A

Major Project-II Report

On

An Experimental Analysis on Biodiesel Production from Karanja Oil and its Performance Testing

A Major Project Thesis Submitted
In the Partial Fulfillment of the Award of the Degree of

MASTER OF TECHNOLOGY

Mechanical (Thermal) Engineering,
2011-2013

by

SAURABH SINGH
2K11/THE/20

Guided by

Dr. AMIT PAL
ASSOCIATE PROFESSOR
DEPTARTMENT OF MECHANICAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY,
DELHI, INDIA

DECLARATION

I, hereby declare that this submission is my own work and that, to the best of my knowledge and belief is being presented in the major project-II entitled **"An Experimental Analysis on Biodiesel production from Karanja Oil and Its Performance Testing"**, is completed under the supervision of **Dr. Amit Pal,** Assoc. Prof., Mechanical Engineering Department, Delhi Technological University. It has not been copied from any source without giving its proper reference, except where due acknowledgement has been made in the text.

Saurabh Singh
2K11/THE/20
M.Tech (Thermal Engineering)
4th Sem, II yr
Department of Mechanical Engineering,
Delhi Technological University,
Delhi, India.

CERTIFICATE

This is to certify that the work in this thesis report entitled **‘‘An Experimental Analysis on Biodiesel production from Karanja Oil and its Performance Testing’’** submitted by **Saurabh Singh** in partial fulfillment of the requirement for the award of degree of M.Tech in Mechanical Engineering, session 2011-2013, Department of Mechanical Engineering, Delhi Technological University, Delhi is a record of the candidate’s own work carried out by him under my supervision and guidance. The student has completed his work with utmost sincerity and diligence.

To the best of my knowledge and belief the matter embodied in this thesis is original and has not been submitted for the award of any other degree.

Date :

Dr. AMIT PAL
Assoc. Professor
Department of Mechanical Engineering
Delhi Technological University
Delhi, India

ACKNOWLEDGEMENT

It gives us a great sense of pleasure to present the report of the M.Tech major project-II undertaken during M.Tech Second Year. I am grateful to my project guide **Dr. Amit Pal,** Asst. Prof. in the Department of Mechanical Engineering, at Delhi Technological University for their expert guidance, meticulous efforts, constructive criticism, inspiring encouragement, unflinching supports and invaluable cooperation which enabled me to enrich my knowledge and reproduce in the present form. Their continuous inspiration has helped me to complete this project.

I would also like to thank **Head of Mechanical Department, Prof. Naveen Kumar** & **Prof. B. D. Pathak** for giving his kind support, sharing of valuable knowledge and approval of necessary infrastructure.

I would also like to thank **Sh. Lalit Kumar**, **Sh. Harjeet Singh and Sh. Vijay Hingorani** of I.C. Engine laboratory for extending their kind support and sharing their valuable time for the completion of this project.

I express my whole-hearted gratitude to all my faculty members who extended their cooperation in completing our project successfully.

Last but not the least I would like to thank my parents (Dr. J.P.S. Pipil & Mrs. Manju Pipil) and my elder sisters (Ritu & Taru) for the co-operation.

Saurabh Singh
2K11/THE/20
M.Tech (Thermal)
Department of Mechanical Engineering,
Delhi Technological University,
Delhi, India.

ABSTRACT

On the face of the upcoming energy crisis, vegetable oils have come up as a promising source of fuel. They are being studied widely because of their abundant availability, renewable nature and better performance when used in engines. Many vegetable oils have been investigated in compression ignition engine by fuel modification or engine modification. The vegetable oils have very high density and viscosity, so we have used the methyl ester of the oil to overcome these problems. Their use in form of methyl esters in non modified engines has given encouraging results.

Karanja oil (Pongamia Pinnata) is non edible in nature and is available abundantly in India. An experimental investigation was made to evaluate the performance, emission and combustion characteristics of a diesel engine using different blends of methyl ester of karanja with mineral diesel. Karanja methyl ester was blended with diesel in proportions of 10%, 20% and 30% by mass and studied under various load conditions in a compression ignition (diesel) engine. The performance parameters were found to be very close to that of mineral diesel. The brake thermal efficiency and mechanical efficiency were better than mineral diesel for some specific blending ratios under certain loads. The emission characteristics were also studied and levels of carbon dioxide, carbon monoxide, nitric oxide and hydrocarbons were found to be higher than pure diesel.

LIST OF ABBREVIATIONS

ASTM	-	American Standard for Testing of Materials
AF	-	Air-Fuel Ratio
BP	-	Brake Power
B5	-	5 % Biodiesel & 95% Diesel Blend
B10	-	10 % Biodiesel & 90% Diesel Blend
B15	-	15 % Biodiesel & 85% Diesel Blend
B20	-	20 % Biodiesel & 80% Diesel Blend
B30	-	30 % Biodiesel & 70% Diesel Blend
B80	-	80 % Biodiesel & 20% Diesel Blend
B100	-	00 % Biodiesel & 100% Diesel Blend
BThE	-	Brake Thermal Efficiency
BMEP	-	Brake Mean Effective Pressure
BSFC	-	Brake Specific Fuel Consumption
CSO	-	Cotton Seed Oil
C.I.	-	Compression Ignition
FFA	-	Free Fatty Acid
FP	-	Frictional Power
IMEP	-	Indicated Mean Effective Pressure
IDP	-	Ignition Delay Period
IP	-	Indicated Power
IOP	-	Injector Opening Pressure
IThE	-	Indicated Thermal Efficiency
KO	-	Karanja Oil
MechE	-	Mechanical Efficiency
MLP	-	Multi Layer Perception
MSE	-	Mean Square Error

OPA	-	Opacity
SFC	-	Specific Fuel Consumption
SVO	-	Straight Vegetable Oil
EGP	-	Exhaust Gas Temperature
VCR	-	Variable Compression Ratio
WCO	-	Waste Cooking Oil

LIST OF FIGURES/GRAPHS

Figure No. & Name | **Page No.**

Fig. 1: Composition of exhaust gases 5

Fig. 2: General Process flow chart of bio-diesel production 35

Fig. 3: Separation of glycerol from bio-diesel 37

Fig. 4: Pure bio-diesel at top layer & clear water at bottom layer 38

Fig. 5: Finally Processed Bio-Diesel 38

Fig. 6: Karanja seed 40

Fig.7. Bunch of Karanja seeds 41

Fig.8. Tree of Karanga seed 41

Fig. 9: Kirloskar Engine Test Bench 42

Fig. 10: Schematic of Test Set-up 42

Fig. 11: Kirloskar Engine 43

Fig. 12: A Smoke Meter and Its Components 51

Fig. 13: Schematic Diagram of Smoke Meter 52

Fig. 14: Variation of Specific Fuel Consumption with Brake Power 55

Fig. 15: Variation of Brake Thermal Efficiency with Brake Power 57

Fig. 16: Variation of Smoke Opacity with Brake Power 59

Fig. 17: Variation of Exhaust Gas Temperature with Brake Power 60

Fig. 18: Variation of Compression Pressure with Crank Angle for 0-720 62

Fig. 19: Variation of CompressionPressure with Crank Angle for 300-400 62

Fig. 20: Variation of Torque with Brake Power 63

Fig. 21: Variation of Air-Fuel Ratio with Brake Power 65

Fig. 22: Variation of Mechanical Efficiency with Brake Power 66

Fig.23. Variation of yield at different molar ratio with KOH 2% 78

Fig.24. Variation of yield at different molar ratio with KOH 3% 79

Fig.25. Variation of yield at different KOH with molar ratio 6:1 80

Fig.26. Variation of yield at different KOH with molar ratio 9:1 81

LIST OF TABLES

Table No.& Name	Page No.
Table 1: Heat of a Combustion and Specific gravity of other vegetable biodiesel fuel compared to Karanja Oil biodiesel fuel	7
Table 2: Demand and Domestic Production of Diesel	9
Table 3: Properties of Diesel and Crude Oils	9
Table 4: Chemical structure of common fatty acids	31
Table 5: The Fatty acid composition of Karajan oil	40
Table 6: Specifications of Test Engine	42
Table 7: Test Fuel Nomenclature	44
Table 8: Components Used in the Kirloskar Engine	46
Table 9: Detail of AVL Smoke Meter	52
Table 10: Specific Fuel Consumption at Different Brake Power	56
Table 11: Brake Thermal Efficiencies at different Brake Power	58
Table 12: Smoke Opacity at different Brake Power	59
Table 13: Exhaust Gas Temperature at different Brake Power	61
Table 14: Torque at different Brake Power	64
Table 15: Air-Fuel Ratio at different Brake Power	65
Table 16: Mechanical Efficiency at different Brake Power	67
Table 17: Yield Variation at different molar ratio with 2% KOH	79
Table 18: Yield Variation at different molar ratio with 3% KOH	79
Table 19: Yield Variation at different KOH	80
Table 20: Yield Variation at different KOH	81

TABLE OF CONTENTS

CONTENT	Pages
• **Declaration**	**ii**
• **Certificate**	**iii**
• **Acknowledgement**	**iv**
• **Abstract**	**v**
• **List of Abbreviations**	**vi**
• **List of Figures/Graphs**	**vii**
• **List of Tables**	**viii**
1. INTRODUCTION	**1-13**
1.1 General	1-6
1.2 History of Vegetable Oil Based Diesel Fuels	6-7
1.3 Indian Energy Scenario of Petroleum	7-9
1.4 Non Availability of Oil	10-11
1.5 Indian Energy Scenario of Bio-Diesel	11-12
1.6 Government's Policies	12-13
1.7. Organization of the Report	13
2. LITERATURE REVIEW	**14-25**
3. PROCESS OF BIO-DIESEL PRODUCTION & ITS PROPERTIES	**26-41**
3.1 Vegetable Oils as Engine Fuels	26-29
3.2 Utilization of Vegetable Oil as Engine Fuel	29-30
3.2.1 Direct Use and Blending	29-30
3.2.2 Micro-Emulsions	30
3.2.3. Pyrolysis (Thermal Cracking)	30

3.3 Chemistry of Transesterification Process	30-32
3.4 Transesterification Reaction	32-33
3.5 Biodiesel Production	33-38
3.5.1 Acid-Catalyzed Pre-Treatment	33-34
3.5.2 Alkali-Catalyzed Transesterification	34-36
3.5.3 Separation	36
3.5.4 Alcohol Removal	36
3.5.5 Glycerine Neutralization	36
3.5.6 Methyl Ester Wash	37
3.5.7 Product Quality	37-38
3.6 Karanja Oil and its Properties	39-41
4. EXPERIMENTAL SET-UP	**42-54**
4.1 Kirloskar Engine	42-50
4.1.1 Description	45-46
4.1.2 Components Used	46-48
4.1.3 Performance of I.C.Engines	48-50
4.2 Smoke Meter	50-54
4.2.1 Basic Operating Principle	50-51
4.2.2 Operating and Display Elements	51-54
5. RESULT AND DISCUSSIONS	**55-67**
5.1 Specific Fuel Consumption (SFC) v/s Brake Power	55-56
5.2. Brake Thermal Efficiency v/s Brake Powe	56-58
5.3 Smoke Opacity v/s Brake Power	58-59

5.4 Exhaust Gas Temperature v/s Brake Power 60-61

5.5 Pressure v/s Crank Angle 61-62

5.6 Torque v/s Brake Power 63-64

5.7 Air-Flue Ratio v/s Brake Power 64-65

5.8 Mechanical Efficiency v/s Brake Power 66-67

6. CONCLUSIONS 68

7. FUTURE SCOPE & RECOMMANDATIONS 69

8. RECOMMENDATION FOR DEVELOPMENT OF BIO FUELS 70-72

8.1. Need for a policy initiative 70-71

8.2. Translation of the policy initiative 71-72

8.3. Bio-diesel policy 72

8.4. Environmental Considerations 72

9. REFERENCES 73-77

1.0 INTRODUCTION

1.1 General

India is at fifth place among the whole world in terms of energy consumption. Today India is dependent on petroleum products for the requirement of energy needs for different purposes like transportation, irrigation and industries, etc. India consumed about 128.50 million metric tonnes of petroleum products during the year 2008, from which 73 million metric tonnes was used for transportation. Because of steady growth in the economy, India by 2025 will be third in the world for petroleum products import after US & China. It is expected that during 2035, India’s total on road fuel consumption for a year will be 371 million metric tonnes, up from 58 million metric tonnes in year 2005, which reflects a larger growth than China (6.4 times for India vs. 3.5 times for China). India will require importing of 6 million barrels per day oil by 2030 to meet the demand of energy for the different areas. Since, India has only 0.4% of world crude oil, therefore alternatives should be found to meet the requirements.

On the other hand petroleum derived fuels have been the major source of the world’s energy, and the whole world is presently confronted with the twin crises of fossil fuel depletion and the environment degradation. Indiscrimination extraction and lavish consumption of fossil fuels have led to reduction in underground based carbon resources. Future projections indicate that economics and energy needs will increase the focus on the production of synthetic fuels derived from non-petroleum sources **[1]**. Furthermore, higher public awareness in recent years of the impacts of fossil fuel emissions on the environment and their potential health hazards triggered the government to impose restrictions on fossil combustion emissions.

The search for alternative fuels, which promises a harmonious correction with sustainable development, energy conservation, efficiency and environmental preservation, has become highly crucial. Many researchers around the world have explored several alternative energy resources, like biogas, biomass, alcohol, hydrogen, vegetable oil, which have the potential to quench the ever-increasing energy thirst of today’s population **[2].** Recent scorching prices of petroleum based fuel (before global economic recession) and reduced biofuel cost due to advanced technological breakthrough, made biofuel competitive with conventional petro-fuel.

One way to solve the problem mentioned above is to look for alternative and renewable energy sources. One of the most promising alternative energy sources is biomass **[3]**. It is renewable, available everywhere and contains much less sulfur and nitrogen contents, which makes it more environmentally friendly than fossil sources. Among the biomass sources, waste cooking oil, vegetable oils (karanja oil, mahua oil, jatropha oil, thumba oil, cotton seed oil, etc) and animal fats have attracted much attention as a potential renewable resource for production of an alternative for petroleum based Diesel fuel.

As already mentioned India lacks in sufficient fossil energy reserves and dependent on petroleum products import. The use of vegetable oil in a diesel engine is not a new concept. India has an abundant resource of vegetable oils. Vegetable oil is easily available, renewable and environment friendly. Vegetable oil can be used as straight vegetable oil (without any modification in engine and in fuel) and as a biodiesel (transesterified vegetable oil) in the CI engines.

Using straight vegetable oils (SVO) in diesel engines is not a new idea. In the early 1900's Diesel engine used peanut oil as a fuel for demonstration of his newly developed compression ignition (CI) engine in year 1910. Later with the availability of cheap petroleum, crude oil fractions were refined to serve as 'diesel', a fuel for CI engines. During the period of World War-II, vegetable oils were again used as fuel in emergency situations when fuel availability became scarce. Nowadays, due to limited resources of fossil fuels, rising crude oil prices and the increasing concerns for environment, there has been renewed focus on vegetable oils and animal fats as an alternative to petroleum fuels. Vegetable oil is easily available worldwide. It is a renewable fuel with short carbon cycle period (1–2 years compared to millions of year for petroleum fuels) and is environment friendly. These are the triggering factors for research all over the world to consider vegetable oils and their derivatives as alternative to petroleum diesel.

