given in the Table 3.5, which shows that the increase in peroxide value for both the sample has been observed with time. However, the increase in peroxide value for sample SA is still lower than sample SB.

Table 3.2: The Specification of JOME and Diesel

S.No.	Fuel Properties	Jatropha Oil	Jatropha Biodiesel (JOME)	Diesel [14,33]	ASTM Standard for Biodiesel [57]
1.	Net Calorific value (MJ/kg)	~36.8	37	42	~ 37.12
2.	Flash point ^{0}C	240	188	60-80	130 (minimum)
3.	Viscosity (cSt, @ 40^{0}C)	55 at 30 ^{0}C	5.5	2.6	1.9-6.0
4.	Acid value (mg KOH/g)	7.5	0.31	0.09	0.8
5	Density (kg/m ^{3}) at 15 ^{0}C	912	889		880
6	Peroxide value (meq peroxide/kg)	-	15		<50[74,75]

Table3.3: Kinematic Viscosity Variation with Time

Sl.No	Parameter / Sample	Kinematic Viscosity (mm ^{2}/s) at 40 ^{0}C					
1	SA	5.5	5.5	5.5	5.9	6.4	6.9
2	SB	5.5	5.5	5.7	6.6	7.1	7.6
3	Month of study	January 3rd	February 3rd	March 3rd	April 3rd	May 3rd	June 3rd

Table 3.4: Acid Value Variation with Time

Parameter / Sample	Acid Value (mgKOH/kg)					
SA	0.31	0.31	0.35	0.42	0.56	0.7
SB	0.31	0.33	0.5	0.75	1.07	1.46
Month of study	January 3rd	February 3rd	March 3rd	April 3rd	May 3rd	June 3rd

Table3.5: Peroxide Value Variation with Time

Parameter / Sample	Peroxide value (meq peroxide /kg)					
PV for SA	15	15	20	25	35	45
PV for SB	15	18	25	40	60	80
Month of study	January 3rd	February 3rd	March 3rd	April 3rd	May 3rd	June 3rd

So in the chapter third, the complete discussion regarding biodiesel production from jatropha oil, evaluation of fuel properties of biodiesel and study of ageing for viscosity, acid value and peroxide value has been done. The major problem in biodiesel production was observed as soap formation due to higher FFA and moisture presence in the jatropha oil. The ageing study for calorific value and density of biodiesel was also done but no significant change was observed. The fuel properties of biodiesel were observed as almost similar to diesel. The ageing study indicates that variation in the fuel properties of biodiesel has been taken place but it was under permissible limit. The color of sample SB was observed as detoriating with time.

CHAPTER-4

PERFORMANCE EVALUATION OF DIESEL ENGINE ON BIODIESEL

4.0 GENERAL

In order to study the engine performance on biodiesel and its blends with diesel, an experimental study has been carried out. The efficiency and brake specific fuel consumption (BSFC) of the engine was measured under variable load conditions for different blends. In addition, the brake specific fuel consumption (BSFC) of B20 blends of aged biodiesel under variable load condition has also been evaluated and the results are reported in this chapter.

4.1 EXPERIMENTAL SETUP

A schematic of experimental setup as shown in the Fig 4.1 consists of following components and are discussed as:

4.1.1 Fuel Measuring Unit

The fuel-measuring unit was fabricated in the local market as per need. It consists graduated transparent glass cylinder. The cylinder was attached to wood stand as shown in Fig. 4.2. The top end of cylinder was open and bottom end was fitted with stopcock. The outlet of stopcock was connected to the filter unit of diesel engine by plastic transparent pipe.

4.1.2 Diesel Engine

The Kirloskar make diesel engine-genrating set was used for experimentation. The technical details are given in Table 4.1. The filter unit of diesel engine was disconnected from its diesel tank and connected directly to fuel measuring unit as stated above.

4.1.3 Generator

The single-phase generator directly coupled with diesel engine was used. The technical details of generator are given in Table 4.2.

4.1.4 Resistive Type Load Panel

The resistive type load panel was fabricated which was equipped with voltmeter, current meter, wattmeter, and energy meter. The loading capacity of this panel was kept as 2.5k W. A photograph of complete experimental set up is shown in the Fig. 4.2

4.2 PARAMETERS MEASURED

The measured parameters during the experimentation are given in the Table 4.3.

4.3 INSTRUMENTATION

Various instrumentation used are discussed as below:

4.3.1 Fuel Measurement

During the fuel measurement, the gradual lowering of fuel level was observed in the specified time during the run of engine. The least count of fuel measurement unit was 1 ml. The fuel consumed at particular load at a given time has been calculated.

4.3.2 Load Measurement

The wattmeter (Model SR-144-1E-IPWM20A) has the least count of 100 W. Before taking the reading, the deflecting needle was set at zero position. During the run of engine, the current deflection shown by needle was taken as load operated on generator.

4.3.3 Voltage Measurement

Digital Voltmeter was used to show the voltage of generator during engine operation. The least count was 1 V.

4.3.4 Current Measurement

Digital Current meter was used to measure the current produced by generator during engine operation. The least count of digital current meter was 0.01 A.

4.3.5 Energy Measurement

Energy meter was AC single-phase 2 wire static kWh meter. The least count of energy meter was 0.1 kWh. The cumulative reading of energy generated in unit had been shown by energy meter. For the value of energy generated for a fuel in the specified time, the current cumulative reading was obtained by subtracting from previous cumulative reading.