Proper collection and processing of the oilseeds those are naturally available in Indian forests, considerable reduction in the import bill of India can be achieved.

Further this may generate huge employment at local level in tribal areas. But the plantation programs of oilseeds are being led to wrong direction due to several government schemes, which are luring the farmers to plant these species on fertile land that was otherwise used for food grain production. The fact that these actions to gain energy security may erode the food security of the nation is grossly being ignored.

Most of the investigations reported in the literature on the usage of vegetable oil as engine fuels have emphasized modifying the oil to work in existing engine designs. The primary problem associated with using straight vegetable oils (SVO) as a fuel in a compression ignition engine is the high viscosity **[4]**. The fuel injection system of new technology engines is sensitive to fuel viscosity changes. High viscosity of the vegetable oil leads to poor fuel atomization, which in turn may lead to poor combustion, ring sticking, injector cocking, injector deposits, injector pump failure and lubricating oil dilution by crank-case polymerization. Among the methods that have been investigated was transforming the vegetable oils to their corresponding esters. The fuel characteristics of these esters are much closer to those of Diesel fuel than those of the fresh vegetable oils **[5]**.

In the 1970s, it was found that the viscosity of vegetable oils could be decreased through a simple chemical process. The process yields a vegetable oil based fuel that works as efficiently as Diesel fuel in modern compression ignition (CI) engines. This fuel is called biodiesel, and the process is called transesterification. It is a chemical process in which a triglyceride in the vegetable oils and fat reacts with an alcohol in the presence of a strong acid or base to produce a mixture of fatty acids alkyl esters and glycerol **[6]**.

Biodiesel, a clean renewable fuel, has recently been considered as the best substitute for a diesel fuel because it can be used in any compression ignition (CI) engine without the need of modification. Chemically, biodiesel is a mixture of methyl esters with long chain fatty acids and is typically made from non-toxic, biodiesel resources such as vegetable oils (Karanja, Cotton Seed, Mahua, Jatropha, Thumba etc.), animal fats, or even waste cooking oils (WCO).

It was **[7]** reported that the transesterification process has been proven worldwide as an effective means of biodiesel production and viscosity reduction of vegetable oil. Temperatures, catalyst type, concentration ratio of alcohol to fuel and stirring speed rate have been observed to influence the transesterification process to a greater extent. The study was done on biodiesel and reveal that biodiesel is a viable and a practical alternative fuel for older in-service engines. Particulate matter was almost negligible with the use of this fuel. Operators reported that the test vehicles had no noticeable drivability downsides. On the other hand, it was observed that the vehicles had some improved power performance while operating under city traffic conditions. It was also found that no significant engine problems were reported in tests with urban bus fleets running on B20. Fuel economy was comparable with diesel fuel and the fuel consumption of biodiesel blend being only 2–5% higher than that of conventional diesel.

Ester blends have been reported to be stable, and did not separate at room temperature over a period of three months. One limitation to the use of biodiesel is its tendency to crystallize at low temperatures below 0 ^{0}C. Such crystals can plug fuel lines and filters, causing problems in fuel pumping and engine operation.

Environmental issues regarding the emission of conventional fuels such as gasoline and diesel are of serious concern worldwide. The standard emission from conventional fuel vehicles are hydrocarbon (HC), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x) and particulate matter (PM). These emissions are harmful gases which can have adverse impact on human body or living being and destroy the environment by playing an important role in formation of the greenhouse effect, acid rain and global warming. Therefore, alternative fuels such as bio diesel, ethanol (alcohol), natural gas, liquefied petroleum gas (LPG), compressed natural gas (CNG) are being considered to replace the role of conventional fuels in order to reduce these harmful emissions from being released to the atmosphere. These alternative fuels may possibly contribute to a significant reduction in emission in most vehicles operating worldwide**.**

Karanja is a forest based tree-borne non-edible oil with a, production potential of 135000 million tonnes. Karanja tree grows all over the country. In parts of India, this tree is also known as pongamia, belongs to the family of Leguminaceae. It is a medium sized tree that attains a height of about 18 m and a trunk diameter greater wider than 50 cm. The fresh extracted oil is yellowish orange to brown and rapidly darkens on storage.

At the end of the day the concept that fulfils all legislative requirements and can be sold at the lowest price will be the winner and that may be an engine running on a conventional or on an alternative fuel or most likely on both.

The alternatives to petroleum-based fuels must meet the following criteria, if they are going to be used widely for transportation.

- Technically acceptable
- Economically competitive
- Environmentally acceptable
- Safe & easily available

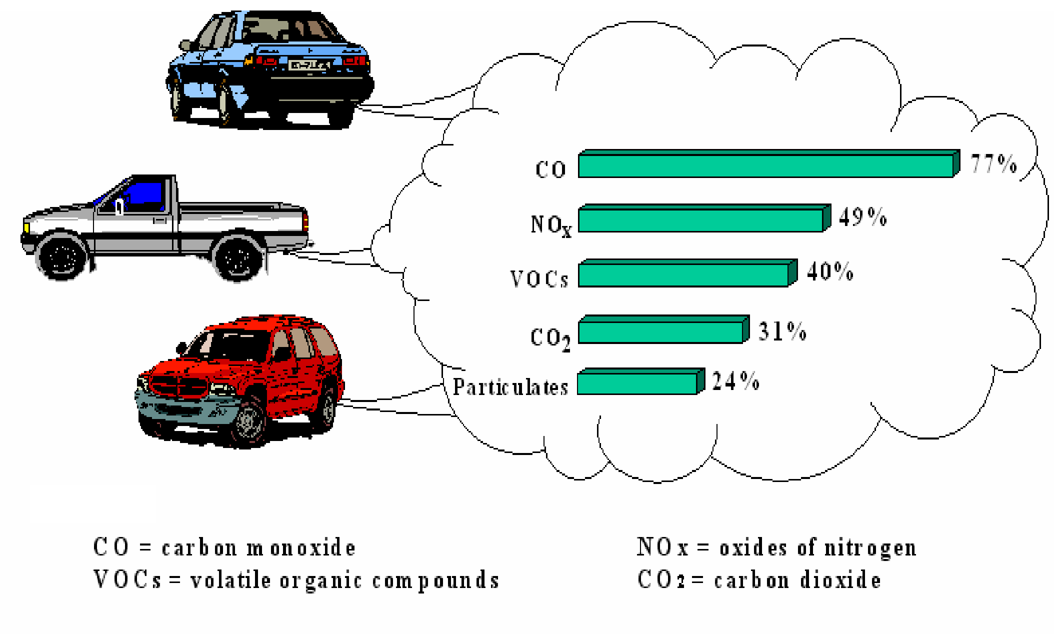


Fig.1. Composition of exhaust gases

In comparison with petroleum-based diesel fuel, bio-diesel is characterized or compared by:- **[8]**

- Lower heating value (by about 10-12 %)
- Higher cetane value (typically 45-60) thus good anti knocking property.

- About 11% oxygen content (petroleum-based diesel contains no oxygen).
- No aromatics contents.
- No sulphur or extremely low sulphur content.
- Better lubricity (about 66% better than petro diesel).
- Higher viscosity
- Higher flash point and freezing temperature.
- Produce lower carbon monoxide and hydrocarbon emissions.
- No toxicity or low toxicity.
- Different corrosive properties.
- Excellent lubricity, a fact that is steadily gaining importance with the advent of low-sulfur petrodiesel fuels, which have greatly reduced lubricity. Adding biodiesel at low levels (1-2%) restores the lubricity.
- Reduction of most exhausts emissions (with the exception of nitrogen oxides, NOx).

Some of the above properties, such as the high cetane value or good lubricity and lower sulfur content, are obvious advantages of bio-diesel while others, including the lower heating value, high freezing point (and inferior flow properties at low temperature), or corrosion properties are its drawbacks. Biodiesel changes the character and can increase the intensity of the odour of diesel exhaust.

1.2 History of Vegetable Oil Based Diesel Fuels

It is generally known that vegetable oils and animal fats were investigated as diesel fuels well before the energy crises of the 1970s and early 1980s sparked renewed interest in alternative fuels. It is also known that Rudolf Diesel (1858-1913), the inventor of the engine that bears his name, had some interest in these fuels. However, the early history of vegetable oil-based diesel fuels is often presented inconsistently and “facts” that are not compatible with Diesel’s own statements are encountered frequently. Transesterification of a vegetable oil was conducted as early as 1853 by scientist E. Duffy and J. Patrick, many years before the first diesel engine became functional. Rudolf Diesel’s prime model, a single 10 ft (3m) iron cylinder with a flywheel at its base, ran on its own power for the first time in Augsburg, Germany, on August 10, 1893. In remembrance of this event, August 10 has been declared "International Biodiesel Day". Rudolf Diesel demonstrated a Diesel engine running on peanut oil (at the request of the French government) built by French Otto Company at the World Fair in Paris, France in 1990, where it received the Grand Prix (highest prize).

This engine stood as an example of Diesel's vision because it was powered by peanut oil – a biofuel, though not biodiesel, since it was not transesterified. He believed that utilization of biomass fuel was the real future of his engine. In a 1912 speech Diesel said "The use of vegetable oils for engine fuels may seem insignificant today but such oils may become, in the course of time, as important as petroleum and the coal-tar products of the present time".

Table 1: Heat of a Combustion and Specific gravity of diesel and vegetable oils. **[4]**

Fuel Type	Heat of Combustion kJ/kg	Specific Gravity
Diesel Fuel	43350	0.815
Sun Flower Biodiesel	40579	0.878
Cotton Seed Biodiesel	40580	0.874
Karanja Biodiesel	39760	0.872
Rape Seed Biodiesel	37620	0.914
Pawpaw Seed Biodiesel	45342	0.867
WCO	45479	0.858

1.3 Indian Energy Scenario of Petroleum

Since, petroleum diesel comes from fossil fuel, so it has also tendency of lavish some day in future. As the population increases and demand for fuels also increases simultaneously to satisfy different requirements of them. The production rate of petroleum products are very very slower than the consumption rate of fossil fuel, and this approaches to depletion of petroleum diesel (fossil fuel) in near future. Reserves of different fossil fuels are given below

Coal

- Global coal reserves estimated 8,60,938 million tonnes by end of 2010 (R/P-118)
- USA has largest share of the global reserves – (27.6%) (R/P-241 yrs)
- Russia has (18.2%) (R/P- 496 yrs)
- China has 13.3% (R/P- 36 yrs)
- Australia has 8.9% (R/P-180 yrs)
- India is 5th in the list with 7.0% (R/P- 106 yrs)

Oil

- Global proven oil reserves estimated 1383.2 million barrels by the end of 2010 (R/P- 46.2)
- Saudi Arabia have largest share of the reserve – 19.1% (R/P-72.4 yrs)
- Venezuela (15.3%) (R/P > 100yrs)
- Iran (9.9%) (R/P- 88.4 yrs)
- Iraq (8.3%) (R/P > 100yrs)
- Kuwait (7.3%) (R/P > 100 yrs)
- UAE (7.1%) (R/P – 94.1 yrs)
- Russia (5.6%) (R/P – 20.6 yrs)
- India has only 0.7% shares of the world reserve (9.0 million barrels) (R/P - 30.0 yrs)

Gas

- Global proven gas reserve estimated 187.1 trillion cubic meters by the end of 2010 (R/P – 58.6 yrs)
- Russia Federation have largest share of the reserve – 23.9% (R/P – 76 yrs)
- Iran (15.8%) (R/P > 100yrs); Qatar has (13.5%) (R/P > 100 yrs)
- India had only 0.8% share of the world reserve (R/p – 29.0 yrs)

Table 2: Demand and Domestic Production of diesel in India. **[8]**

Year	Domestic Production (Mt)	Demand (Mt)	Self Reliance (%)
1990-91	33.02	53.72	61.4
1995-96	35.17	62.51	56.2
2000-01	32.43	106.523	30.4
2001-02	32.03	110.738	28.92
2003-04	33.38	123.815	26.96
2004-05	33.98	129.84	26.17
2006-07	33.99	144.85	23.46
2009-10	33.69	192.95	17.4

Import 159.26 million tonnes

Country spent 3.753 trillion INR worth valuable foreign exchange in 2009-10.

Table 3: Properties of Diesel and Biodiesel Oils

S.NO	PROPERTY	DIESEL	KARANJA OIL
1	Calorific Value	43,000 kJ/kg	39,648 kJ/kg
2	Flash Point	440 ^{0}C	2340 ^{0}C
3	Fire Point	490 ^{0}C	1920 ^{0}C
4	Viscosity	0.278 poise	2.52 poise
5	Density	835 kg/m3	850 kg/m3

1.4 Non Availability of Oil

In India edible oils are in short supply. Hence prices of edible oils are higher than that of petroleum diesel. Due to this, these are not viable and use of non-edible oils was suggested for biodiesel manufacture.

Indian culture uses vegetable oil lamps for lighting in homes and in temples (like candles in other cultures). When prices of edible oil shot up, some people turned to a bit cheaper non-edible oils. The requirement of this sector is more than 15 million tons (Bio-kerosene). Since seeds can be collected and crushed in a small scale in far flung villages, the use of non-edible oils for lamps is picking up very fast. This is the best way of use for millions of rural Indians. This is depriving biodiesel industry its supply of oil.

All over the world edible oils are used for manufacture of biodiesel. These are Rape seed in Europe, Soy in Americas and Palm in South East Asia. Rape seed and soy are used for its de-oiled meal as cattle feed and oil is not that important. Hence these were in excess, and had to be disposed off at lower prices. Hence initially it was a viable raw material for biodiesel manufacture and a lot of manufacturing units came up based on these oils. Now excess oil is committed, and fresh sources need to be developed.

Collection of non-edible oil seeds is a manual operation, and for large biodiesel plant it is a logistical nightmare. In a day, a person can collect up to 80 kilograms of seeds, which can produce 20 to 23 liters of oil. The collection is done for 3 months, once or twice a year. For 100 tons per day (8 million gallons per year) plant, you need 15,000 people to collect it. Collecting and organizing such a large manpower is a challenge.

Most of the edible oils used currently are stable (do not get rancid). These do not decompose much on storage. Hence these are preferred for trans-esterification process. Non-edible oils are not that stable, and need a lot of pre-treatment adding to the cost of manufacture of biodiesel. If these are used as lamp oil, even oils with 50% free fatty acids can be used.

The use of lamp oil is increasing rapidly in India, as there is no electrical power supply for 10 to 14 hours a day in rural areas. Soon people will face shortage of these oils for lighting purposes. Cottage soap industry can use vegetable oils with high free fatty acid contents. Since prices of edible oils have doubled, many soap manufacturers in unorganized sector are using these oils as these are a bit cheaper.

There are billions of other trees (Karanja, Mahua, Neem), all over India, with oil bearing seeds. Traditionally Karanja (Pongamia Pinatta) is planted along the highways. Petrol pump owners along the highways should be encouraged to collect the Karanja seeds. Neem (Azadirachta Indica) is planted everywhere for purification of air. Mahua (Madhuca Indica) and Sal (Shorea robusta) grows wildly in Forests. Collection and processing mechanism for these seeds is not yet developed. Hence most of these seeds lie on the ground (and ultimately get converted into bio-fertilizer).

1.5 Indian Energy Scenario of Bio-Diesel

Indian faces formidable challenges in meeting its energy needs and in providing adequate energy of desired quality in various forms in a sustainable manner and at competitive prices. India needs to sustain an 8% economic growth rate, over the next 25 years, if it is to eradicate poverty and meet its human development goals. To deliver a sustained growth rate 8% through 2031-32 and to meet the lifeline energy needs of all citizens, India needs, at the very least, to increase its primary energy supply **[9]**. The country's energy demand is expected to grow at an annual rate of 6.8% over the next couple of decades. Most of the energy requirements are currently satisfied by fossil fuels – coal, petroleum based products and natural gas. Past and projected increase demand is shown in table. With an expected growth rate of Diesel consumption of more than 14% per annum, shrinking crude oil **[10]**. In these circumstances biodiesel is going to play an important role in meeting India's growing energy needs. Bio fuels offer an attractive to fossil fuels, but a consistent scientific framework is needed to ensure policies that maximize the positive and minimize the negative aspects of bio fuels.

As India is deficient in edible oils, non-edible oil is the main choice for producing biodiesel. Some development works have been carried out with regards to the production of transesterification non-edible oil and its use in biodiesel.

The government of India has formulated an ambitious National Biodiesel Mission to meet 20 per cent of the country's diesel requirements by 2016-2017. A commercialization period during 2007-2012 will continue vegetable oilseeds cultivation and install more transesterification plants which will position India to meet 20 per cent of its diesel needs through biodiesel. Biodiesel in India is virtually a non-starter. There are many reasons for that. The main reasons are non-availability of vegetable oil and government's policies.

1.6 Government's Policies

Government of India started Bio-fuel mission in 2003, but it announced bio-fuel policy on 11th September 2008. The Union Cabinet in its meeting gave its approval for the national policy on bio-fuel prepared by the Ministry of New and Renewable Energy, and also approved for setting up of an empowered National Bio-fuel Coordination Committee, headed by Prime Minister of India and a Bio-fuel Steering Committee headed by Cabinet Secretary. Ministry of New and Renewable Energy has been given the responsibility for the national policy on bio-fuels and overall co-ordination by Prime Minister under the allocation of business rules. A proposal on "National Policy on Bio-fuels & its Implementation" was prepared after wide scale consultations and inter-Ministerial deliberations. The draft Policy was considered by a Group of Ministers under the Chairmanship of, Union Minister of Agriculture, Food & Public Distribution. After considering the suggestions of Planning Commission and other Members, the Group of Ministers recommended the National Bio-fuel Policy to the Cabinet.

Salient features of the National Bio-fuel Policies are as under:-

- Bio-diesel production will be taken up from non-edible oil seeds in waste / degraded / marginal lands.
- The focus would be on indigenous production of bio-diesel feedstock and import of Free Fatty Acid (FFA) based such as oil, palm etc. would not be permitted.
- Bio-diesel plantations on community / Government / forest waste lands would be encouraged while plantation in fertile irrigated lands would not be encouraged.

- Minimum Support Price (MSP) with the provision of periodic revision for bio-diesel oil seeds would be announced to provide fair price to the growers. The details about the MSP mechanism, enshrined in the National Biofuel Policy, would be worked out carefully subsequently and considered by the Bio-fuel Steering Committee.
- Minimum Purchase Price (MPP) for the purchase of bio-ethanol by the Oil Marketing Companies (OMCs) would be based on the actual cost of production and import price of bio-ethanol. In case of biodiesel, the MPP should be linked to the prevailing retail diesel price.
- The National Bio-fuel Policy envisages that bio-fuels, namely, biodiesel and bio-ethanol may be brought under the ambit of “Declared Goods” by the Government to ensure unrestricted movement of bio-fuels within and outside the States. It is also stated in the policy that no taxes and duties should be levied on bio-diesel.

1.7. Organization of the Report

First chapter is introduction which deals with the energy demand over world and need of renewable energy to secure the future demand of energy. This chapter comprises of general, history of vegetable oil based diesel fuels, Indian scenario in bio-diesel, non availability of oil, government's policies and Indian scenario in petroleum

Second chapter is literature review in which literatures available biodiesel production, it’s properties and its performance testing are summarized.

Third chapter deals with biodiesel production techniques and its feasibility. In this chapter vegetable oils as engine fuels, chemistry of transesterification process, biodiesel production and Karanja oil properties has been discussed.

Fourth chapter is discussed about the experimental set up, that is used for taking the readings for different blends and pure diesel.

Fifth chapter is discussed about the result that we get from the Kirloskar (CI) engine and gives brief description about the trends of curve.

2.0 LITERATURE REVIEW

Straight Vegetable Oil (SVO) is being used in the existing compression ignition (CI) engines by a number of researchers with or without any modification in the engine, but this results malfunctioning of the engine by poor combustion, ring sticking, injector cocking, injector deposits, injector pump failure and lubricating oil dilution by crank-case polymerization and etc due to high viscosity of the vegetable oil. A number of researchers also worked SVO processing and then used in the CI engine, which shows comparative good result with petroleum diesel. To study the performance and emission characteristics of SVO and processed biodiesel and production processes we have gone through a number of research papers and other data sources, few important are discussed here:

Hebbal et al. [11] investigates the performance and combustion characteristic of single cylinder, naturally aspirated, water cooled, compression ignition (CI) engine running on karanja oil (B100) and blend of karanja biodiesel with diesel (B10, B15, and B20). All the experiments were conducted at rated engine speed of 1500 rpm under varying load conditions of 0, 20%, 40%, 60%, 80%, 100% of rated load for B10, B15, B20 fuels and 0, 25%, 50%, 75%, 100% of rated load for B100 and diesel fuels. After completion of each experiment the engine was run on diesel in order to flush the fuel in the fuel line. The results obtained from experiment were compared with the diesel. The results showed that the fuel properties of K100 (density, viscosity, flash point and carbon residue) were found to be higher than that of diesel and calorific value is lower than that of diesel. Based on performance and combustion characteristics of the various blends, the optimum blend was found to be B15.

Bajpai et al. [12] tested performance and emission characteristics of karanja (*Pongamia pinnata*) oil blended with conventional diesel in various proportions, in a single cylinder direct injection constant speed diesel engine without major engine modifications. Diesel and karanja oil fuel blends (B5, B10, B15 and B20) were used to conduct engine performance and emission tests at varying loads (0%, 20%, 40%, 60%, 80%, and 100%). Tests were carried out over the entire range of engine operation and engine performance parameters such as fuel consumption, thermal efficiency, exhaust gas temperature, and exhaust emissions (smoke, CO, CO_2, HC, NO_x, and O_2) were recorded. The brake specific energy consumption (BSEC), brake thermal efficiency (BTE), and exhaust emissions were evaluated to determine the optimum fuel blend. Higher BSEC was observed at full load for neat petro-diesel. Petroleum diesel blend of 10% karanja oil (B10) showed higher BTE at a 60% load. Similarly, the overall emission characteristics were found to be best for the case of B10 over the entire range of engine operation.

Agarwal et al. [13] carried out experiments for performance and emission characteristics of a compression ignition engine fuelled with Karanja oil and its blends (B10, B20, B50 and B75) with petroleum diesel. The effect of temperature on the viscosity of Karanja oil has also been investigated. Fuel preheating in the experiments – for reducing viscosity of Karanja oil and blends has been done by a specially designed heat exchanger, which utilizes waste heat from exhaust gases. A series of engine tests, with and without preheating/pre-conditioning have been conducted using each of the above fuel blends for comparative performance evaluation. The performance parameters evaluated include thermal efficiency, brake specific fuel consumption (BSFC), brake specific energy consumption (BSEC), and exhaust gas temperature whereas exhaust emissions include mass emissions of CO, HC, NO and smoke opacity. These parameters were evaluated in a single cylinder compression ignition engine typically used in agriculture sector of developing countries. The results of the experiment in each case were compared with baseline data of petroleum diesel. Significant improvements have been observed in the performance parameters of the engine as well as exhaust emissions, when lower blends of Karanja oil were used with preheating and also without preheating. The gaseous emission of oxide of nitrogen from all blends with and without preheating are lower than petroleum diesel at all engine loads. Karanja oil blends with diesel (up to B50) without preheating as well as with preheating can replace diesel for operating the CI engines giving lower emissions and improved engine performance.

Raheman et al. [14] shows the results of investigations carried out in studying the fuel properties of karanja methyl ester and its blend with diesel from B20 to B80 by volume and in running a diesel engine with these fuels. Engine tests have been carried out with the aim of obtaining comparative measures of torque, power, specific fuel consumption and emissions such as CO, smoke density and NO_x to evaluate and compute the behaviour of the diesel engine running on the above-mentioned fuels.

The reduction in exhaust emissions together with increase in torque, brake power, brake thermal efficiency and reduction in brake-specific fuel consumption made the blends of karanja esterified oil (B20 and B40) a suitable alternative fuel for diesel and could help in controlling air pollution.

Prabhu et al. [15] produced **b**iodiesel from karanja oil alkali catalyzed transesterification process. Performance of IC engine using karanja biodiesel blending with diesel in various ratios has been evaluated. The engine performance studies were conducted with a prony brake-diesel engine set up. Parameters like speed of engine, fuel consumption and torque were measured at different loads for pure diesel and various combinations of blends. Brake power, brake specific fuel consumption and brake thermal efficiency were calculated. The test results indicate that the dual fuel combination of B40 can be used in the diesel engines without making any engine modifications. Also the cost of biodiesel and diesel blend (B40) can be considerably reduced than pure diesel. They found from experiments that all the fuel samples tested, torque, brake power and brake thermal efficiency reach maximum values at 70% load and B40 can be recommended for use in the diesel engines without making any engine modifications. Also the cost of dual fuel (B40) can be considerably reduced than pure diesel.

Baiju et al. [16] investigates the scope of utilizing biodiesel developed from both through the methyl as well as ethyl alcohol route (methyl and ethyl ester) from Karanja oil as an alternative diesel fuel. The physical and chemical properties of ethyl esters were comparable with that of methyl esters. However, viscosity of ethyl esters was slightly higher than that of methyl esters. Cold flow properties of ethyl esters were better than those of methyl esters. Performance and exhaust emission characteristics of the engine were determined using petroleum diesel as the baseline fuel and several blends of diesel and biodiesel as test fuels. The result of their experiments shows that methyl esters produced slightly higher power than ethyl esters. Exhaust emissions of both esters were almost identical. This study show that both methyl and ethyl esters of Karanja oil can be used as a fuel in compression ignition engine without any engine modification, among the blends methyl esters show better performance and emission characteristics than ethyl esters, most of the major exhaust pollutants such as CO, HC and smoke are reduced with the use of neat biodiesel and the blends, but NO_x emissions increase by 10–25% when fuelled with diesel– biodiesel fuel blends as compared to conventional diesel fuel at part loads. At full load, diesel emits more NO_x than esters.

Mohite et al. [17] did the experimental work carried out to analyze the emission and performance characteristics of a single cylinder 3.67 kW, compression ignition (CI) engine fuelled with petroleum diesel and diesel-biodiesel blends at an injection pressure of 200 bar. The performance parameters were break thermal efficiency, break specific energy consumption (BSEC) and the emissions measured were carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbon (HC), and oxides of nitrogen (NO_x). The results of experimental investigation with biodiesel blends were compared with that of baseline diesel. The results indicate that the CO emissions were slightly higher, HC emissions decreased from 12.8 % for B20 and 2.85 % for B40, NO_x emissions decreased up to 39 % for B20 and 28 % for B40. The efficiency decreased slightly for blends in comparison with diesel. The BSEC was slightly more for B20 and B40. From the investigation they concluded that biodiesel can be used as an alternative to diesel in a compression ignition engine without any engine modifications.

Kumar et al. [18] conduct the experiment to find the results of performance and emission analyses carried out in an unmodified diesel engine fuelled with Pongamia pinnata methyl ester (PPME) and its blends with diesel. Engine tests have been conducted to get the comparative measures of brake specific fuel consumption (BSFC), brake specific energy consumption (BSEC) and emissions such as CO, CO2, HC, NOx to evaluate the behaviour of PPME and diesel in varying proportions. The results reveal that blends of PPME with diesel up to 40% by volume (B40) provide better engine performance (BSFC and BSEC) and improved emission characteristics. It was found that blends of PPME and diesel could be successfully used with acceptable performance and better emissions than pure diesel up to a certain extent. From the experimental investigation, it is concluded that blends of PPME with diesel up to 40% by volume (B40) could replace the diesel for diesel engine applications for getting less emissions and better performance and will thus help in achieving energy economy, environmental protection and rural economic development. In the near future conventional fuels will be fully replaced by biodiesel and will provide a viable solution for the much threatening environmental pollution problems.

Sahoo et al. [19] produced biodiesel from non-edible filtered Jatropha (Jatropha curcas), Karanja (Pongamia pinnata) and Polanga (Calophyllum inophyllum) oil based mono esters (biodiesel) and blended with diesel. The blends were tested for their use as substitute fuels of compression ignition (CI) engines. The major objective of their investigations was to experimentally access the practical applications of biodiesel in a single cylinder diesel engine used in generating sets and the agricultural applications in India. Diesel, neat biodiesel from Jatropha, Karanja and Polanga and their blends (B20 and B50) were used for conducting combustion tests at varying loads (0, 50 and 100%). The engine combustion parameters such as peak pressure, time of occurrence of peak pressure, heat release rate and ignition delay were computed. Combustion analysis revealed that neat Polanga biodiesel that results in maximum peak cylinder pressure was the optimum fuel blend as far as the peak cylinder pressure was concerned. The ignition delays were consistently shorter for neat Jatropha biodiesel, varying between 5.9^0 and 4.2^0 crank angles lower than diesel with the difference increasing with the load. Similarly, ignition delays were shorter for neat Karanja and Polanga biodiesel when compared with diesel. It is concluded from the paper that neat Polanga biodiesel which results in maximum peak cylinder pressure (6.61 bars higher than that of diesel) is the optimum fuel blend as far as the peak cylinder pressure is concerned. The ignition delays are consistently shorter for JB100, varying between 5.9^0 and 4.2^0 crank angle lower than diesel with the difference increasing with the load. Similarly, ignition delays are shorter for KB100 (varying between 6.3^0 and 4.5^0 crank angle) and PB100 (varying between 5.7^0 and 4.2^0 crank angle) lower than diesel.

Dhinagar et al. [20] has the main objective of the research work is to utilise the higher amounts of exhaust energy of the LHR engines. Three vegetable oils (neem oil, rice bran oil and karanji oil) were tested in the low heat rejection engine. An electrical heater was used to heat the thick vegetable oils or the air and the results were studied. The electrical heater energy was correlated with the energy available in the exhaust of the LHR engine, so that the electrical heater can be replaced by a heat exchanger in the actual engine. The three vegetable oils, without heating, indicated a lower brake thermal efficiency of 1-4% when compared with the standard diesel engine. When these thick vegetable oils are heated and used in LHR engines the brake thermal efficiency improves. For every vegetable oil, there is an optimum temperature at which it gives the best performance. Karanja oil operates at the maximum brake thermal efficiency (5% higher than the standard engine with karanja oil operation) at 110 °C fuel temperature, Rice bran oil and neem oil gives peak performance at 80 °C. For rice bran oil the improvement in brake thermal efficiency over the standard engine is 4% and standard diesel engine is 3%.