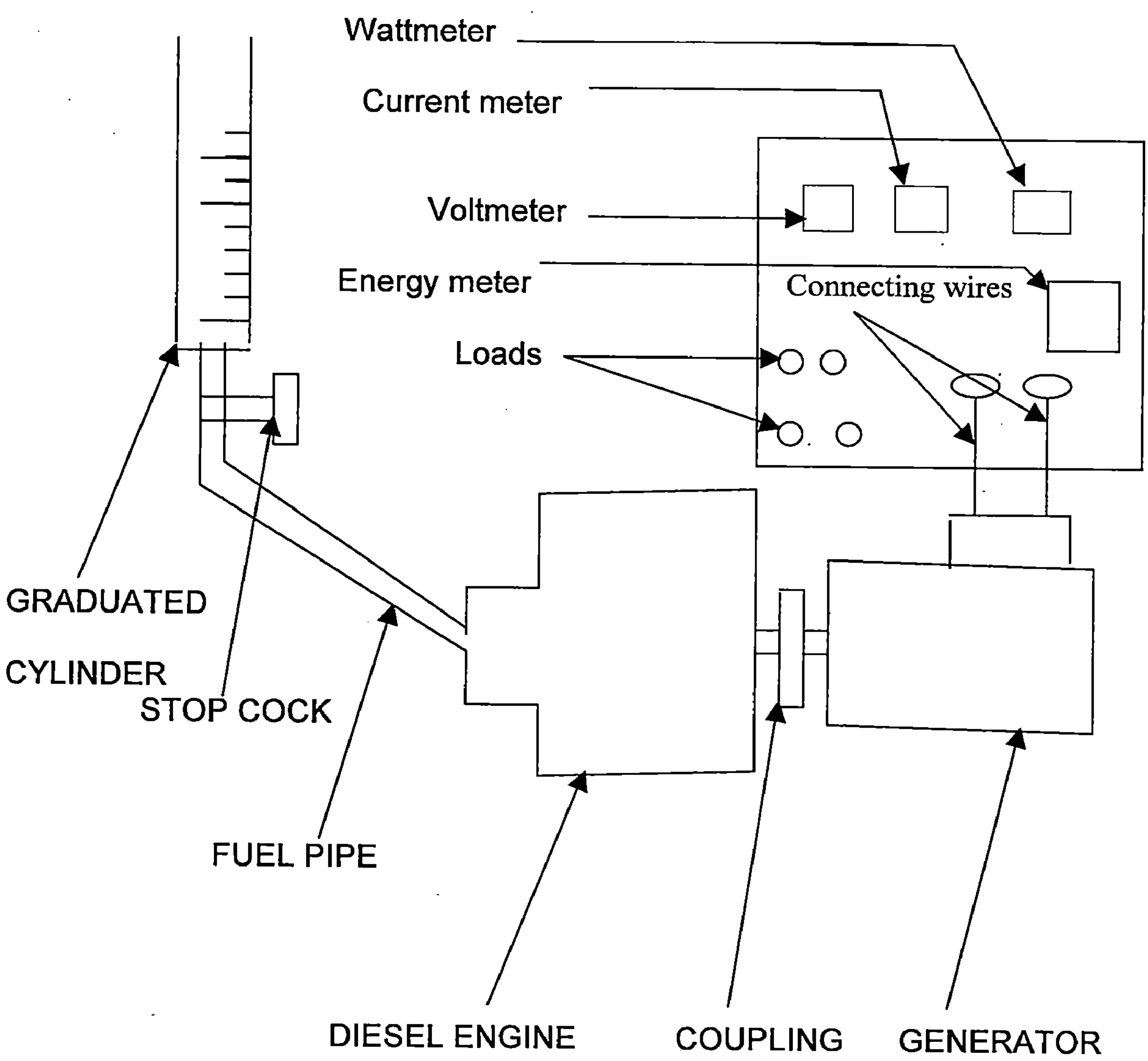

Fig. 4.1: Schematic of Experimental Setup

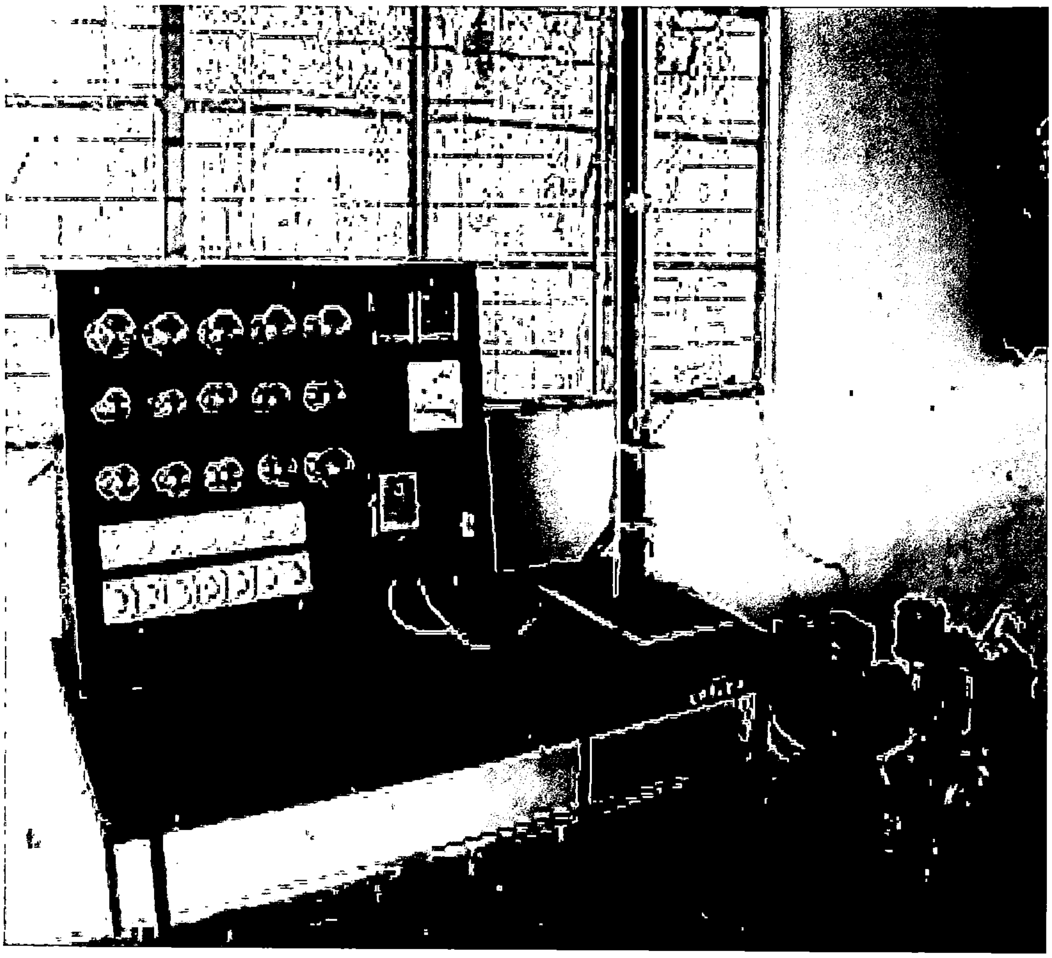

Fig 4.2: Engine Setup for Performance Testing

Table 4.1: Technical Specification of Diesel Engine Used

Sl No.	Parameters	Details
1	Make and model	Kirloskar,AA35
2.	Type of engine	Vertical, 4-stroke, single acting high speed compression ignition diesel engine
3.	No of cylinder	1
4.	IS rating at 1500 rpm	2.6 kw (3.5 bhp)
5.	Base	30 mm
6.	Stroke	76 mm
7.	Cubic capacity	0.382 liters
8.	Compression ratio	15.6: 1
9.	Fuel timing for standard engine by spill (BTDC)	24^0
10	BMEP at 1500 rpm	5.50 kg/ cm^2
11.	Rate speed	1500 rpm
12	Direction of rotation	Clock wise when looking at flywheel end
13	Inlet valve open BTDC	4.5^0
14	Inlet valve closes at ABDC	35.5^0
15	Exhaust valve opens at BBDC	35.5^0
16	Exhaust valve closes ATDC	4.5^0
17	Governor type	Mechanical, centrifugal type
18	Nozzle opening pressure	190-210 kg/ cm^2
19	Fuel oil tank capacity	3.75 liters
20	Lube oil sump capacity	1.3 liters

Table 4.2: Technical Specification of Generator Used

Sl.No	Parameters	Values
1	Make type	Kirogen Alternator Single Phase
2	Model	KBM-102
3	Out Put	2 kVa
4	Voltage	200 V
5	Current	8.7 Amp.
6	Power factor	1
7	Frequency	50 Hz.
8	RPM	1500

Table 4.3: Measured Parameters

Sl.No	Parameters name	Unit	Range
1	Fuel consumption	ml	0-1000
2	Load	W	0-5000
3	Voltage	V	0-500
4	Current	A	0-20
5	Energy	KWh	0-10000

4.4 EXPERIMENTAL PROCEDURE

The engine was directly coupled with 2KVA alternator and loaded by electrical resistance. The separate volumetric fuel measurement unit (least count 1ml) was integrated with the engine. A resistive load was attached to the output end of generator. The Diesel –Generator (DG) set was run initially for diesel fuel for 15 minutes at each part load of 25%, 50%, 75% and 100% of 2 kW respectively. At each time, the revolution of engine was maintained at 1500 rpm. The total fuel consumption was noted for the above time period measured by stopwatch. At the same time, the reading of energy meter was also noted. Seven blends (v/v) namely B5, B10, B15, B20, B35 and B100 were prepared for evaluation its performance in the engine. Each blend was mixed thoroughly before pouring in the fuel tank. Then, the total fuel consumption and energy produced were recorded in the similar fashion. During each blend, the filter of diesel engine was opened and complete mixture of biodiesel and diesel was drained so that it could not impure next blend by mixing with its previous blend. Then again for another blend, in the similar fashion, the experiment was repeated for knowing the above stated parameters. In this way continuously one week, the experimentation was performed for all type of blends as stated above.

4.5 RESULTS

The results for neat biodiesel and aged biodiesel and its blends with diesel were obtained and reported below:

4.5.1 Fuel Consumption of Neat Biodiesel

The total fuel consumption for each type of fuel was measured for run of 15 minutes. During the volumetric fuel measurement, the other parameters like voltage, current, load and energy generation were also measured. Since the density of each type of fuel is different in the nature so to compare the fuel consumption, the fuel consumption on mass basis has been calculated by the multiplication of density of each type of fuel with corresponding fuel consumed in ml. During each type of blend, the filter unit of diesel engine was open and complete mixture was drained. It was done to avoid the impurity occurred due to mix problem with another type of blends. The obtained results during the experimentation are given in Table 4.4, 4.5,4.6&4.7.

4.5.2 Fuel Consumption for Aged B20

The same procedure was followed for evaluation of engine performance with five month aged sample SA and SB. Another sample SC (thermally aged) was prepared by heating at 100 ^{0}C for 10 hours in the open atmosphere. The experiment was performed for three consecutive days for each type of blends. Here also, during each blend, the filter unit of engine was completely drained to avoid the mix problems with another blends The total fuel consumption for 15 minutes for above sample for blend B20 of SA, SB and SC was measured and obtained data is given in the Table 4.8,4.9,4.10&4.11.

Table 4.4: Measured Fuel Consumption (ml) and other Parameters for Neat Biodiesel at 500 W

Values / Fuel Type	Fuel Consnsumed (ml)	Voltage (V)	Current (A)	Load (W)	Energy (kWh)	RPM
Diesel	119	255	2.21	550	0.1	1500
B5	113	255	2.21	550	0.1	1500
B10	115	254	2.25	550	0.1	1500
B15	114	255	2.21	550	0.1	1500
B20	118	257	2.27	550	0.1	1500
B35	122	255	2.21	550	0.1	1500
B50	124	255	2.21	550	0.1	1500
B100	130	253	2.25	550	0.1	1500

Table 4.5: Measured Fuel consumption (ml) and other Parameters for Neat Biodiesel at 1000 W

Values / Fuel Type	Fuel Consnsumed (ml)	Voltage (V)	Current (A)	Load (W)	Energy (kWh)	RPM
Diesel	152	253	4.16	1050	0.3	1500
B5	146	254	4.18	1050	0.3	1500
B10	151	252	4.16	1050	0.3	1500
B15	156	253	4.17	1050	0.3	1500
B20	153	251	4.16	1050	0.3	1500
B35	161	253	4.19	1050	0.3	1500
B50	162	252	4.15	1050	0.3	1500
B100	165	254	4.16	1050	0.3	1500

Table 4.6 Measured Fuel consumption (ml) and other Parameters for Neat Biodiesel at 1500 W

Values / Fuel Type	Fuel Consnsumed (ml)	Voltage (V)	Current (A)	Load (W)	Energy (kWh)	RPM
Diesel	184	252	4.15	1500	0.3	1500
B5	175	254	4.12	1500	0.3	1500
B10	184	253	4.14	1500	0.3	1500
B15	186	254	4.16	1500	0.3	1500
B20	183	251	4.17	1500	0.3	1500
B35	194	253	4.16	1500	0.3	1500
B50	199	252	4.18	1500	0.3	1500
B100	200	253	4.16	1500	0.3	1500

Table 4.7 Measured Fuel consumption (ml) and other Parameters for Neat Biodiesel at 2000 W

Values / Fuel Type	Fuel Consnsumed (ml)	Voltage (V)	Current (A)	Load (W)	Energy (kWh)	RPM
Diesel	231	240	8.1	1950	0.4	1500
B5	214	242	8.05	1950	0.4	1500
B10	219	241	7.95	1950	0.4	1500
B15	222	243	8.1	1950	0.4	1500
B20	228	241	8.07	1950	0.4	1500
B35	234	242	8.09	1950	0.4	1500
B50	237	240	8.1	1950	0.4	1500
B100	249	240	8.05	1950	0.4	1500

Table 4.8: Measured Fuel Consumption (ml) and other Parameter for Aged Biodiesel at 500 W

Values / Fuel Type	Fuel Consnsumed (ml)	Voltage (V)	Current (A)	Load (W)	Energy (kWh)	RPM
B20 of SA	119	255	2.21	550	0.1	1500
B20 of SB	125	255	2.21	550	0.1	1500
B20 of SC	132	253	2.25	550	0.1	1500

Table 4.9: Measured Fuel Consumption (ml) and other Parameters for Aged Biodiesel at1000 W

Values / Fuel Type	Fuel Consnsumed (ml)	Voltage (V)	Current (A)	Load (W)	Energy (kWh)	RPM
B20 of SA	154	253	4.19	1050	0.3	1500
B20 of SB	159	252	4.15	1050	0.3	1500
B20 of SC	175	254	4.16	1050	0.3	1500

Table 4.10: Measured Fuel Consumption(ml) and other Parameters for Aged Biodiesel at1500 W

Values / Fuel Type	Fuel Consnsumed (ml)	Voltage (V)	Current (A)	Load (W)	Energy (kWh)	RPM
B20 of SA	184	253	4.16	1500	0.3	1500
B20 of SB	188	252	4.18	1500	0.3	1500
B20 of SC	224	253	4.16	1500	0.3	1500

Table 4.11: Measured Fuel Consumption (ml) and other Parameters for Aged Biodiesel at 2000 W

Values / Fuel Type	Fuel Consnsumed (ml)	Voltage (V)	Current (A)	Load (W)	Energy (kWh)	RPM
B20 of SA	229	242	8.1	1950	0.4	1500
B20 of SB	233	240	8.09	1950	0.4	1500
B20 of SC	267	240	8.05	1950	0.4	1500

4.6 ENGINE PERFORMANCE EVALUATION

The following parameters for engine performance have been discussed on the basis of above experimental results:

4.6.1 Brake Specific Fuel Consumption(BSFC)

The brake specific fuel consumption is defined as fuel consumed by engine in gm for per kW per hour. The output power has not been measured at the shaft end of engine. In order to assess the out put power at shaft end, the efficiency of generator is taken as 90%. From the fuel consumption data of Table 4.4,4.5,4.6&4.7, BSFC has been calculated using the following equation::

Brake specific fuel consumption (g/kW-h)

$$=W_f / P_b \qquad (4.1)$$

Where, W_f =fuel consumed (g/h)

P_b =brake power (kW) is calculated as:

$$P_b = P_g / \eta_g \qquad (4.2)$$

Where, P_g =load (kW) at generator end

η_g = efficiency of generator

So to calculate the fuel consumption in g, the fuel consumed in ml was multiplied with the density of specific blend. The mathematical relation for this is given as:

$$\text{Fuel consumed (g)} = (Fv) * (D) \qquad (4.3)$$

Where, Fv=fuel consumed in ml

D = density of fuel

The density for each type of blends was measured in the laboratory and it is given in the Table 4.12.

Table 4.12: Density of Biodiesel Blends

Sl.No.	Blends Type	Density (kg/m^3)
1	Diesel	830
2	B5	833
3	B10	836
4	B15	839
5	B20	842
6	B35	851
7	B50	860
8	B100	889

On the basis of density value available to particular blend in the above Table, The fuel consumed in ml was multiplied by the density of particular blends to obtain the fuel consumption in gram. The fuel consumption in (g) by engine for each type of blend is given in the Table 4.13 & 4.14.

Table 4.13: -Fuel Consumption (g) for Neat Biodiesel

Load (W)	Diesel (g)	B5 (g)	B10 (g)	B15 (g)	B20 (g)	B35 (g)	B50 (g)	B100 (g)
550	99	94	96	96	99	104	107	116
1050	126	122	126	131	129	137	139	147
1500	153	146	154	156	154	165	171	178
1950	192	178	183	186	192	199	204	221

Table 4.14 : Fuel Consumption (g) for Aged Biodiesel (B20)

Sl.No	Load (W)	B20 of SA (g)	B20 of SB (g)	B20 of SC (g)
1	550	100	105	111
2	1050	130	134	147
3	1500	155	158	189
4	1950	193	196	225

4.6.1.1 Brake specific fuel consumption for neat biodiesel

On the basis of formula given in equation (4.1), the brake specific fuel consumption for different fuel at different loads is given in the Table 4.15.

Table4.15: Brake Specific Fuel Consumption (g/kW-h) for Neat Biodiesel

Sl.No	Load (w)	Diesel	B5	B10	B15	B20	B35	B50	B100
1	610	649	616	630	630	649	682	702	761
2	1165	433	419	433	450	443	470	477	505
3	1665	368	351	370	375	369	396	411	427
4	2165	355	329	338	344	355	368	377	408

4.6.1.2 Brake specific fuel consumption for aged biodiesel

In the above manner with the help of equation 4.1,4.2 &4.3, the brake specific fuel consumption for aged B20 was calculated. It was compared with diesel as well as B20 of fresh biodiesel and the compared results are given in the Table 4.16.

Table 4.16: Brake Specific Fuel Consumption (g/kw-h) of Aged Blend (B20)

Sl No	Load (W)	Diesel	B20 Neat	B20 of SA	B20 of SB	B20 of SC
1	610	649	649	656	689	728
2	1165	433	443	446	460	505
3	1665	368	369	372	379	454
4	2165	355	355	357	362	416

4.6.2 Brake Thermal Efficiency

The brake thermal efficiency is defined as ratio of output energy available at engine shaft to input energy given to engine. The mathematical formulation for brake thermal efficiency is given as as:

Brake thermal efficiency (%)

$$\eta_b = (Pb) \times (60) / (J) \times (wf) \times (NCV) \quad (4.4)$$

Where, ηb =brake thermal efficiency, P_b = brake power (kW)

J= 4.2 joule/calorie, wf =fuel consumption (kg/min) , NCV=lower calorific value of fuel(kcal/kg)

Net calorific value of diesel =42 000 KJ/kg (by measurement)

The NCV for biodiesel blends was calculated on the basis of simple law of mixture. The NCV formula for particular blend is given as:

NCV of Blend =xx * NCV of biodiesel + (100-xx) * NCV of diesel (4.5)

Where, xx shows the (v/v %) of biodiesel.

4.6.2.1 Brake thermal efficiency for neat biodiesel

On the basis of above formula given in the equation 4.4&4.5, the brake thermal efficiency for different fuel at different loads is given in the Table 4.17.

Table 4.17: Brake Thermal Efficiency (%) for Neat Biodiesel

Sl.No	Load(W)	Diesel	B5	B10	B15	B20	B35	B50	B100
1	610	13.2	13.98	13.78	13.86	13.52	13.11	12.98	12.79
2	1165	19.8	20.57	20.04	19.39	19.81	19.0	19.08	19.26
3	1665	23.31	24.56	23.43	23.26	23.66	22.48	22.08	22.44
4	2165	24.15	26.21	25.65	25.38	24.74	24.32	24.17	23.82

4.6.2.2 Brake thermal efficiency for aged biodiesel

In the similar manner, the brake thermal efficiency for aged Biodiesel for B20 blend was evaluated and results are given in the Table 4.18:

Table4.18: BrakeThermal Efficiency (%) for aged B20 blend

Sl No	Load (W)	Diesel	B20 Neat	B20 of SA	B20 of SB	B20 of SC
1	610	13.2	13.52	13.39	12.72	12.15
2	1165	19.8	19.81	19.66	19.07	17.54
3	1665	23.31	23.66	23.52	23.06	19.51
4	2165	24.15	24.74	24.61	24.24	21.28

On the basis of above results, it seems that biodiesel may be good substitute for diesel fuel. The brake specific fuel consumption for all type of blends with diesel was higher by about 15% however; the brake thermal efficiency was almost similar to diesel. The minimum BSFC was observed for Blend B5 and it for efficiency also. Being lower calorific value for biodiesel and having almost similar efficiency shows the better release of energy from biodiesel than diesel. Five month aged blend B20 for SA has shown almost same BSFC and efficiency as it was for neat B20 blend. However, BSFC was higher by 1-2% and 17% for sample SB and SC respectively. The efficiency for sample SC was lower by 2-3% than neat B20 blend.

RESULTS AND DISCUSSION

5.0 GENERAL

The continuous change in certain fuel properties of biodiesel with time was experimentally estimated. The experiment for change in fuel properties was performed at an interval of one month. The engine performance was evaluated using neat biodiesel as well as aged biodiesel. The results obtained are discussed in this chapter.

5.1 EFFECT OF AGEING ON VISCOSITY

Viscosity tends to increase over time as evident from the fact that significant increase in the viscosity of sample (SA) and sample (SB) was observed with time. The variation in the viscosity at 40 ^{0}c with time for both the above stated sample is shown in the Fig.5.1, which indicates that there is no significant change in viscosity in the month of January and February, perhaps due to low temperature of atmosphere during the above months. But after March onwards, significant change was observed due to sufficient temperature of the atmosphere. There was an increase of 25 % during five-months period as against 34 % increase for seven month [59] and 38% in the viscosity value for sample SA and SB respectively. However, the ASTM limit for viscosity is 1.9-6 cSt. So from the graph, it is quite clear that if the viscosity of neat biodiesel lies between 4-4.5 cSt, then after 25% increase in five months, it will not cross the

ASTM limit, if it is kept in airtight container at room temperature. But if it is kept in open atmosphere, the viscosity of five month aged biodiesel will go beyond the limit given in ASTM. If viscosity increases; it can reduce the efficiency of the engine due to improper atomization. The increase in viscosity occurs due oxidation from atmospheric oxygen. The oxidation of the ester occurs due to unsaturation. The viscosity increase may be either oxidation due to molecular oxygen or due to atmospheric oxygen in the ester. So to avoid it, biodiesel should be stored in the airtight container in the absence of sunlight i.e dark color container.

5.2 AGE EFFECT ON ACID VALUE

The acid value for the sample SA does not vary for initial two month while there is a continuous increase in sample SB. Acids can be formed when traces of water cause hydrolysis of the ester into alcohol and acids. The variation of acid value with time is given in the Fig.5.2, which shows that significant change has occurred in acid values for both the sample. For sample SA, the acid value has increased from 0.31 mg KOH/g to 0.7 mgKOH/g in five-month time i.e. increase of 116% against increase of 62% in 3.5 month for rapeseed methyl ester [61]. Still, it is within limit of ASTM standard value of 0.8 mg KOH/g [Table 2.8]. It therefore indicates that biodiesel kept in steel or glass inside room at ambient temperature would have no problem from acid value point of view up to 5 - 6 months in case of Jatropha biodiesel. The acid value is responsible for corrosion in injector part of the engine, While in case of sample SB, the acid value has increased from 0.31 mg KOH/g to 1.46 mg KOH/g i.e. increase of 370% against increase of 250% during 3.5 months for rapeseed methyl ester [61]. It indicates that light acts as catalyst for free fatty acid formation (FFA) which led to increase in acid value. Due to insufficient light in the month of January and February, no significant change was observed for both the samples. The formation of FFA takes place due to presence of water in the biodiesel. From the above result it is clear that after washing, the quantity of water should be below the allowable limit 0.05wt%(ASTM).