Naik et al. [21] gives the idea about the production of biodiesel from high free fatty acid. Sometimes the oil is contaminated with high free fatty acids (FFAs) depending upon the moisture content in the seed during collection as well as oil expression. The study deals with production of biodiesel from high FFA Karanja oil because the conventional alkali-catalyzed route is not the feasible route. They gives the mechanism of a dual process adopted for the production of biodiesel from Karanja oil containing FFA up to 20%. The first step is acid-catalyzed esterification by using 0.5% H_2SO_4, alcohol 6:1 molar ratio with respect to the high FFA Karanja oil to produce methyl ester by lowering the acid value, and the next step is alkali-catalyzed transesterification. The yield of biodiesel from high FFA Karanja oil by dual step process has been observed to be 96.6–97%.

Dhar et al. [22] had experimental study on performance, emission and combustion characteristics of Karanja oil blends (K10, K20, K50 and K100) with petroleum diesel were investigated in unheated conditions in a direct injection CI engine at different engine loads and constant engine speed (1500 rpm) and compare with baseline data from petroleum diesel. Analysis of performance parameters such as brake specific fuel consumption (BSFC), thermal efficiency, and exhaust gas temperature, mass emissions of various gaseous pollutant species, combustion parameters such as in-cylinder pressure rise, instantaneous heat release and cumulative heat release etc. were carried out. Detailed combustion analysis revealed that the combustion duration increased significantly even with smaller concentration of Karanja oil in the fuel blend. HC, CO and Smoke emissions were found to decrease for 20-50% (v/v) Karanja oil content in the fuel blends. Fuel consumption and thermal efficiency are relatively inferior for all Karanja oil blends compared to petroleum diesel. HC emissions were lower for Karanja oil blends than mineral diesel for the whole engine operating range across all blend concentrations. CO and NO emissions were slightly higher for higher Karanja oil blends. Smoke opacity was lower for lower Karanja oil blends compared to petroleum diesel. Combustion characteristics showed smaller ignition delay and slower combustion leading to longer combustion duration for Karanja oil blends. Karanja oil's higher concentration blends are not suitable as alternate fuels in unmodified diesel engines. Injection timing optimization with unheated blends and pre heating the Karanja oil may be potentially techno economically feasible methods to use Karanja oil in diesel engines. However, lower concentration blends (upto B20) can be readily used as alternate fuels to augment mineral diesel supplies.

Raeissi et al. [23] investigates the pre-treatment step of biodiesel production from high free fatty acid vegetable oils. Oil with high free fatty acid content is selected and the main parameters in the biodiesel production reaction are investigated in this experiment. The effects of methanol-to-oil ratio (in the range of 0.2 to 1.2 v/v), the amount of catalyst (in the range of 0.5 to 6% v/v) and time (in the range of 20 to 120 min) on the progress of the reaction are studied. Results showed that regardless of the initial amounts of methanol, increasing the catalyst will not affect conversion in ranges higher than 2% v/v catalyst. Variations in methanol-to-oil ratio also could not bring conversion to one hundred percent, because the reaction is reversible. Monitoring the progress of the reaction with time also confirms the fact that equilibrium acts as the main inhibitor in completion of the esterification reaction. Finally, since even small amounts of FFA in the oil is of great importance for the operations that follow, water removal techniques during reaction, can be used to reduce the high FFA to the lowest possible values.

Lotero et al. [24] gives reviews on some of the research related to biodiesel production using acid catalysts, including solid acids. Basically, alkaline bases are used to catalyze the reaction. These catalysts require anhydrous conditions and feedstocks with low levels of free fatty acids (FFAs). Inexpensive feedstocks containing high levels of FFAs cannot be directly used with the base catalysts currently employed. Strong liquid acid catalysts are less sensitive to FFAs and can simultaneously conduct esterification and transesterification. However, they are slower and necessitate higher reaction temperatures. Nonetheless, acid-catalyzed processes could produce biodiesel from low-cost feedstocks, lowering production costs. Better yet, if solid acid catalysts could replace liquid acids, the corrosion and environmental problems associated with them could be avoided and product purification protocols reduced, significantly simplifying biodiesel production and reducing cost.

Nandagopal et al. [25] they report the production of a biodiesel fuel by acid-catalyzed esterification of high free fatty acid (FFA) karanja oil (KO). Pre-treated KO was converted to biodiesel by a process of alkaline catalyzed transesterification. Optimum acid-catalyzed esterification was achieved using 1% Sulfated Zirconia (SZ) as a solid acid catalyst with a methanol-to-oil ratio of 9:1, temperature at 60 ^{0}C and reaction time of 2 hrs. During this process, FFA was converted into fatty acid methyl esters. The acid value of karanja oil was reduced to 1.3 mg KOH/g from 12.27 mg KOH/g, which confirmed the conversion. Consequently, this pre-treatment reduces the overall complexity of the process and reduces the cost of producing biodiesel fuel. SZ has been found to be a promising strong solid acid catalyst for the esterification of KO with methanol and showed high catalytic activity, significantly reducing the FFA value. The results prove that this catalyst is an attractive and less expensive alternate to treat oils with high amount of free fatty acids. SZ appears as a possible alternative catalyst for esterification of FFA, particularly in non-edible oils leading to higher final conversions.

Gerpen et al. [26] described a technique to reduce the free fatty acids content of the feedstocks using an acid–catalyzed pre-treatment to esterify the free fatty acids before transesterifying the triglycerides with an alkaline catalyst to complete the reaction. Initial process development was performed with synthetic mixtures containing 20% and 40% free fatty acids, prepared using palmitic acid. Process parameters such as the molar ratio of alcohol, type of alcohol, acid catalyst amount, reaction time, and free fatty acids level were investigated to determine the best strategy for converting the free fatty acids to usable esters. They showed that the acid level of the high free fatty acids feedstocks could be reduced to less than 1% with a two step pre-treatment reaction. The reaction mixture was allowed to settle between steps so that the water–containing alcohol phase could be removed. The two step pre-treatment reaction was demonstrated with actual feedstocks, including yellow grease with 12% free fatty acids and brown grease with 33% free fatty acids. After reducing the acid levels of these feedstocks to less than 1%, the transesterification reaction was completed with an alkaline catalyst to produce fuel grade biodiesel.

Singh et al. [27] did experimental investigation to evaluate the performance, emission and combustion characteristics of a diesel engine using different blends of methyl ester of karanja with mineral diesel. Karanja methyl ester was blended with diesel in proportions of B5, B10, B15, B20, B30, B40, B50 and B100 by mass and studied under various load conditions in a compression ignition (CI) engine. The performance parameters were found to be very close to that of mineral diesel. The brake thermal efficiency and mechanical efficiency were better than mineral diesel for some specific blending ratios under certain load. Karanja methyl ester seems to have a potential to use as alternative fuel in diesel engines. Blending with diesel decreases the viscosity considerably. The brake thermal efficiency of the engine with karanja methyl ester-diesel blend was marginally better than with neat diesel fuel. Brake specific energy consumption is lower for karanja methyl ester-diesel blends than diesel at all loading. The exhaust gas temperature is found to increase with concentration of karanja methyl ester in the fuel blend due to coarse fuel spray formation and delayed combustion. The mechanical efficiency achieved with KME30 is higher than diesel at lower loading conditions. At higher loads, the mechanical efficiency of certain blends is almost equal to that of diesel.

Nagarhalli et al. [28] in this investigation an attempt has been made to use blends of two biodiesel oils to run a single cylinder, 4 stroke, constant speed, D.I. diesel engine. Blends of transesterified jatropha and karanja have been used in different proportions (10% to 90%) and neat biodiesel were tested for performance, brake thermal efficiency, brake specific energy consumption (BSEC) and their emissions CO, HC, NOx. at an injection pressure of 200 bar and 210 bar. The results are compared with that of neat diesel. For K20-J80 blend the brake thermal efficiency was higher than diesel at all injection pressures used i.e. 200 bar and 210 bar. Carbon monoxide (CO) emissions were minimum for K20-J80 blend at 200 bar (0.06-0.08%) and 220 bar (0.05-0.07%) compared to diesel operation. At 210 bar CO emissions of K20-J80 blend were higher than diesel at all loads. Hydrocarbon (HC) emissions for

K20-J80 blend (22-37 ppm) at 200 bar were lower than diesel (32- 40 ppm) at 210 bar. Oxides of nitrogen (NO_x) were higher for K20-J80 at all injection pressures as shown below. Hence K20-J80 blend and injection pressure of 200 bar and 210 bar gives better performance and emissions (except NO_x). It is recommended to use this blend in the engine so that diesel import can be reduced. Hence, blends of jatropha and karanja can be used in existing diesel engines without any engine modifications.

Patil et al. [29] in this work, Karanja (Pongamia pinnata) biodiesel important physical & chemical properties were tested & compared with the petroleum diesel. It is found that these properties are approximately similar to diesel fuel and suitable to use in diesel engine. Petroleum diesel was used before and after the biodiesels for verifying the engine condition due to biodiesels. The biodiesel from Karanja oil is used in a Mahindra & Mahindra Turbo Charged make four stroke, four cylinders, and water cooled diesel engine in pure and blended form without any modification in engine design or fuel system. The performance characteristics of an engine are studied with different proportions of biodiesel and petroleum diesel .The power, torque, and brake thermal efficiency using biodiesel are found higher at various load conditions than the petro-diesel; however specific fuel consumption is found slightly more. The biodiesel blend B30 have shown better performance than the diesel and other blends. It was observed that the biodiesel has good lubricity when used in diesel engines. The biodiesel with B20, B30 and B40 blends were used in the conventional diesel engine without any modification in engine design or fuel system the biodiesel performance evaluation was done. No other trouble was found during entire running period of the engine. It was observed that the Brake power (B.P), Brake thermal efficiency, Mechanical efficiency, and time for fuel consumption is higher at constant speed and also at variable speed and load condition for 20% and 40% biodiesel blends with diesel fuel.

Mallikarjun et al. [30] in this work the results of investigations carried out in studying the fuel properties of karanja methyl ester (KME) and its blend with diesel fuel from 20 to 100% by volume and in running a diesel engine with these fuels. Engine tests had been carried out with the aim of obtaining comparative measures of Brake power, specific fuel consumption and emissions such as CO2, CO, HC, smoke density and NO_x to evaluate and compute the behaviour of the diesel engine running on above mentioned fuels. The reduction in exhaust emissions together with increase in brake power, brake thermal efficiency and reduction in specific fuel consumption make the blends of karanja esterified oil (B20) a suitable alternative fuel for diesel and could help in controlling air pollution. At 20% blending trial particularly at full load and half load conditions the specific fuel consumption and indicated thermal efficiency are very closer to the values obtained without blending. So at some considerable conditions KME blends can be the good substitute of petroleum diesel. From the experiments conducted, it is concluded that biodiesel and its blends as a fuel for diesel engine have better emission characteristics compared with diesel. More over its impact on environment is very poor when compared with diesel. The NOx, HC, CO and Smoke density emissions are less compared with diesel. Thus KME biodiesel may be the promising fuel for the future.

Velraj et al. [31] in this work they investigates the preparation of pongamia pinnata methyl ester (PPME) i.e. biodiesel from raw pongamia oil through transesterification process, estimation of the properties of the blends of diesel and PPME in varying proportions from 20%, 40%, 60%, 80% and 100% (B20, B40, B60, B80 and B100), performance and exhaust emission analysis in a 3.68 kW Compression Ignition (C. I.) engine. In the experimental investigation, it was found that 40% substitution of biodiesel with petro diesel resulted in reduced emissions and improved efficiency without loss in the engine power. This would go a long way in solving the basic problems of energy crisis and environmental pollution leading to sustainable development. Biodiesel with higher flash point, biodegradability and nontoxic nature are safe to handle, store and create lesser problems in case of accidental release or spillage and hence superior to diesel oil. Based on the above experimental investigations, it was found that blends of PPME and diesel could be successfully used in diesel engines without any modification, with acceptable performance and better emissions. Based on the engine performance, the blends B20 and B40 are comparable and better in some aspects than that of fossil diesel, and from emission point of view, blends B40 and B60 are superior to diesel. Hence it is concluded that the biodiesel up to 40% (B40) could replace the diesel in diesel engine applications of transport sector, remote rural electrification for getting the expected power output with less emissions leading to energy economy and environmental protection. It is clearly evident that biodiesel with several desirable characteristics would allow modern diesel engines to use biodiesel without engine modifications and without any reduction in the engine performance. Much attention should be focused on the use of biodiesel to replace fossil fuel in order to prevent environmental degradation due to fossil combustion. In the near future conventional fuels would be fully replaced by biodiesel and would provide a viable solution for the much threatening energy crisis and environmental pollution problems.

3.0 Process of Bio-Diesel Production & its Properties

3.1 Vegetable Oils as Engine Fuels

Dr. Rudolf Diesel invented the diesel engine to run on a host of fuels including coal dust suspended in water, heavy mineral oil, and, vegetable oils. Dr. Diesel's first engine experiments were catastrophic failures, but by the time he showed his engine at the World Exhibition in Paris in 1900, his engine was running on 100% peanut oil. Dr. Diesel was visionary. In 1911 he stated ''the diesel engine can be fed with vegetable oils and would help considerably in the development of agriculture of the countries, which use it''. In 1912, Diesel said, ''the use of vegetable oils for engine fuels may seem insignificant today. But such oils may become in course of time as important as petroleum and the coal tar products of the present time''. Since Dr. Diesel's untimely death in 1913, his engine has been modified to run on the polluting petroleum fuel, now known as ''diesel''. Nevertheless, his ideas on agriculture and his invention provided the foundation for a society fuelled with clean, renewable, locally grown fuel **[32]**.

Dr. Rudolf Diesel

In the 1930s and 1940s, vegetable oils were used as diesel substitutes from time to time, but usually only in emergency situations. Recently, because of increase in crude oil prices, limited resources of fossil oil and environmental concerns, there has been a renewed focus on vegetable oils and animal fats to make biodiesel.

Continued and increasing use of petroleum will intensify local air pollution and magnify the global warming problems caused by carbon dioxide. In a particular case, such as the emission of pollutants in the closed environment of underground mines, biodiesel has the potential to reduce the level of pollutants and the level of potential for probable carcinogens **[33]**.

The advantages of using vegetable oils as fuels are:

- Vegetable oils are liquid fuels from renewable sources.
- They do not over-burden the environment with emissions.
- Vegetable oils have potential for making marginal land productive by their property of nitrogen fixation in the soil.
- Vegetable oil's production requires lesser energy input in production.
- Vegetable oils have higher energy content than other energy crops like alcohol. Vegetable oils have 90% of the heat content of diesel and they have a favourable output/input ratio of about 2–4:1 for un-irrigated crop production.
- The current prices of vegetable oils in world are nearly competitive with petroleum fuel price.
- Vegetable oil combustion has cleaner emission spectra.
- Simpler processing technology.