5 . 3 AGE EFFECT ON PEROXIDE VALUE

Peroxide values (PV) are related to auto oxidation of the esters. With time, esters first oxidize to form peroxides, and then undergoes complex reactions including a disintegration into more reactive aldehydes, which further oxidize into acids. During the month of January and February due to cold atmosphere, the significant rise in PV was not observed for both the sample, however after March, higher rate of growth was observed for both the samples. The variation in the peroxide value with time is given in the Fig.5.3 , which shows that PV has increased three times and more than five times for the sample SA and SB respectively. The higher growth for the sample SB might be due to direct interaction of atmospheric air in the presence of sunlight. The accelerated growth has been taken place after March onwards, which indicates the clear effect of sunlight. But both are acceptable as fuel as per report [60]. The acceptable limit for freshly prepared biodiesel is 40 meq/kg of sample and even it can accept up to 81 meq/kg of sample because Cetane number of fuel increases upto to this limit. The peroxide value is mainly responsible for gum and sediment formation that clogs the filter in engine.

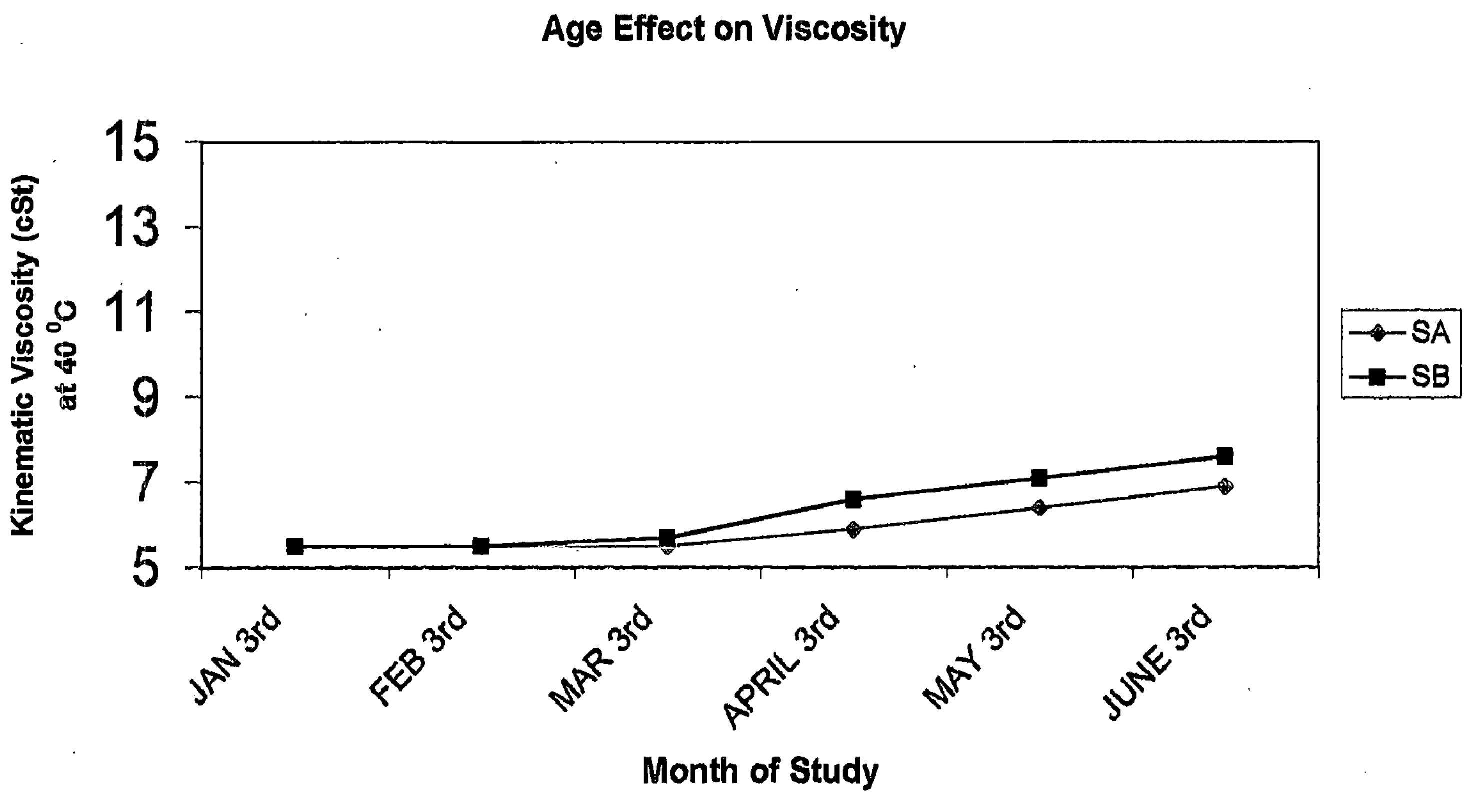

Fig. 5.1: Variation of Viscosity with Time

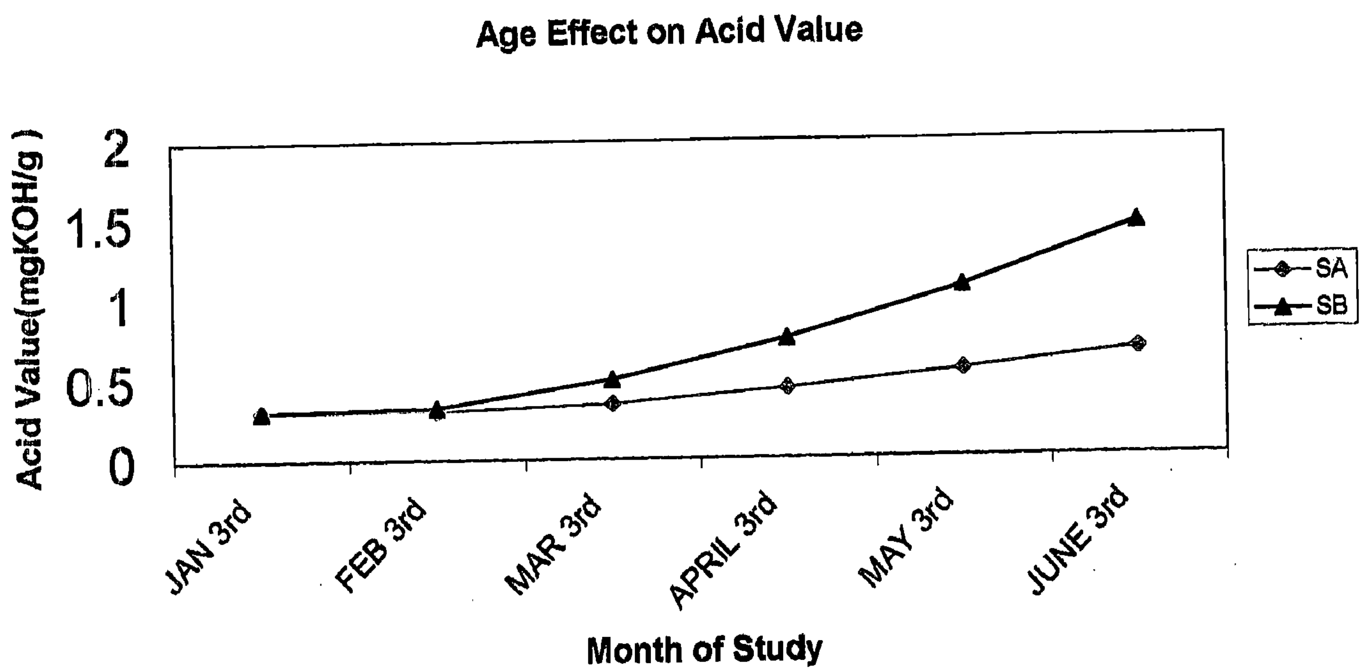

Fig. 5.2: Variation of Acid Value with Time

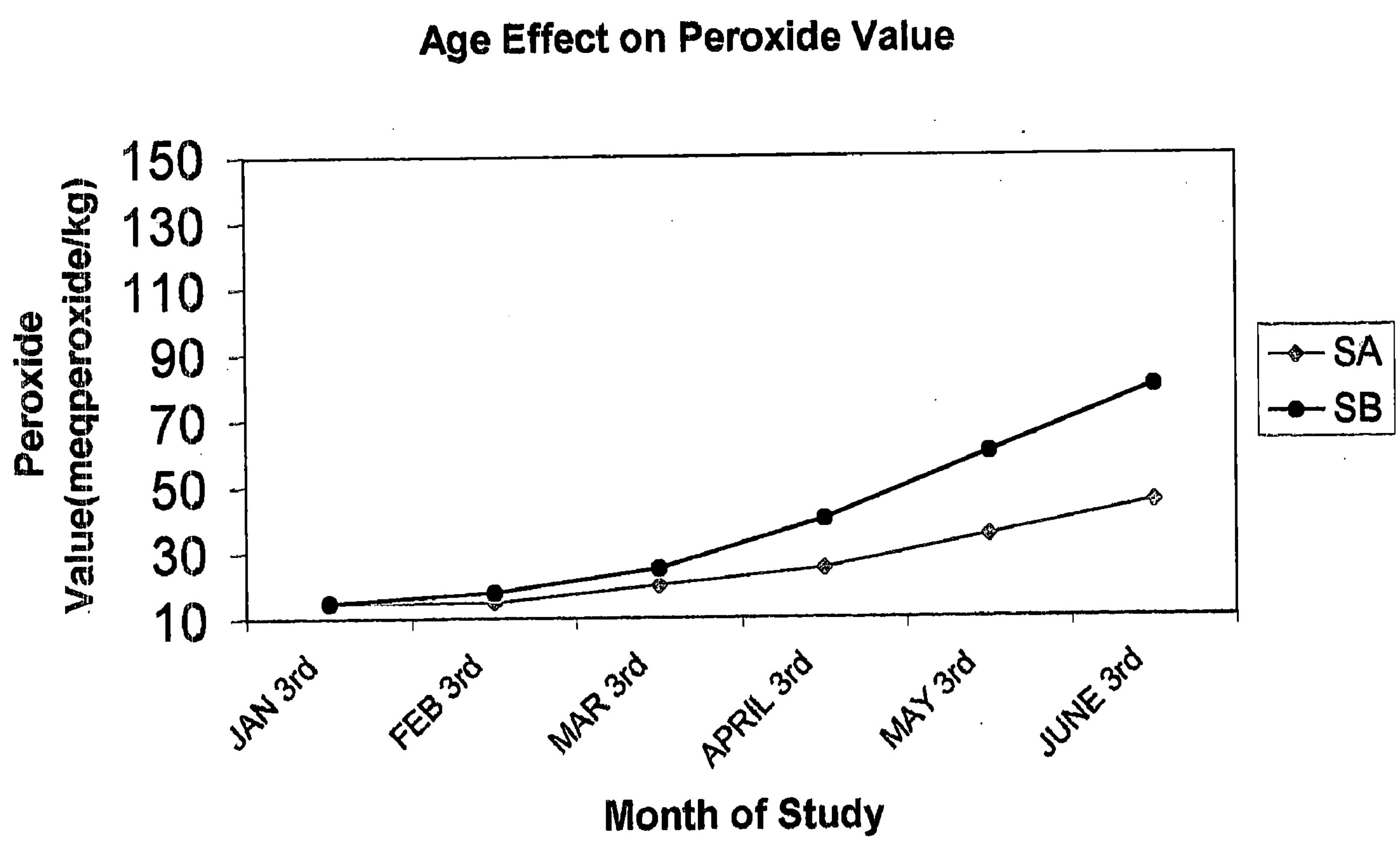

Fig. 5.3: PV Variation with Time

5.4 ENGINE PERFORMANCE EVALUATION

The main advantages related to usage of biodiesel in diesel engine are related to the high oxygen content of fatty acid and therefore more complete combustion and lower emission of harmful species such as particulate matter (PM) and smokes. The actual proportion in mass between carbon and hydrogen of JOME is 6.5 compared to 6.9 in diesel. The oxygen content of diesel is 0.4% (w/w) compare to 10.9% (w/w) in biodiesel. The various proportion of oxygen (w/w) in different blends of B5, B10, B20, B35 and B100 are 0.925%, 1.45%, 2.5%, 4.075% and 10.9% respectively and its pictorial representation is given in Fig.5.4.

5.4.1 Brake Specific Fuel Combustion (BSFC) for Neat Biodiesel

The brake specific fuel consumption (g/kW-h) decreases as the load increases for all type of fuel combination. The possible reason may be that, at higher load, cylinder wall temperature gets increased, which reduces the ignition delay. Thus, shortening in ignition delay improves combustion and reduces fuel consumption. The trend of BSFC for different blends of neat biodiesel at different loads is given in Fig.5.5, which indicates that the highest BSFC for B100 (408g/kW-h) is about 13-15% higher than diesel (355g/ kW-h) at 2.165 kW load & rated rpm and it matched with the result reported in literature [15,20,21,24,32]. This happened possibly due to 13-14% lower net calorific value of JOME than diesel. The BSFC of diesel engine depends on the relationship among volumetric fuel injection system, fuel specific gravity, viscosity, and heating value. The more amount of B100 is needed to produce same amount of energy due to its high specific gravity and lower heating value in comparison to diesel fuel. The comparison of lower heating value for different blend group has been given in Fig. 5.6. The lowest BSFC for B5 (329 g/kW-h) is about 7% lower than diesel at 2.165 kW load & rated rpm. The reduction in BSFC for B10, B15 is about 5% and 3% respectively. The BSFC for B20 is almost same as diesel and it is also reported in literature [15]. So the one reason may be like that it may possible that upto B20, the presence of inherent oxygen (1.45%) is dominating for better combustion than diesel alone. The other reason may be due to higher volumetric fuel delivery per stroke because of higher viscosity. It has been reported in the literature [25] that a higher viscosity of biofuel increases volumetric fuel delivery per stroke by about 2.6% because of the reduced internal leakages of the injection pump. However after B20, the lower calorific value is dominating over inherent oxygen presence. This may be the explanation that the BSFC for B50 is about 6% higher than diesel.