But

- these are not economically feasible yet and
- Need further R&D work for development of on farm processing technology.

Due to the rapid decline in crude oil reserves, the use of vegetable oils as diesel fuels is again promoted in many countries. Depending upon climate and soil conditions, different nations are looking into different vegetable oils for diesel fuels. For example, soybean oil in the USA, rapeseed and sunflower oils in Europe, palm oil in Southeast Asia (mainly Malaysia and Indonesia), and coconut oil in Philippines are being considered as substitutes for mineral diesel.

An acceptable alternative fuel for engine has to fulfil the environmental and energy security needs without sacrificing operating performance. Vegetable oils can be successfully used in CI engine through engine modifications and fuel modifications. Engine modifications include dual fueling, injection system modification, heated fuel lines etc. Fuel modifications include blending of vegetable oils with diesel, transesterification, cracking/pyrolysis, micro-emulsion, and hydrogenation to reduce polymerization and viscosity **[34]**.

From amongst the large number of vegetable oils available in the world, if any specific oil needs to be adopted as a continuing energy crop, it is then essential that an oilseed variety having higher productivity and oil content must be produced. Nevertheless, technologies must be developed for the use of vegetable oils as an alternative diesel fuel that will permit crop production to proceed in an emergency situation. Vegetable oil in its raw form cannot be used in engines. It has to be converted to a more engine-friendly fuel called biodiesel. System design approach has taken care to see that these modified fuels can be utilized in the existing diesel engine without substantial hardware modification. It will be expensive and time-consuming to incorporate even a minor design alteration in the system hardware of a large number of existing engines operating in the rural agricultural sector of any country.

In its simplest form, the carbon cycle of vegetable oil consists of the fixation of carbon and the release of oxygen by plants through the process of photosynthesis and then combining of oxygen and carbon to form CO2 through processes of combustion. It is appropriate to mention here that the CO2 released by petroleum diesel was fixed from the atmosphere during the formative years of the earth, whereas the CO2 released by biodiesel gets continuously fixed by plants and may be recycled by the next generation of crops. The carbon cycle time for fixation of CO2 and its release after combustion of biodiesel is quite small as compared (few years) to the cycle time of petroleum based fuels (few million years). It is well known that petroleum refiners are now facing new sulphur and aromatic compound specifications. Since biodiesel is a fuel made up of esters derived from oils and fats from renewable biological sources, it has been reported to emit substantially lower quantities of most of the regulated pollutants compared to mineral diesel **[35]**. Biodiesel has comparable energy density, cetane number, heat of vaporization, and stoichiometric air/fuel ratio with mineral diesel. The large molecular size of the component triglycerides result in the oil having higher viscosity compared with that of mineral diesel. Viscosity affects the handling of the fuels by pump and injector system, and the shape of fuel spray. The high jet penetration and poor atomization results in larger droplets. The fuel Jet tends to be a solid stream instead of spray of small droplets hence the fuel does not get mixed with air required for burning. Larger droplets have poor combustion leading to loss of engine power and fuel economy. In small engines, the fuel spray may even impinge upon the cylinder walls, washing away the lubricating oil film and causing the dilution of crank case oil leading to excessive wear of moving parts.

3.2 Utilization of Vegetable Oil as Engine Fuel

Neat vegetable oils are not suitable as fuel for diesel engines; hence they have to be modified to bring their combustion-related properties closer to those of mineral diesel. This fuel modification is mainly aimed at reducing the viscosity to get rid of flow and combustion-related problems. Considerable efforts have been made to develop vegetable oil derivatives that approximate the properties and performance of HC-based fuels. Vegetable oils can be used through at least four ways:

- Direct use and blending.
- Micro-emulsion.
- Pyrolysis (thermal cracking).
- Transesterification.

3.2.1 Direct Use and Blending

Caterpillar (Brazil) in 1980 used pre-combustion chamber engines with a mixture of 10% vegetable oil to maintain total power without any alterations or adjustments to the engine. At that point, it was not practical to substitute 100% vegetable oil for diesel fuel, but a blend of 20% vegetable oil and 80% mineral diesel was successful. Some short-term experiments used up to a 50/50 ratio **[36]**. Pramanik et al. **[39]** found that 50% blend of Jatropha oil can be used in diesel engine without any major operational difficulties but further study is required for the long-term durability of the engine.

Direct use of vegetable oils and/or the use of blends of the oils have generally been considered to be not satisfactory and impractical for both direct and indirect diesel engines. The high viscosity, acid composition, free fatty acid content, as well as gum formation due to oxidation, polymerization during storage and combustion, carbon deposits and lubricating oil thickening are obvious problems. The probable reasons for the problems and the potential solutions are shown in **[37]**.

3.2.2 Micro-Emulsions

To solve the problem of the high viscosity of vegetable oils, micro-emulsions with solvents such as methanol, ethanol and 1-butanol have been investigated. A micro-emulsion is defined as a colloidal equilibrium dispersion of optically isotropic fluid microstructures with dimension generally in the 1–150 nm range, formed spontaneously from two normally immiscible liquids. They can improve spray characteristics by explosive vaporization of the low boiling constituents in the micelles. Shortterm performance of micro-emulsions of aqueous ethanol in soybean oil was nearly as good as that of no. 2 diesel, in spite of the lower cetane number and energy content **[38]**.

3.2.3. Pyrolysis (Thermal Cracking)

Pyrolysis is the conversion of one substance into another by means of heat or by heat in presence of a catalyst. The paralyzed material can be vegetable oils, animal fats, natural fatty acids or methyl esters of fatty acids. The pyrolysis of fats has been investigated for more than 100 years, especially in those areas of the world that lack deposits of petroleum. Many investigators have studied the pyrolysis of triglycerides to obtain products suitable for diesel engine. Thermal decomposition of triglycerides produces alkanes, alkenes, alkadines, aromatics and carboxylic acids **[36]**.

3.3 Chemistry of Transesterification Process

The overall transesterification reaction is given by Eq. (1). However, three consecutive and reversible reactions are believed to occur. These reactions are represented in Eq. (2). The process flow chart for bio-diesel production from pungamia oil is shown in Fig. 2.

$$\text{Triglycerides} + \text{ROH} \rightleftharpoons \text{Diglycerides} + R^{1}COOR$$

$$\text{Diglycerides} + \text{ROH} \rightleftharpoons \text{Monoglycerides} + R^{2}COOR$$

$$\text{Monoglycerides} + \text{ROH} \rightleftharpoons \text{Glycerol} + R^{3}COOR$$

Equation. 1

The first step in the conversion is triglycerides to diglycerides followed by the conversion of diglycerides to monoglycerides and of monoglycerides to glycerol yielding one methyl ester molecule from each glycerides at each step.

Table 4: Chemical structure of common fatty acids

Name of fatty acid	Chemical name of fatty acids	Structure (xx:y)	Formula
Lauric	Dodecanoic	12:0	C12H24O2
Myristic	Tetradecanoic	14:0	C14H28O2
Palmitic	Hexadecanoic	16:0	C16H32O2
Stearic	Octadecanoic	18:0	C18H36O2
Arachidic	Eicosanoic	20:0	C20H40O2
Behenic	Docosanoic	22:0	C22H44O2
Lignoceric	Tetracosanoic	24:0	C24H48O2
Oleic	cis-9-Octadecenoic	18:1	C18H34O2
Linoleic	cis-9,cis-12-Octadecadienoic	18:2	C18H32O2
Linolenic	cis-9,cis-l2,cis-15-Octadecatrienoic	18:3	C18H30O2
Erucle	cis-13-Docosenoic	22:1	C32H42O2

xx:y indicates xx carbons in the fatty acid chain with y double bonds.

Fatty acids vary in carbon chain length and in the number of unsaturated bonds (double bonds). The structures of common fatty acids are given in Table 4.

3.4 Transesterification Reaction

Biodiesel is mono alkyl esters of long chain fatty acids derived from vegetable oils or animal fats. It is produced through a chemically reversible reaction called transesterification or alcoholysis, which has been widely used to reduce the high viscosity of triglyceride **[39]**. A variety of oils both edible and non-edible oils can be used to produce biodiesel but most are derived from edible oils, such as sunflower, soybean, and palm oils. Since the prices of edible vegetable oils are high, the less expensive raw materials containing FFAs, such as non-edible crude oils, waste food oils, animal fats, and by-products of the refining vegetable oils, are preferred. However, the FFA content in the oil has significant effect on the transesterification of glyceride with alcohol using an alkaline catalyst. These FFAs react with the alkaline catalyst to produce soaps, which inhibit the separation of the product from glycerine and wash water. In addition, soap increases the viscosity of the reactants and results in the lower yield of methyl ester. From this reason, the oil should not contain more than 1% FFA for alkalicatalyzed transesterification reaction. Thus, the one-step process involves an alkali-catalyzed transesterification is insufficient for high FFA feedstock **[40]**. An alternative way of processing the high FFA oil is to use an acid-catalyzed transesterification but it requires a much longer time than alkali-catalyzed transesterification. Therefore, alternative processes were investigated by several researchers to use the various oils and fats with high FFA as feedstock to produce biodiesel.

Transesterification **[41]** also called alcoholysis is the displacement of alcohol from an ester by another alcohol in a process similar to hydrolysis except that an alcohol is used instead of water. This has been widely used to reduce the viscosity of the triglycerides. The transesterification is represented as:

$$\underset{\text{Ester}}{RCOOR'} + \underset{\text{Alcohol}}{R''OH} \rightleftharpoons \underset{\text{Ester}}{R'COOR''} + \underset{\text{Alcohol}}{ROH}$$

Equation. 2

If methanol is used in this process then it is called methanolysis. Methanolysis of triglycerides represented in Eq. (3).

$$\begin{array}{lllll} CH_2\text{-}COOR^1 & & & CH_2OH & R^1COOCH_3 \\ | & & & | & + \\ CH\text{-}COOR^2 & +3CH_3OH & \rightleftharpoons & CH\ OH & +\ R^2COOCH_3 \\ | & & & | & + \\ CH_2\text{-}COOR^3 & & & CH_2OH & R^3COOCH_3 \\ \text{Vegetable oil} & \text{Alcohol} & & \text{Glycerol} & \text{Methyl-ester} \end{array}$$

Equation. 3

Transesterification is one of the reversible reactions and proceeds essentially by mixing the reactants. However, the presence of a catalyst (a strong acid or base) accelerates the conversion.

3.5 Biodiesel Production

Preliminary experiments were conducted on the production of biodiesel from the karanja oil using the one-step alkaline-catalysed transesterification process. It was found that the ester's yield was low and separation of esters was problematic due to the high acid values. Therefore, a two-step process was performed. The first step was an acid-catalysed pre-treatment to esterify the FFA and therefore reduce the acid value before the second step wherein the triglycerides were transesterified with an alkaline catalyst.

3.5.1 Acid-Catalyzed Pre-Treatment

The acid-catalyzed esterification reaction was conducted in a laboratory-scale experiment. The mixture in the reaction flask was heated and stirred at the same speed for all test runs. The karanja oil feedstock, methanol, and concentrated sulphuric acid were used in amounts established for each experiment. A known amount of karanja oil feedstock was poured into the reaction flask and heated to the desired temperature.

The methanol was added to the preheated karanja oil and stirred for a few minutes. Required amount of concentrated sulphuric acid was then added to the mixture and the measurement of time was started at this point. Heating and stirring were continued for different reaction times at the atmospheric pressure. After the reaction, the mixture was allowed to settle for 2 hrs in the separatory funnel and the methanol‑water fraction at the top layer was removed. The lower layer consisted of karanja oil having lower content of FFA and impurities were purified by washing gently with hot distilled water at 60 ^{0}C until the washing water had a pH value that was similar to that of distilled water.

The karanja oil layer was then dried under reduced pressure at 70 ^{0}C by rotary evaporator. Finally, the acid value of the oil product was determined by using standard test method. In this section, the effect of process parameters such as methanol- to-oil ratio, catalyst concentration, reaction temperature, and reaction time was studied. The optimum of each parameter was determined by considering the FFA content while the other parameters remained constant. After each parameter's optimum value was attained, this value was kept to be constant during the optimization of the next parameter was determined. The product having FFA content less than 1% by using the lowest amounts of methanol and acid catalyst and the lowest reaction temperature in the minimum reaction time was used as the starting material for the second step, alkali-catalyzed transesterification.

3.5.2 Alkali-Catalyzed Transesterification

The alkali-catalyzed transesterification reaction was carried out by using the same experiment setup of acid-catalyzed pre-treatment step. The oil product from the pre-treatment step was preheated to the desired temperature in the reaction flask. The solution of potassium hydroxide in methanol was prepared freshly in order to avoid the moisture absorbance and maintain the catalytic activity **[42]**. The methanolic solution was then added to the heated oil in the reaction flask. The measurement of time was started at this point. Heating and stirring were continued for different reaction times at atmospheric pressure. After the reaction, the mixture was allowed to separate into two layers by settling overnight in the separatory funnel. The upper layer consisted of methyl esters, whereas the lower layer contained a mixture of glycerol and impurities. The methyl ester layer was purified by washing gently with hot distilled water at 60 ^{0}C until the washing water had a pH value that was similar to that of distilled water. The methyl ester layer was then dried under reduced pressure at 70 ^{0}C by rotary evaporator.

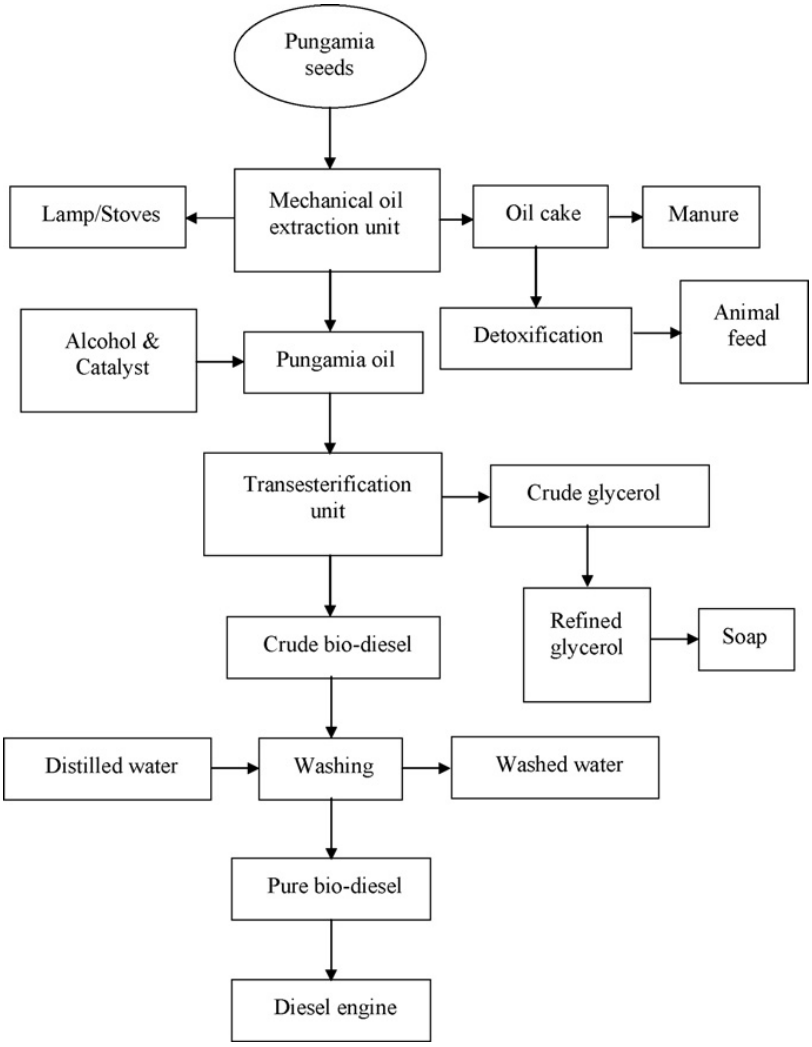


Fig.2. General Process flow chart of bio-diesel production.

The methyl ester content in the product was determined by GC. In this section, the parameters, such as methanol-to-oil ratio, catalyst concentration, reaction temperature, and reaction time, were studied for their effect on alkali-catalyzed transesterification. After each optimum was attained, this value was kept constant during the optimum of next parameter was determined. The condition provided methyl ester content within the acceptable level of Biodiesel (B100) specification (min 96.5% w) by using the lowest amounts of methanol and alkaline catalyst at the lowest reaction temperature in the minimum reaction time was considered to be the optimum condition for this step. Finally, the karanja biodiesel properties were determined by using standard test methods. After completion of the reaction the product is kept for a certain time interval for separation (approx. 12 h) of bio-diesel & glycerol layer as shown in Fig. 3. The mixture of KOH and methanol settles at the bottom of the funnel because of higher density compare with bio-diesel. Whereas small amount of catalyst, methanol & glycerol are in the upper bio-diesel layer. The upper layer is collected for further purification by washing.

3.5.3 Separation

Once the reaction is complete, two major products are obtained: glycerine and biodiesel. Each has a substantial amount of the excess alcohol that was used in the reaction. The reacted mixture is sometimes neutralized at this step if needed. The glycerine is much denser than biodiesel and the two can be gravity separated with glycerine simply drawn off the bottom of the settling vessel. In some cases, a centrifuge is used to separate the two materials faster.

3.5.4 Alcohol Removal

Once the glycerine and biodiesel phases have been separated, the excess alcohol in each phase is removed with a flash evaporation process or by distillation. In others systems, the alcohol is removed and the mixture neutralized before the glycerine and esters have been separated. In either case, the alcohol is recovered using distillation equipment and is re-used. Care must be taken to ensure no water accumulates in the recovered alcohol stream.

3.5.5 Glycerine Neutralization

The glycerine by-product contains unused catalyst and soaps that are neutralized with an acid and sent to storage as crude glycerine. In some cases the salt formed during this phase is recovered for use as fertilizer. In most cases the salt is left in the glycerine. Water and alcohol are removed to produce 80-88% pure glycerine that is ready to be sold as crude glycerine. In more sophisticated operations, the glycerine is distilled to 99% or higher purity and sold into the cosmetic and pharmaceutical markets.

3.5.6 Methyl Ester Wash

Once separated from the glycerine, the biodiesel is sometimes purified by washing gently with warm water to remove residual catalyst or soaps, dried, and sent to storage. In some processes this step is unnecessary. This is normally the end of the production process resulting in a clear amber-yellow liquid with a viscosity similar to mineral diesel. In some systems the biodiesel is distilled in an additional step to remove small amounts of colour bodies to produce a colourless biodiesel.

3.5.7 Product Quality

Prior to use as a commercial fuel, the finished biodiesel must be analyzed using sophisticated analytical equipment to ensure it meets any required specifications. The most important aspects of biodiesel production to ensure trouble free operation in diesel engines are:

- Complete Reaction
- Removal of Glycerine
- Removal of Catalyst
- Removal of Alcohol
- Absence of Free Fatty Acids

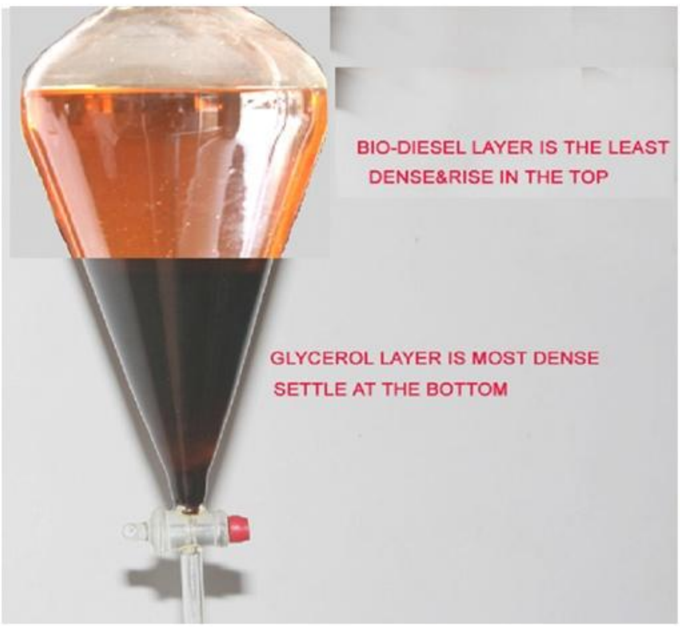


Fig.3. Separation of glycerol from bio-diesel

Fig.4. Pure bio-diesel at top layer & clear water at bottom layer.

Fig.5. Finally Processed Bio-Diesel.

3.6 Karanja Oil and Its Properties

Karanja (Pongamia Pinnata) is one of the forest-based tree-borne non-edible oil with a production potential of 135,000 metric tons per year in India. It is one of the few nitrogen fixing trees (NFTs), which produce seeds containing 30–40% oil. The Karanja tree is cultivated for two purposes: (1) as an ornamental tree in gardens and along avenues and roadsides, for its fragrant Wisteria-like flowers and (2) as a host plant for lace insects. This species is commonly called pongam, Karanja, Pongamia, or a derivation of these names.

Karanja is a medium sized fast-growing evergreen tree, which reaches 40 feet in height and spread, forming a broad, spreading canopy casting moderate shade **[43]**. Flowers are pink, light purple, or white. Pods are elliptical, 3– 6 cm long and 2–3 cm wide, thick walled, and usually contains a single seed (Fig. 5). Seeds are 10–20 mm long, fig oblong and light brown in color. Native to humid and subtropical environments, Karanja thrives in areas having an annual rainfall ranging from 500 to 2500 mm. In its natural habitat, the maximum temperature ranges of maximum from 27 to 38 ^{0}C and minimum 1–16 ^{0}C. Mature trees can withstand water logging and slight frost. This species grows up to elevations of 1200 m. It can grow on most soil types ranging from stony to sandy to clayey, including Verticals. It does not do well on dry sands. It is highly tolerant of salinity. It is commonly found along waterways or seashores, with its roots in fresh or salt water. Highest growth rates are observed on well-drained soils with assured moisture.

Air-dried Karanja kernels have typically 19.0% moisture, 27.5% fatty oil, 17.4% protein, 6.6% starch, 7.3% crude fiber, and 2.4% ash. Fatty acid composition and structure of Karanja oil is given in Table 5. A single tree is said to yield 9–90 kg seed per year, indicating a yield potential of 900–9000 kg seed/ha. A thick yellow–orange to brown, bitter, non-drying, non-edible oil is extracted from seeds. Yields of 25% (v/v) are possible using a mechanical expeller. It is typically used for tanning leather, soap, and as illuminating oil. The oil has a high content of triglycerides, and its disagreeable taste and odor are due to bitter falconoid constituents such as pongamiin and karanja. The oil is also used as a lubricant, water-paint binder, and pesticide. The oil has also been tried as fuel in diesel engines, showing a good thermal efficiency **[44]**.

Fig.6. Karanja seed **[45]**.

Table 5: The Fatty acid composition of Karajan oil

Fatty acid name	Molecular formula	Composition (%)
Palmitic acid	$C_{16}H_{32}O_6$	11.65
Stearic acid	$C_{18}H_{36}O_2$	7.50
Tetracosonaic acid	$C_{24}H_{48}O_2$	1.09
Dosocasnoic acid	$C_{22}H_{44}O_2$	4.45
Oleic acid	$C_{18}H_{34}O_2$	51.59
Linoleic acid	$C_{18}H_{32}O_2$	16.64

Fig.7. Bunch of Karanja seeds

Fig.8. Tree of Karanga seed

Graphs and discussion of the biodiesel production are given in Appendix I.

4.0 EXPERIMENTAL SET-UP

4.1 Kirloskar Engine

Fig.9. Kirloskar Engine Test Bench

Table 6: Specifications of Test Engine.

General details	4-Stroke, water cooled, CI engine
Rated power	3 .7 kW
Speed	1500 rpm (constant)
Number of cylinder	Single cylinder
Compression ratio	18:1
Bore	80mm
Stroke	110 mm

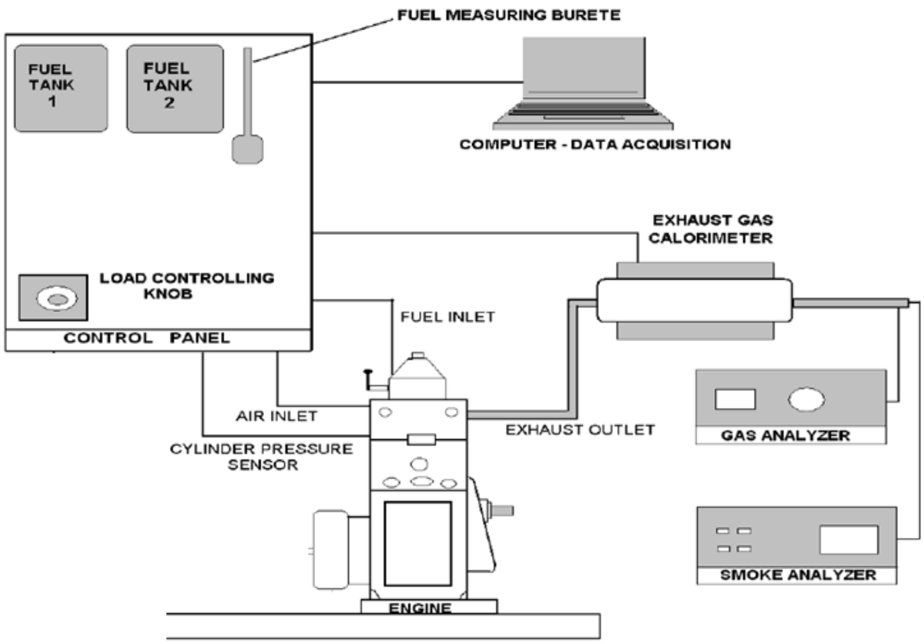


Fig .10. Schematic of Test Set-up

A four stroke, direct injected, water-cooled, single cylinder, naturally aspirated diesel engine was used for investigation. Details of the engine specifications are given in table.

At the first stage tests were performed at different engine loads. The experiments were conducted at five load levels viz. 0.5kW, 1.0kW, 1.5kW, 2.0kW, 2.5kW, 3.0kW and 3.5kW load. The engine is coupled to an eddy current dynamometer through which load is applied by increasing the field voltage. The required engine load percentage was adjusted by using the eddy current dynamometer. A fixed 23° BTDC injection timing and 18.0 compression ratio were used throughout the experiments. In all tests the engine was allowed to warm up for 15min to reach equilibrium. This was determined by monitoring the exhaust and coolant temperatures. All the parameters of engine were recorded and calculated by computer system which is directly connected to software.

Since it was decided to determine the effect of substituting cotton seed oil for diesel fuel while keeping the total fuel energy constant, as obtained from diesel fuel at full rack setting it was first necessary to determine the total fuel energy supplied for each condition within the test matrix used. This was done by running the engine at each test condition on the baseline fuel.

The blends of pre-heated cotton seed oil and diesel was prepared and observed that the blends were stable over a period of time. Engine first tested with diesel fuel then with the blends with diesel- pre-heated cotton seed oil. Cooling water temperature was maintained constant as 60°C throughout the experiment. Fuels used were diesel, cottonseed oil and blends of cottonseed oil-diesel pre heated to 70°C.

Table 7: Test Fuel Nomenclature

Fuel	Diesel	Pre-heated Cotton Seed Oil
Diesel	1 Kg	00 mg
B-10	900mg	100mg
B-20	800mg	200mg
B-30	700mg	300mg

Kirloskar Engine (Technical specifications)

- Model TV1
- Make Kirloskar Oil Engines Ltd.
- Type Four stroke, Water
- cooled, Diesel
- No. of cylinder One
- Bore 87.5 mm
- Stroke 110 mm
- Combustion principle Compression ignition
- Cubic capacity 0.661 litres
- Compression ratio 3 port 17.5:1
- Peak pressure 77.5 kg/cm2
- Direction of rotation Clockwise (Looking from
- flywheel end side)
- Max. speed 2000 rpm

- Min. idle speed 750 rpm
- Min. operating speed 1200 rpm
- Fuel timing for std. engine 230 BTDC
- Valve timing
- Inlet opens BTDC 4.50
- Inlet closes ABDC 35.50

4.1.1 Description

The setup consists of single cylinder, four stroke, VCR (Variable Compression Ratio) Diesel engine connected to eddy current type dynamometer for loading. The compression ratio can be changed without stopping the engine and without altering the combustion chamber geometry by specially designed ***tilting cylinder block*** arrangement. Setup is provided with necessary instruments for combustion pressure and crank-angle measurements. These signals are interfaced to computer through engine indicator for P θ −PV diagrams.

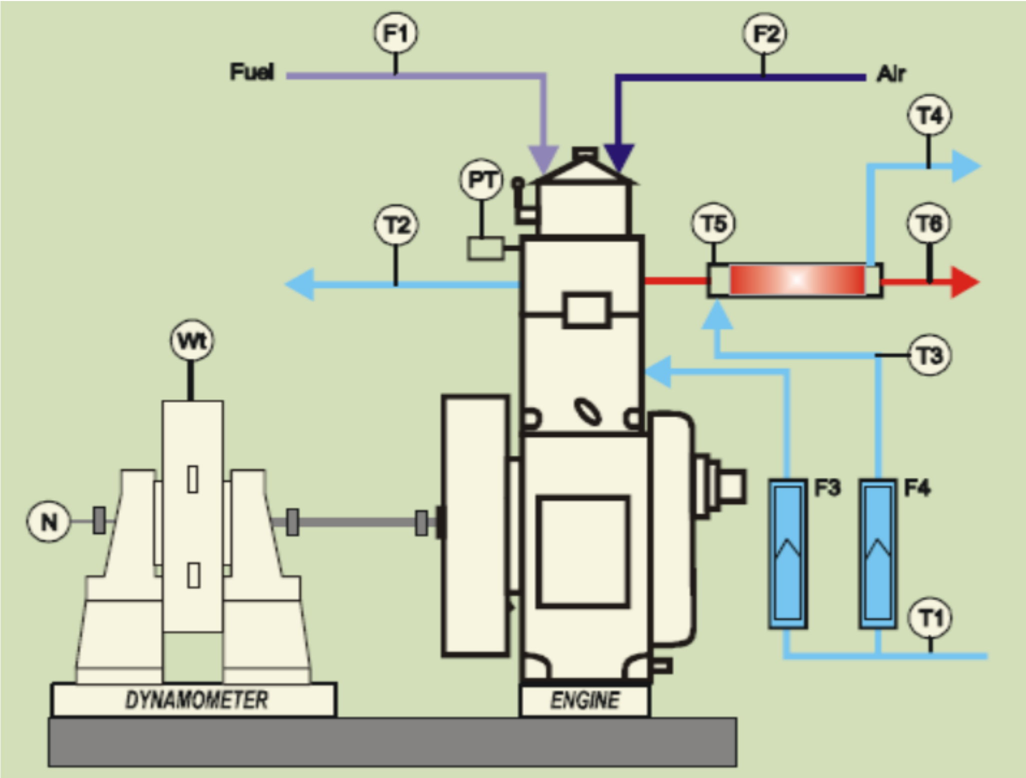


Fig.11. Schematic Diagram of Kirloskar Engine

Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The set up has stand-alone panel box consisting of air box, two fuel tanks for duel fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rotameters are provided for cooling water and calorimeter water flow measurement. The setup enables study of VCR engine performance for brake power, indicated power, frictional power, BMEP, IMEP, brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, volumetric efficiency, specific fuel consumption, A/F ratio and heat balance. Labview based Engine Performance Analysis software package “Enginesoft LV” is provided for on line performance evaluation. A computerized Diesel injection pressure measurement is optionally provided.