5.4.2 Brake Specific Fuel Consumption for Aged B20

The engine test was performed with sample SA, SB and SC respectively in the similar fashion as it was tested with fresh biodiesel. The trend of variation is given in the Fig. 5.7, which indicates that there is no much variation for BSFC in between B20 neat and sample SA. While in case of sample SB, 1-2% more BSFC was observed in compare to B20 neat. The more BSFC may be because of poor combustions due significant increase of viscosity, and peroxide value of sample SB which has been kept in direct contact of air and sunlight .It assures that Jatropha oil methyl ester (JOME) stored in airtight container away from sunlight will not show underperformance as fuel in engine for at least 5-6 months. The ASTM 6751 also indicates that six month aged biodiesel can be used as fuel without showing any underperformance in the engine use. But in case of sample SC, the BSFC is about 17% more than that of B20 neat. This may be due higher oxidation and lower net calorific value. The calorific value of sample SC was measured and about 5% decrement was observed.

5.4.3 Brake Thermal Efficiency for Neat Biodiesel

The variation of brake thermal efficiency is shown in the Fig.5.8, which indicates that the brake thermal efficiency of JOME (23.82%) is almost similar to diesel (24.15%) at 2.165 kW load and rated rpm in conformation with the results reported in [14&24]. The brake thermal efficiency for biodiesel for all blends range (from B5 to B100) was found almost comparable to efficiency of diesel fuel. It indicates that higher cetane number and inherent presence of oxygen in the biodiesel produced better combustion. The brake thermal efficiency for B5 (26.21%) was about 8% higher than diesel, however it was 2.5% higher for B20 (24.74) than diesel. The reason for higher efficiency up to B20 may be because of better combustion due to inherent oxygen (1.45%) and higher Cetane number. Beyond B20, the lower calorific value and higher viscosity might be dominating factor over inherent oxygen and higher Cetane number. Due to higher viscosity, the atomization of fuel will not be as good as it will be for lower viscosity at same level of pressure developed by injector pump.

5.4.4 Brake Thermal Efficiency for Aged B20

The brake thermal efficiency was calculated on the basis of fuel consumption for each aged sample. No significant change with time in calorific value of biodiesel was observed, so the previous calorific value of B20 was used for calculation. The variation of brake thermal efficiency at different loads for each sample is given in the Fig. 5.9, which indicates that there is no significant variation in the brake thermal efficiency for sample SA and SB with compare to B20 fresh. However 2-3% variation in system efficiency for sample SC was observed and this may be because of formation of aldehyde, ketones and acids at higher level of peroxide value.

So in this chapter, it has been observed that the properties of biodiesel would not be change beyond the limit specified by ASTM standard within 5-6 months if it is stored in the absence of sunlight and air. The temperature would act as catalyst for the oxidation of biodiesel and air may act as reaction initiator for its oxidation. The brake thermal efficiency of neat biodiesel is almost similar to efficiency of diesel. Due to lower calorific value of biodiesel, the brake specific fuel consumption for neat B100 would be more by 13-15%, however blend up to B20 has shown the same fuel economy as in diesel. Even blends up to B15 have shown higher fuel economy than diesel. No significant change in performance of engine is visible for five months aged biodiesel if it is stored in airtight container at room temperature, but 1-2% higher BSFC was observed for biodiesel stored in open atmosphere in presence of direct sunlight.