4.1.2 Components Used

Table 9: Components Used In the Kirloskar Engine

Engine	Make Kirloskar, Type 1 cylinder, 4 stroke Diesel, water cooled, power 3.5 kW at 1500 rpm, stroke 110 mm, bore 87.5 mm. 661 cc, CR 17.5, Modified to VCR engine CR range 12 to 18
Dynamometer	Make Saj test plant Pvt. Ltd., Model AG10, Type Eddy current
Dynamometer Loading unit	Make Apex, Model AX-155. Type constant speed, Supply 230V AC.
Propeller shaft	Make Hindustan Hardy Spicer, Model 1260, Type A
Manometer	Make Apex, Model MX-104, Range 100-0-100 mm, Type U tube, Conn. 1/4`` BSP hose back side, Mounting panel
Fuel measuring unit	Make Apex, Glass, Model:FF0.012
Piezo sensor	Make PCB Piezotronics, Model HSM111A22, Range

	5000 psi, Diaphragm stainless steel type & hermetic sealed
White coaxial Teflon cable	Make PCB piezotronics, Model 002C20, Length 20 ft, Connections one end BNC plug and other end 10-32 micro
Crank angle sensor	Make Kubler-Germany Model 8.3700.1321.0360 Dia: 37mm Shaft Size: Size 6mmxLength 12.5mm, Supply Voltage 5-30V DC, Output Push Pull (AA,BB,OO), PPR: 360, Outlet cable type axial with flange 37 mm to 58 mm
Data acquisition device	NI USB-6210 Bus Powered M Series,
Piezo powering unit	Make-Cuadra, Model AX-409.
Temperature sensor	Make Radix Type K, Ungrounded, Sheath Dia.6mmX110mmL, SS316, Connection 1/4"BSP (M) adjustable compression fitting
Temperature sensor	Make Radix, Type Pt100, Sheath Dia.6mmX110mmL, SS316, Connection 1/4"BSP(M) adjustable compression fitting
Temperature transmitter	Make Wika, model T19.10.3K0-4NK-Z, Input Thermocouple (type K), output 4-20mA, supply 24VDC, Calibration: 0-1200deg.C.
Temperature transmitter	Make Wika, Model T19.10.1PO-1 Input RTD(Pt100), output 4-20mA, supply 24VDC, Calibration: 0-100°C
Load sensor	Make Sensotronics Sanmar Ltd., Model 60001,Type S beam, Universal, Capacity 0-50 kg
Load indicator	Make Selectron, model PIC 152–B2, 85 to 270VAC,

	retransmission output 4-20 mA
Power supply	Make Meanwell, model S-15-24, O/P 24 V, 0.7 A
Digital voltmeter	Make Meco, 3.1/2 digit LED display, range 0-20 VDC, supply 230VAC, model SMP35
Fuel flow transmitter	Make Yokogawa, Model EJA110-EMS-5A-92NN, Calibration range 0-500 mm H2O, Output linear
Air flow transmitter	Range (-) 250 mm WC
Rotameter	Make Eureka Model PG 5, Range 25-250 lph, Connection ¾" BSP vertical, screwed, Packing neoprene
Rotameter	Make Eureka Model PG 6, Range 40-400 lph, Connection ¾" BSP vertical, screwed, Packing neoprene
Pump	Make Kirloskar, Model Mini 18SM, HP 0.5, Size 1"x1", Single ph 230 V AC

4.1.3 Performance of I.C.Engines

Indicated thermal efficiency (η_{ith}): Indicated thermal efficiency is the ratio of energy in the indicated power to the fuel energy.

$$\eta_{ith} = \text{Indicated Power / FuelEnergy}$$

$$\eta_{ith}(\%) = \frac{\text{IndicatedPower (Kw)}}{\text{FuelFlow (Kg/Hr)} \times \text{CalorificValue (KJ/Kg)}} \times 100$$

Brake thermal efficiency (η_{bth}): A measure of overall efficiency of the engine is given by the brake thermal efficiency. Brake thermal efficiency is the ratio of energy in the brake power to the fuel energy.

$$\eta_{bth} = \text{Brake Power / FuelEnergy}$$

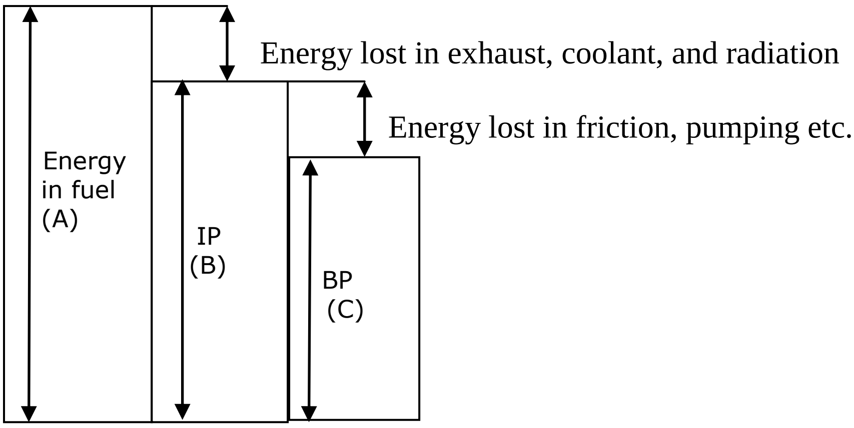
$$\eta_{bth}(\%) = \frac{\text{Brake Power (Kw)}}{\text{FuelFlow (Kg/Hr)} \times \text{CalorificValue (KJ/Kg)}} \times 100$$

Mechanical efficiency (η_m): Mechanical efficiency is the ratio of brake horse power (delivered power) to the indicated horsepower (power provided to the piston).

$$\eta_m = \text{Indicated Power / Brake Power}$$

And Frictional power = Indicated power – Brake power

Following figure gives diagrammatic representation of various efficiencies,



Indicated thermal efficiency = B/A

Brake thermal efficiency = C/A

Mechanical efficiency = C/B

Volumetric efficiency (η_v): The engine output is limited by the maximum amount of air that can be taken in during the suction stroke, because only a certain amount of fuel can be burned effectively with a given quantity of air. Volumetric efficiency is an indication of the 'breathing' ability of the engine and is defined as the ratio of the air actually induced at ambient conditions to the swept volume of the engine. In practice the engine does not induce a complete cylinder full of air on each stroke, and it is convenient to define volumetric efficiency as:

$$\eta_v(\%) = \frac{\text{Mass of air consumed}}{\text{mass of flow of air to fill swept volume at atmospheric conditions}}$$

Specific fuel consumption (SFC): Brake specific fuel consumption and indicated specific fuel consumption, abbreviated BSFC and ISFC, are the fuel consumptions on the basis of Brake power and Indicated power respectively.

Fuel-air (F/A) or air-fuel (A/F) ratio: The relative proportions of the fuel and air in the engine are very important from standpoint of combustion and efficiency of the engine. This is expressed either as the ratio of the mass of the fuel to that of the air or vice versa.

Power and Mechanical efficiency: Power is defined as rate of doing work and equal to the product of force and linear velocity or the product of torque and angular velocity. Thus, the measurement of power involves the measurement of force (or torque) as well as speed.

4.2 SMOKE METER

4.2.1 Basic Operating Principle

The AVL437c SMOKEMETER measures the opacity of polluted air, in particular diesel exhaust gases (in a measurement chamber of a defined measurement length.) The opacity is the extinction of light between light source and receiver. The gas to be measured is fed into a chamber with non-reflective inner surfaces.

The effective length of the light absorption track is determined by taking into consideration possible influences of devices used to protect the light source and the photocell. The effective length is 0.430:1:0.005 m.

Light scatter on the photocell from reflections or diffused light inside the chamber is reduced to a minimum by the use of matt black light traps. The light source is an incandescent bulb with a cooler temperature between 2800° K and 3250° K. The receiver is a photocell with spectral sensitivity tuned to the sensitivity curve of the human eye.

The entire electric circuitry, including the display, is designed so that the current delivered from the photocell is a linear function of the intensity of the received light within the operating temperature range.

The absorption coefficient is calculated in accordance with ECE-R24 ISO 3173. With an absorption coefficient of 1.7 m^{-1}, for example, the smoke meter display enables this to be read to an accuracy of 0.025 m^{-1}.

The response time of the electrical circuit, specified as the time within which the indicator reaches 900/0 of the full scale when a completely opaque plate is placed in front of the photocell, is between 0.9 and 1.1 seconds.

The temperature of the gas to be measured should be between 70 and 1300C at each point in the measurement chamber. An appropriate temperature sensor connected to a regulator ensures that temperature in the measurement chamber is maintained at 100-105°C.

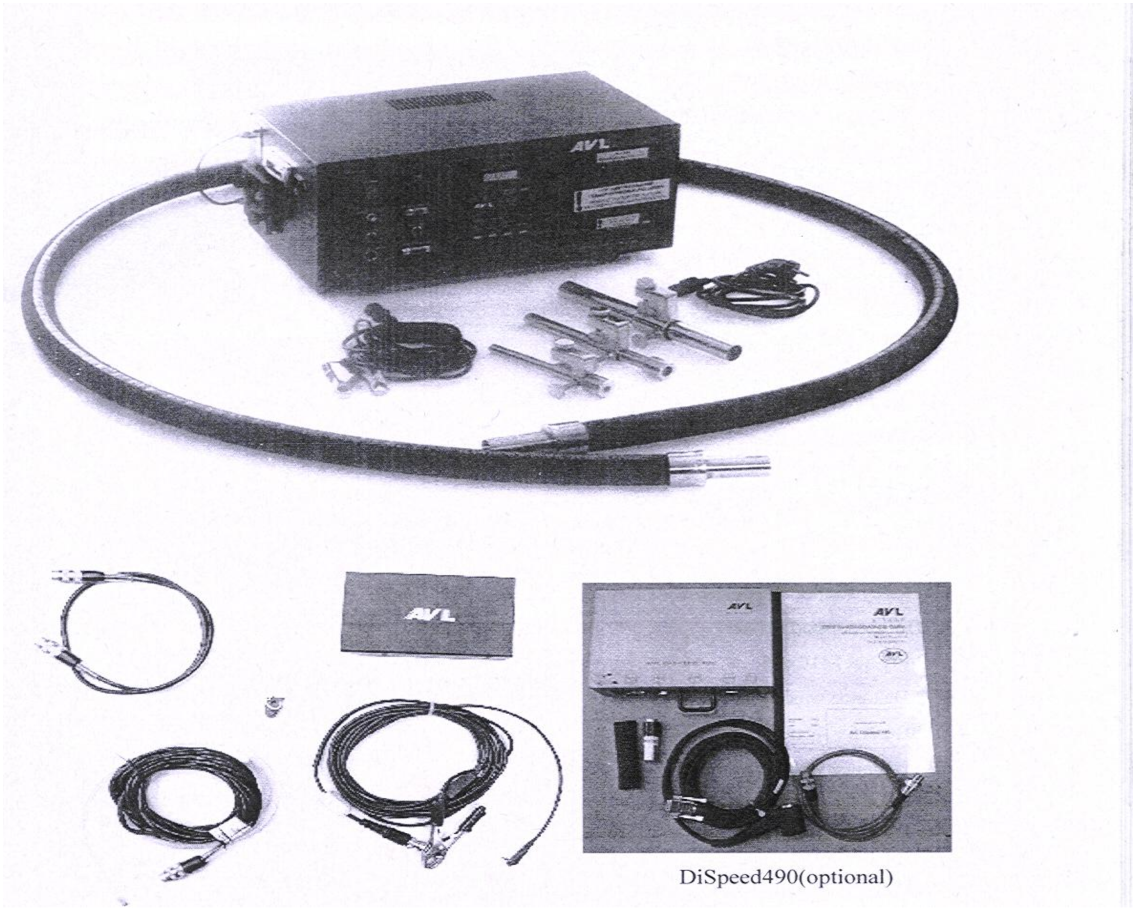


Fig. 12. A Smoke Meter and Its Components

The equipments have a microprocessor controlled program sequence to check the measurement process and to store such values as pressure, temperature, opacity, absorption.

Optional: The temperature of the gas through heating elements. The portable remote control unit- the operating unit - is principally used to control the measurement process, e.g. from the driver's cab. Results of all tests started by the user can be printed out to provide clear documentation of the vehicle under test.