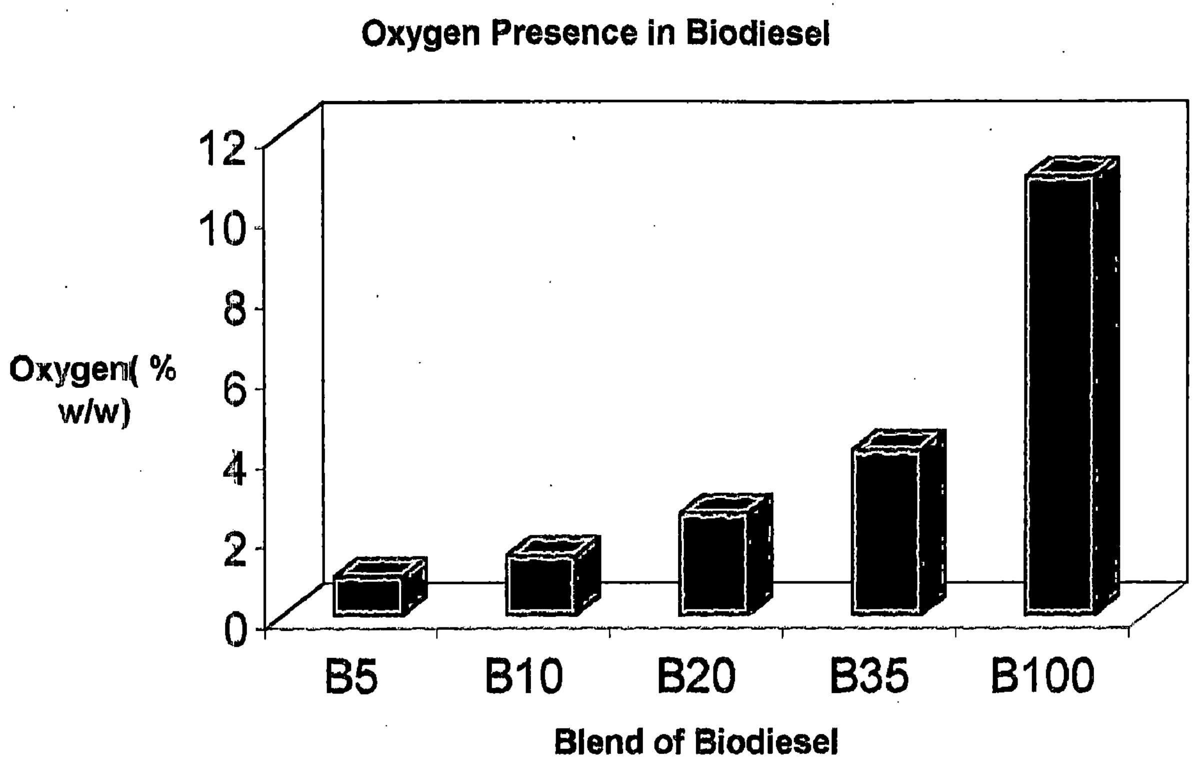

Fig. 5.4: Oxygen Presence in Biodiesel

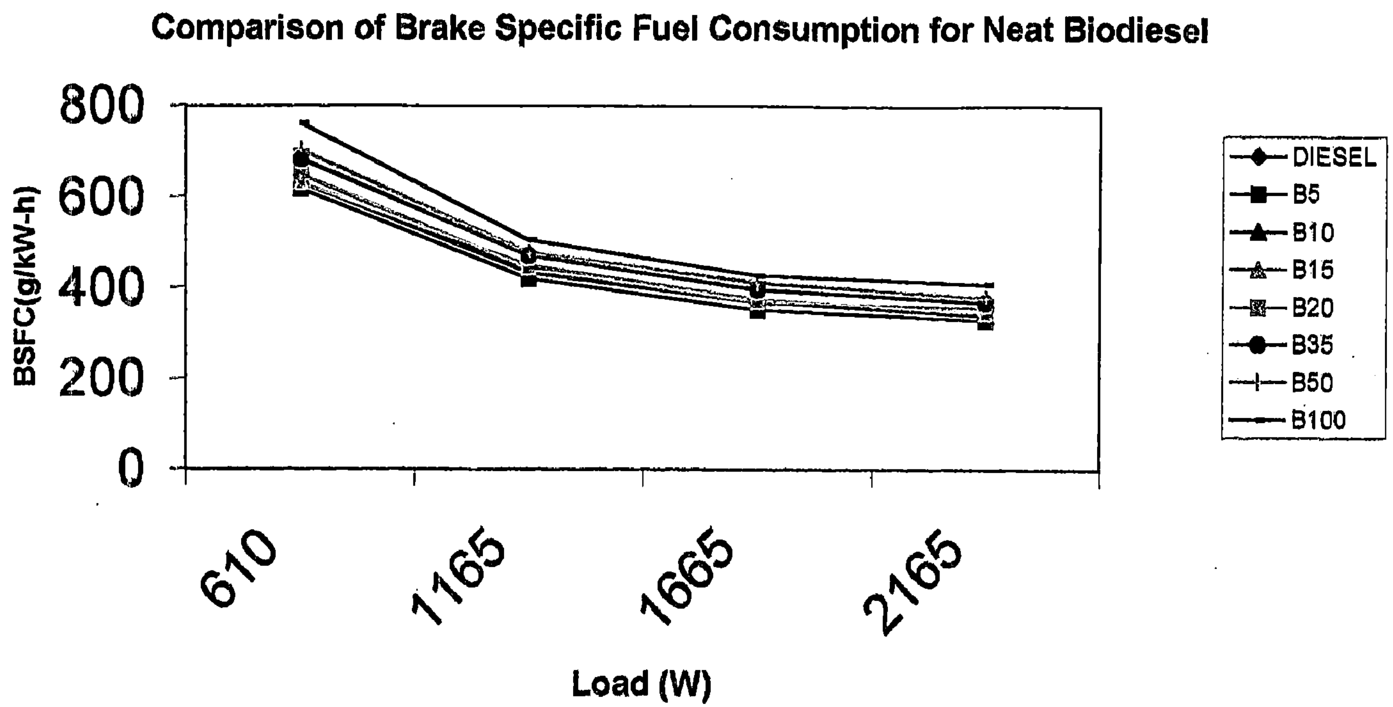

Fig.5.5: Brake Specific Fuel Consumption for Neat Biodiesel

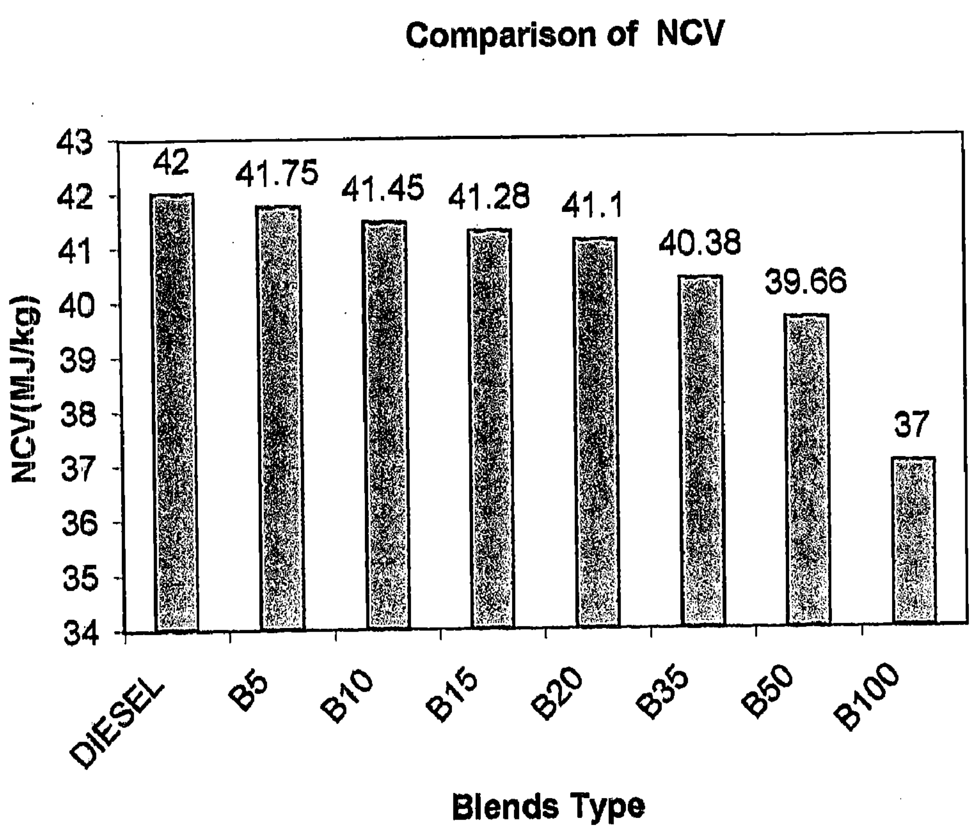

Fig 5.6: Net Calorific Values of Biodiesel Blends

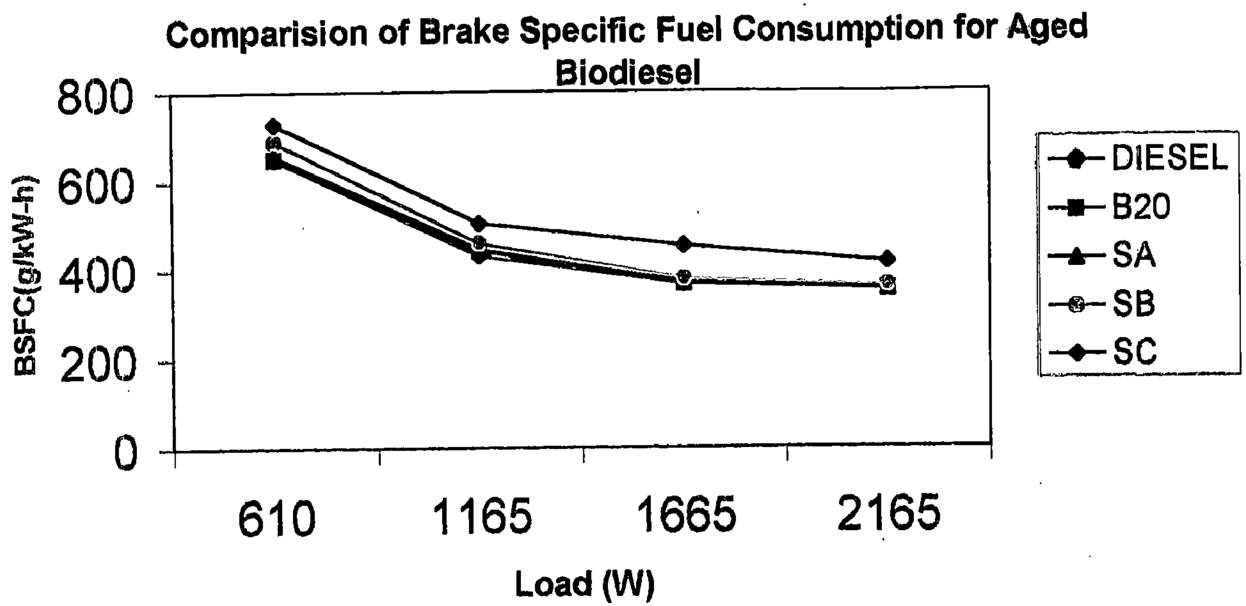

Fig.5.7: Brake Specific Fuel Consumption for Aged B20

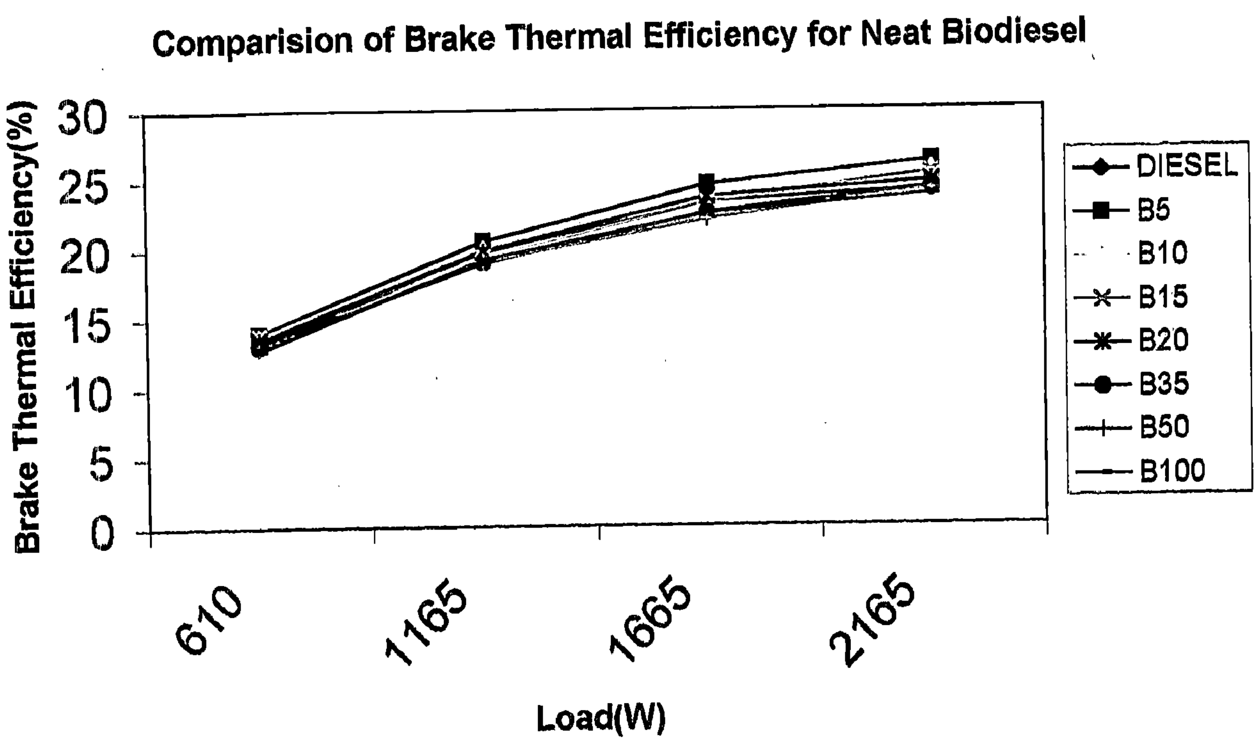

Fig. 5.8: Brake Thermal Efficiency of Neat Biodiesel

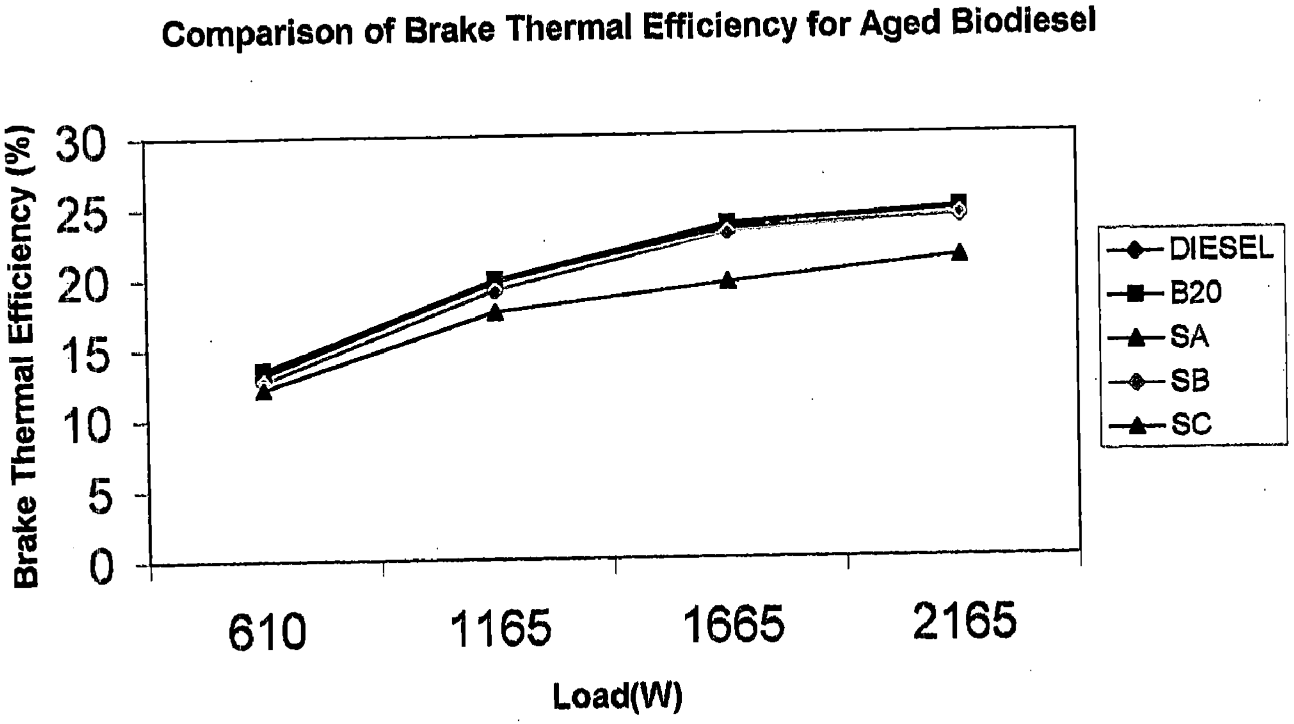

Fig.5.9: Brake Thermal Efficiency of Aged Biodiesel (B20)

CONCLUSIONS & RECOMMENDATIONS

6.1 CONCLUSIONS

The present study dealt with the production and utilization of biodiesel from Jatropha oil. The effect of various parameters on engine loading together with effect of ageing on engine performance was evaluated. Based on the results, the following conclusions can be drawn:

(i) It was found that the sunlight has negative effect on the storage of biodiesel due to acceleration of oxidation in the chemical structure. It is evident that the increase in viscosity was 38% in SB than SA.

(ii) The increase in viscosity in SB (5 months aged) was 38% as compared to 25% in SA sample.

(iii) The brake specific fuel consumption for B100 was found 13-15% higher than diesel fuel at 2.165 kW load and rated rpm while the BSFC of B20 was comparable to diesel and this is perhaps the reason that B20 has been recommended as optimized blend by many researchers.

(iv) The brake thermal efficiency (BTE) of B100 was almost same compared to diesel (24.15%) at 2.165 kW load and rated rpm while it was slightly higher for B20 (24.74) than B100 (23.82).

(v) The BSFC for B20 of aged sample SB was found 1-2% more than neat B20, while efficiency was found slightly lower than neat B20.

It was found that the ageing of biodiesel has little effect on the brake specific fuel consumption and brake thermal efficiency. The BSFC and BTE of B20 were found almost similar to diesel. And using other blends level above than B20 gave higher BSFC than diesel. In terms of BSFC and BTE, B20 has been found an optimum & comparable to diesel and is therefore rated as the optimum blend of biodiesel with diesel.

6.2 RECOMMENDATIONS AND FURTHER SCOPE OF STUDY

The long storage study of biodiesel is required to visualize the significant effect of age on oxidation of biodiesel. The composition of triglycerides in Jatropha oil varies as per different locality of production, so the fuel peroperties of biodiesel changes as per triglycerides composition and therefore study is required to evaluate the average fuel properties of biodiesel. The long run engine performance study based on biodiesel for higher blend level than B20 is also required to visualize the compatibility of different materials of different parts of engine.

REFERENCES

[1] "A Quarterly Newsletter of Bio-Energy" , Ministry of Non Conventional Energy Sources, Government of India, *Bio Energy News*, **8** , pp.10-11, Sep.2005.

[2] Tiwari, BK, "Bio Energy for Transport Sector", *Bio Energy News*, **7** , pp.14-20, 2003.

[3] Vellerguth, B, "Performance of Vegetable Oils and Their Monoesters as Fuels for Diesel Engine", *Society of Automotive Engineers*, pp. 831-358, 1983.

[4] "Energy Statistics" Declared by Central Statistical Organization, *Ministry of Statistics and Programme Implementation*, *Government of India*, New Delhi,2003-2004

[5] Subramaniam, KA, Singal, SK and Saxena Mukesh, "Utilization of Liquid Biofuel in Automotive Diesel Engine: An Indian Perspective", *Journal of Biomass and Energy*, **29**,pp. 65-72, 2005.

[6] www.giss.nasa.gov.

[7] www.siamindia.com .

[8] "Production of Oil Seeds", *Ministry of Agriculture*, *Government of India*, New Delhi, 2005.

[9] Shay, EB, "Deisel Fuel from Vegetable Oils, Status and Opportunities", *Biomass and Bio Energy*, **4**, pp. 227-243,1993,.

[10] Boenny, E, Schwab, B, Anghertry, JB, Pryde, H and Heakin, J, "Fuel Properties of Eleven Vegetable Oils", *Trans. ASAE* ,**25**, pp. 1472-1483, 1982.

[11] Pryor, RW, Hanna, MA, SchinStock, JL and Bashford, LL, "Soybean Oil Fuel in a Small Diesel Engine", *Trans. ASAE* ,**26**, pp. 333-398, 1982.

[12] Formo, MW," Physcial Properties of Fats and Fatty acids" (4th ed.), Baily's *Industrial Oil and Fat Products*, John Wiley & Sons, Newyork, 1979.

[13] Haas ,MJ and Bloomer Sand Scott K ,"High Efficiency Synthesis of Fatty Acid Methyl Esters from Soap Stocks", *JAOCS*,**77**,pp. 373-379,2000.

[14] Puhan, Sukumar , Vedaraman, N , Boppana,B, Bharat Ram ,V, "Performances and Emission Study of Mahua Oil Ethyl Ester in a 4- Stroke Natural Aspirated Direct Injection Diesel Engine" , *Renewable Energy*, **30** , pp. 1269-1278, 2005.

[15] Monyem, Al, Gerpen, J, van, H, "The Effect of Biodiesel Oxidation on Engine Performance and Emissions" ,*Biomass and Bioenergy* , **28**, pp. 317-325, 2001.

[16] Medonal, F, Purcell DL, Mcculure BT, Kitilson DB, "Emissions Characteristics of Soyamethyl Ester Fuels in an IDI Compression Ignition Engine", *Society of Automotive Engineers*, Paper No. 950400, Warrendale PA, 1995.

[17] Thompson CJ, Peterson LC, Reece LD, Beck M S, "Two Year Storage Study with Methyl and Ethyl Esters of Rapeseed" ,IN , Condiff J, editor, *Liquid Fuels and Industrial Products from Renewable Resources,*

Proceeding of the Third Liquid Fuel Conference Mashville, TN, pp. 15-17, 1996.

[18] Arg, SG, Choo, XM, Hotan, AH, Hock ,BS, "Palm Oil as Alternative Renewable Energy", Proceeding of the Third *ASCOPE* conference, Kuala Lampur, Malaysia, pp.441-458 , 1985.

[19] Masjuki,H and Sohif, M , "Performance Evaluation of Palm Oil Diesel Blends on Small Engine", *J . Energy& Heat Mass Transfer*,**13,** pp. 125-133, 1991.

[20] Bhattacharya,S and Reddy,CS, "Vegetable Oils as Fuels for Internal Combustion Engines: A Review", *Journal of Agricultural Engineering Resources* , **57**, pp. 157-166, 1994.

[21] Carraretto,C, Mirandola, A, Stoppato ,C and Tanon ,C , "Biodiesel as Alternative Fuel: Experimental Analysis and Energetic Evaluations", *Energy,* **29** , pp. 2195-2211, 2004.

[22] Sukumar, Puhan, Vedaraman, N, Boppanna , VB ,Sankarnarayanan ,G and Jaychandran,K, "Mahua Oil Methyl Ester as Biodiesel Preparation and Emission Characteristics", *Biomass and Bioenergy,* pp. 87-93, , 2005

[23] Schumacher L., "Fueling used Diesel Engine with Methyl Esters Soybean oil" , *Soybean Research Documents*, online htpp:/ stratsoy.ag.uiuc.edu, 1999.

[24] Kumar, M. senthil , Ramesh, A and Nagalirgon, B , "An Experimental Comparison of Methods to Use Methanol and Jatropha Oil in a Compression Ignition Engine" , *Biomass and Bioenergy* , **25**, pp. 309-318; 2003.

[25] Labeckas, Gviidonas, Salvinskos Stasys m, "The Effect of Rape seed oil Methyl Ester on Direct Injection Diesel Engine Performance and Exhaust Emission" , *Energy Conversion and Management* , Article in press , Available on line 20 October 2005, www.science direct .com

[26] Groboski ,MS, Cormic ,MC, Alleman ,ML, Herring ,TL ,"The Effect of Biodiesel Composition on Engine Emission from a DDC Seriec 60 Diesel Engine", Final Report, *NREL/SR-510-31461, National Renewable Energy Laboratory*,Golden,USA, 2003.

[27] Agrawal Ak, and Das LM, "Biodiesel Development And Characterization For Use As Fuel In Compression Ignition Engine", *J. ENG. Gas Turbine Power, Trans. ASME*,**123**,pp. 440-447,2001.

[28] Dorado Mp, Ballesterous E , Arnal Jm, Gomez J and Lopez F.J, "Exhaust Emissions from a Diesel Engine Fuelled with Transesterified Waste Olive Oil" , *Fuel* 82, **11**, pp. 1311-1315,2003.

[29] Kalligoros S, Zannikos, F, Stournas ,S loiseand Anastopoulos G, "An Investigation of Using Biodiesel / Marine Diesel Blends on the Performance of a Stationary Diesel Engine", *Biomass and Bioenergy*, **24,** , pp. 141-149 , 2003.

[30] Lee,R,Peddy, J, Hobbs , CH, “Fuel Quality Impact on Heavy Duty diesel Emission : Literature Review”, *SAE Paper no. 982649*,Warrendale, PA,1998

[31] Ulman TL,Spreen KB, Mason RL, “Effect of Cetane Number , Cetane Improver, Aromatics And Oxygenates on Heavy Duty Diesel Engine Emission”, *SAE Paper No, 941020*,,Warrelande,PA,1994

[32] Freedom, B, Pryde, EH and Mounts,TL, “Variables Affecting the Yields of Fatty Esters from Transesterified Vegetable Oils”, *Journal of American Oil Chemists Society* , **61** , pp, 1638-1643 , 1984

[33] Fongnui MA and Hanna, MA , “Biodiesel Production a review”, *Bio Resource Technology*; **70** , pp. 1-15, 1999.

[34] Srivastva ,A and Prasad ,R , “Triglycrides – Based Diesel Fuel”, *Renewable & Sustainable Energy Reviews* , **4**, pp. 111-113, 2000.

[35] Kerbitz, W , “Biodiesel Production in Europe and America : An Encouraging Prospect”, *Renewable Energy*, **16** , pp. 1078-1083, 1999.

[36] Beer, T Vrant, T, David ,W and Harry ,W , “Fuel Cycle Green House Emissions from Alternative Fuels in Australion Heavy Vehicles” *Atmospheric Environment* ,**36** , pp. 753-763, 2002.

[37] Sims, RH, “Bioenergy- a Renewable Carbon Sink”, *Renewable Energy* , **22** , pp. 31-37, 2001.

[38] Mehar, LC, Sagar ,D , Naik, SN, “Technical Aspects of Biodiesel Production by Transesterification a Review” , *Renewable and Sustainable Energy Reviews* , **20**, pp. 1-21, 2004.

[39] Ma, F, Elements, LD and Hanna, MA, "The Effects of Catalyst, Free Fatty Acids and Water onTrans -esterification of Beef Tallow" , *Trans. ASAE* , **41** , pp. 1261-1264 , 1998.

[40] Bradshow, VB , Menly, WC, "Preparation of Detergents" , *US Patent* **2** , pp. 360-844 , 1944.

[41] Feuge, RO and Grose, T , "Modification of Vegetable Oils. VII. Alkali Catalyzed Trans-eresterification of Peanut Oil with Ethanol" , *JAOCS*, **26** , pp. 97-102 , 1949.

[42] Keim , GI, "Process for Treatment of Fatty Glycerides", *US. Patent* **2** , pp. 383-601 , 1945.

[43] Ali ,Y, "Beef Tallow as a Biodiesel Fuel" ,*Ph.D. Dissertation* , Biological System Engineering, University of Nebraska Lincoln, 1995.

[44] Jackson, MA, and King, JW, "Methanolysis of Seed Oil in Flowing Supercritical Carbon Dioxides" , *JAOCS* ,**73** , pp. 353-356, 1996.

[45] Marckley , KS,"Fatty Acids (2nd ed.)", *Inter-science*, New York ,1960.

[46] Goering CE, Schwab AW, Daugherty MJ, Pryde EH, Heakin AJ,"Fuel Properties of Eleven Vegetable oils", *Trans. ASAE* , pp.1472–1483, 1982.

[47] Kapur JP, Bhasin SD and Mathur KC, "Oilseeds for Food and Industrial Applications", *Chemical Age of India* ,**33** , pp. 475–482 ,1982.

[48] Ali, Y, Hanna, MA and Cuppett, SL ,"Fuel Peroperties of Tallow and Soyabean Oil Esters", *J. Am. Oil.Soc.* , **72**, pp. 1557–1564 ,1995.

[49] Rao P.S. and Gopalakrishnan KV, "Vegetable Oils and Their Methyl esters as Fuels for Diesel Engines", *Indian Journal of Technology* ,**29**, , pp. 292–297, 1991.

[50] Ziejewski M, Kaufman KR, Pratt GL, "Vegetable Oil as Diesel Fuel", Seminar II, Northern Regional Research Center, Peoria, Illinois, pp.19–20 , 1983.

[51] Schwa, A.W. , Dykstr, G,J , Selke, E, Sorenso SC and Pryde EH "Diesel Fuel from Thermal Decomposition of Soybean Oil" , J. *Am. Oil Chem. Soc.*, **65** , pp. 1781–1785,1988.

[52] Bagby, MO, " International Winter Meeting of the ASAE", *Hyatt Regency Chicago*, 15–18 December 1987.

[53] Schwab AW , Bagby, MO and Freedman, B, "Preparation and Properties of Diesel Fuels from Vegetable Oils", *Fuel* **66** , pp. 1372–1378, 1987

[54] Kusdiana D, and Saka S, "Biodiesel Fuel for Diesel Fuel Substitute Prepared by a Catalyst Free Super Critical Methanol", *Graduate School of Energy and Science*, Kyoto University, Japan,606501,2002

[55] Marchetti JM, Miguel VU and Errazu AF , "Possible Methods for Biodiesel Production" , *Renewable and Sustainable Energy Reviews* , Available On online at www.sciencedirect.com, 2005.

[56] Mittelbach M, "Diesel Fuel Derived from Vegetable Oils, VI: Specifications and Quality Control Of Biodiesel", *Bioresource Technology* , **27** , pp. 435–437,1996.

[57] www.nrel.gov.

[58] Tyson, KS, "Biodiesel Handling and Use Guide Lines", *National Renewable Laboratory*, US Department of Energy, Midwest, USA, 2001

[59] Sangha M, Gupta. P, Thaper, V, "Storage Studies on Plant Oils and their Methyl esters" , *CIGR Journal of Scientific Research and Development* , **6** ,2004.

[60] Frame EA, "Evaluation of Biodiesel as Fuel Lubricity Enhancer", *U.S Army Tardec Fuels and Lubricants Research Facility* (TFLRF) Southwest Research Institute(SWRI) TFLRF No. 99-008, 2000.

[61] www.defra.gov.uk.

LIST OF PUBLICATIONS

(I) R.D. Chauhan, M.P. Sharma & S.K. Singal, " Study on the Applicability of Mixture Rule for Biodiesel Blends ", *National Conference on Energy Management in Changing Business Scenario* (EMCBS- 2005), Organized by Birla Institute of Technology, Pilani, Rajasthan, 8-9 Oct., 2005.

(II) R.D. Chauhan, M.P. Sharma & S.K. Singal, "Comparative Study of Viscosity for Biodiesel Blends of Pongamia Oil", *International Conference on Plant & Environment Pollution* (ICPEP-3), Poster Presentation, Organized by International Society of Environmental Botanists & National Botanical Research Institute Lucknow, 28 Nov-2 Dec., 2005.

(III) R.D. Chauhan, M.P. Sharma, R.P. Saini & S.K. Singal, "Jatropha – A Hope for Biodiesel in Uttarpradesh", *International Conference on Plant & Environment Pollution* (ICPEP-3), Poster Presentation, Organized by International Society of Environmental Botanists & National Botanical Research Institute Lucknow, 28 Nov-2 Dec., 2005.

(IV) R.D. Chauhan, M.P. Sharma, R.P. Saini & V. Kumar, " Biodiesel –A Case Study for UPSRTC", National Seminar on Recent Trends in Science, Technology & its Application, Organized by S.D College of Engineering & Technology, Muzaffarnagar, UP, 7-8 Jan., 2006.

(V) R.D. Chauhan, M.P. Sharma, R.P. Saini & S.K. Singal," Biodiesel from Jatropha as a Transport Fuel – A Case Study of UP State" has been submitted for publication in Journal of Scientific & Industrial Research (JSIR), **[Communicated]**.