4.2.2 Operating and Display Elements

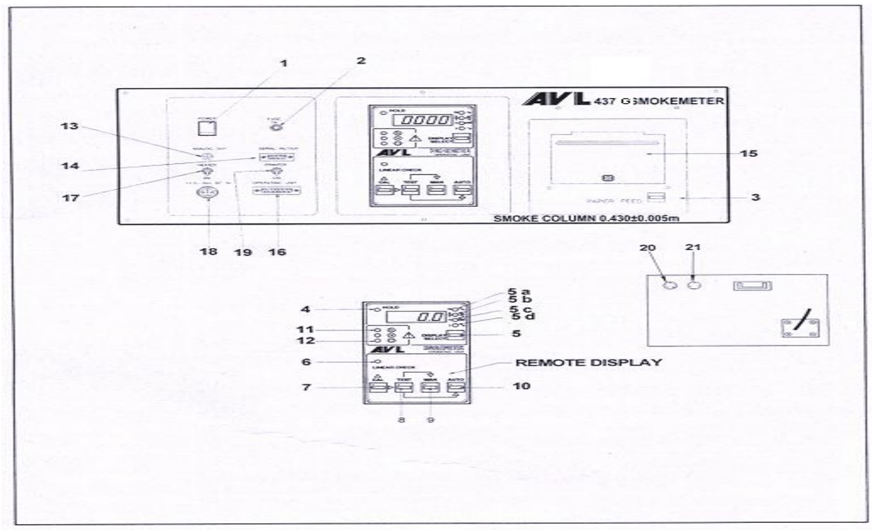


Fig. 13. Schematic Diagram of Smoke Meter

Table 9: Detail of AVL Smoke Meter

Number	Explanation
1 Power	Mains power switch illuminated
2 Fuse	Fuse protection against overload
3 PAPER FEED	Press-button for manual paper feed (e.g. for inserting paper in the printer)
4	LED indicating current measurement value is being stored during

HOLD	measurement using TEST mode or that printing is going on
5 DISPLAY SELECT	LED for digital display of opacity N%
5a N%	LED for digital display of coeffcient of absorption in m LED for digital display of oil temperature in °C
5b $\frac{k\ m^{-1}}{T^{0}C}$	LED for digital display of engine rpm in min^{-1}
5d $t^{0}C$	LED for digital display of temperature in measurement chamber in °C
6 LINEAR CHECK	LED for linearity check with subsequent protocol
7 CAL	Key for automatic zero point calibration with clean gas in the measuring track light source is switched on and off.
8 TEST	Key for "Measurement" operating mode (PREPARAnoN FOR KEYS 9 AND 10)
9 MAN	Key for holding instantaneous measurement value and for starting printout during continuous steady operation.
10 AUTO	Key for starting automatic measurement process using free acceleration
11 ^{0}C	LED warning when measurement chamber temperature is below 70°C (optional)
12 BATT	LED warning when voltage of equipment's built in power unit is too low / high NB : LED s 11,12 and 13 are warning lights.
13 Analog out	Analog output for connecting XT recorders and other recorder etc. Opacity output [%]
14 Serial IN/ OUT	RS 232 serial interface for follow- on data processing
15	Printer Cover

16 Operating unit socket	Connection of operating unit to the Smokemeter 43 7C unit (optional)
17 Heater Switch	On / Off switch for Heater
18	Power supply from external battery 11.5....36V DC
19 Printer Switch	On I Off switch for Printer
20 RPM	Connector for RPM
21 Oil Temperature	Connector for oil temperature probe

5. RESULT AND DISCUSSIONS

A single cylinder Kirloskar diesel engine was used to conduct the experiment to find the performance, combustion and emission characteristics of diesel and blends of diesel with karanja biodiesel fuel. An extended experimental study was conducted on a Kirloskar CI engine, at constant compression ratio of 18.0, The diesel and blends of diesel with karanja biodiesel fuel in weight/weight percentage were tested at various loads between 0-full loads/ brake power.

5.1 Specific Fuel Consumption (SFC) v/s Brake Power

Specific fuel consumption (SFC) is a measure of volumetric fuel consumption for any particular fuel. Figure 14, shows a decrease of specific fuel consumption (SFC) with increase in the brake power, for karanja biodiesel (B10, B20 and B30) and diesel. SFC for B-30 is higher than diesel at higher load.

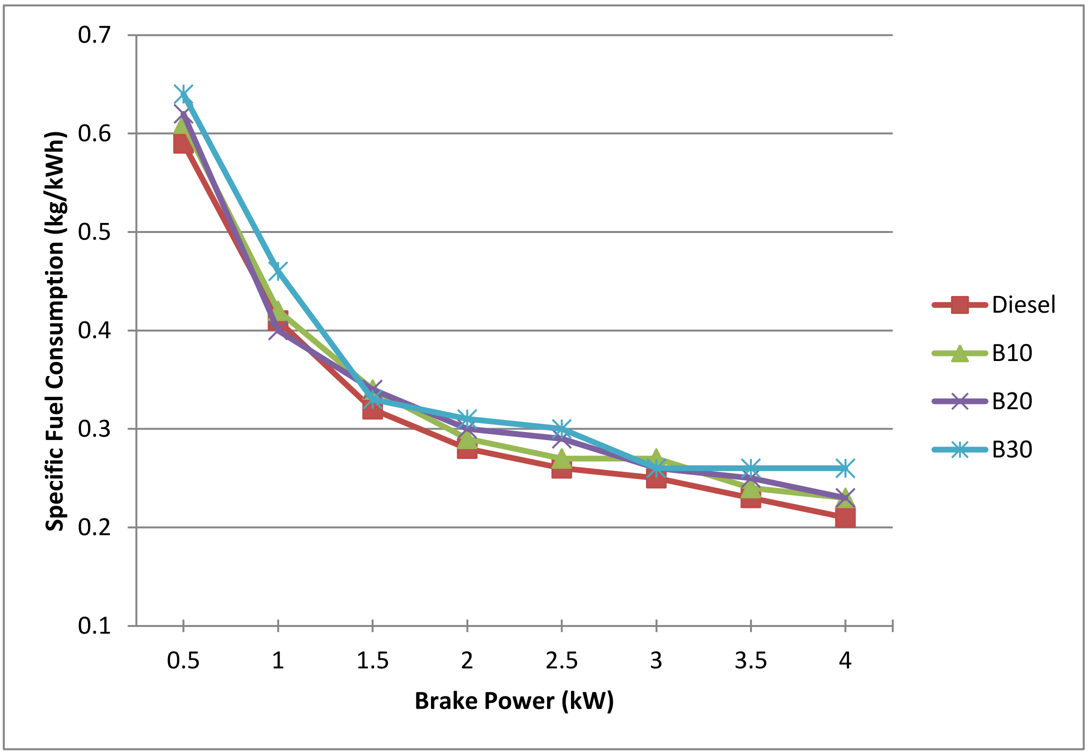


Fig. 14. Variation of Specific Fuel Consumption with Brake Power

This is mainly due to the combined effects of the fuel density, viscosity and lower heating value of karanja biodiesel. Higher density of karanja biodiesel leads to more fuel flow rate for the same displacement of the plunger in the fuel injection pump, thereby increasing SFC.

Table 10: Specific Fuel Consumption at Different Brake Power

Brake Power (kW)	Diesel (kg/kWh)	B10 (kg/kWh)	B20 (kg/kWh)	B30 (kg/kWh)
0.5	0.59	0.61	0.62	0.64
1	0.41	0.42	0.4	0.46
1.5	0.32	0.34	0.34	0.33
2	0.28	0.29	0.3	0.31
2.5	0.26	0.27	0.29	0.3
3	0.25	0.27	0.26	0.26
3.5	0.23	0.24	0.25	0.26
4	0.21	0.23	0.23	0.26

5.2. Brake Thermal Efficiency v/s Brake Power

The brake thermal efficiency v/s brake power graph plot in Figure.15 shows an increase of brake thermal efficiency with increase in the engine load. Almost all blends show slightly better BTE than diesel at higher load conditions.

The blend containing 10%, 20% and 30% diesel shows an increase in brake thermal efficiency, which is very close to diesel. This is due to the reduction in viscosity, density and improved atomization, fuel-air mixture formation and increase in the heating value as the proportion of diesel in the blend increases. This enhances the fuel atomization leading to improved fuel air mixing. Oxygenated fuel gives a better fuel combustion delivering improved thermal efficiency. The higher thermal efficiencies may be due to the additional lubricity provided by the fuel blends Raheman et al. **[16]** also report higher BTE for the B30 blend.

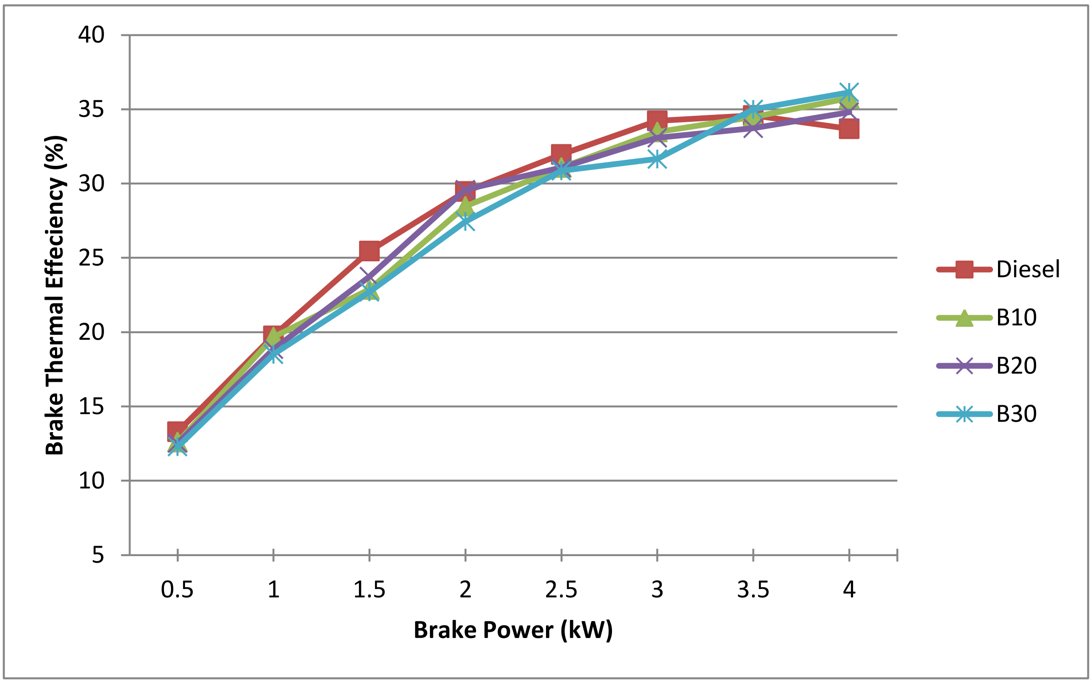


Fig. 15. Variation of Brake Thermal Efficiency with Brake Power

Table 11: Brake Thermal Efficiencies at different Brake Power

Brake Power (kW)	Diesel (%)	B10 (%)	B20 (%)	B30 (%)
0.5	13.3	12.6	12.54	12.3
1	19.75	19.67	18.85	18.51
1.5	25.46	22.87	23.74	22.71
2	29.47	28.47	29.59	27.45
2.5	31.96	31.08	31.07	30.86
3	34.22	33.47	33.08	31.65
3.5	34.58	34.49	33.72	34.99
4	33.69	35.74	34.81	36.14

5.3 Smoke Opacity v/s Brake Power

Figure.16 shows the variation of Smoke emission with brake power for diesel, and blends petroleum diesel and the karanja biodiesel. The results show that the smoke level increased with the power output of the engine for all the fuels. Smoke emissions usually increase very slowly at low engine speed. With karanja biodiesel B30, the smoke level is 27.4 that are lower than karanja biodiesel. The decreasing cetane number of the blends deteriorates the combustion process. Additionally, the oxygen content of the blends enhanced the fuel air mixing process especially in the fuel rich region of the cylinder by providing more oxygen, and mixing karanja biodiesel with diesel fuel causes a leaning effect of the blends due to lower stoichiometric air/fuel ratio of the karanja biodiesel, thus lowering the smoke opacity. The smoke emission is 40.6 with diesel, when compared to karanja biodiesel, this value is high which indicates a better combustion. Increasing concentration of Karanja oil in the fuel blend increases fuel’s oxygen content, which improves its combustion characteristic show ever increased fuel viscosity and poor volatility results in poor mixing of air and fuel spray.

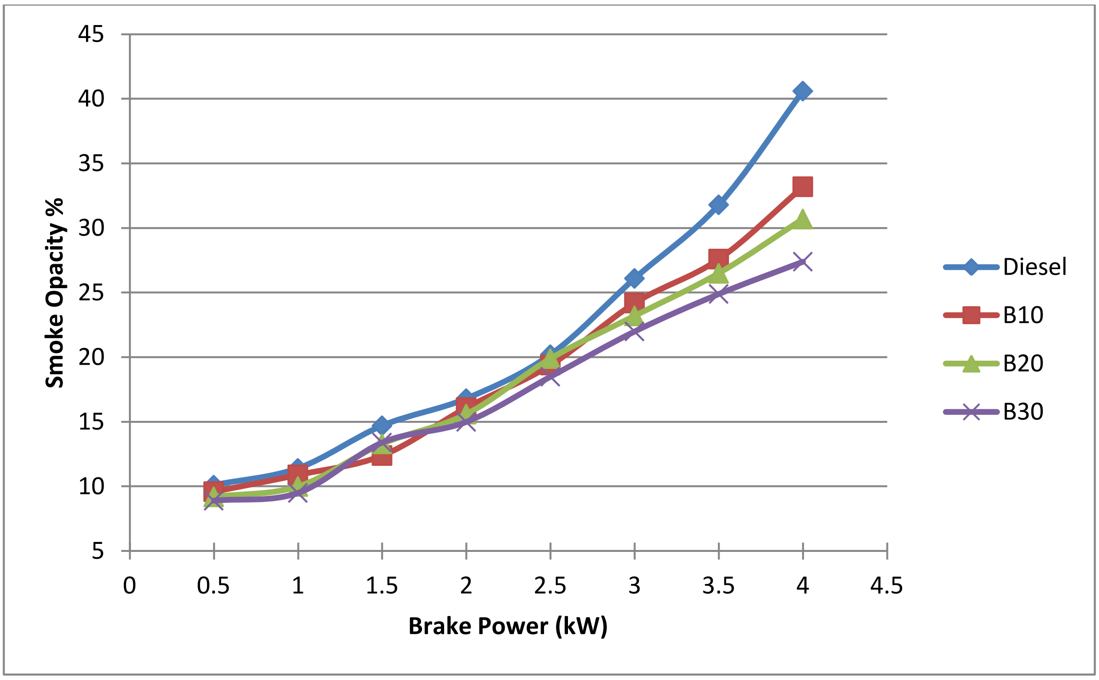


Fig. 16. Variation of Smoke Opacity with Brake Power

Table 12: Smoke Opacity at different Brake Power

Brake Power (kW)	Diesel (%)	B10 (%)	B20 (%)	B30 (%)
0.5	10.1	9.6	9.2	8.9
1	11.4	10.9	10	9.5
1.5	14.7	12.4	13.3	13.4
2	16.8	16.1	15.6	15
2.5	20.2	19.4	19.9	18.5
3	26.1	24.2	23.2	22
3.5	31.8	27.6	26.5	24.9
4	40.6	33.2	30.7	27.4

5.4 Exhaust Gas Temperature v/s Brake Power

The exhaust gas temperature of an engine is an indication of the conversion of heat into work. The variation of exhaust gas temperature is shown in Figure.17. There is an increase in exhaust gas temperature with increase the percentage of karanja biodiesel. It is 289.74 ºC for diesel at 4kW. Exhaust gas temperature for B30 is highest. For the diesel fuel, the exhaust gas temperature is the lowest among all the tested fuels. This is mainly due to higher viscosity of karanja biodiesel leads to late burning of fuel. There is a slight increase in exhaust gas temperature with karanja biodiesel. The exhaust gas temperature reduces as the proportion of diesel is raised due to the better vaporization of mixture. Exhaust gas temperatures is 307.42 ºC for B10, 311.58 ºC for B20 and 316.42ºC for B30 diesel blend at the 4kW. The reduction in the exhaust gas temperature of the blends indicates that the premixed combustion of the blend has improved. This is mainly due to the reduction in the viscosity of the fuel. In the case of karanja methyl ester-diesel fuel blends, the heat release may occur in the later part of the power stroke. So this may result in lower time for heat dissipation and higher exhaust gas temperatures.

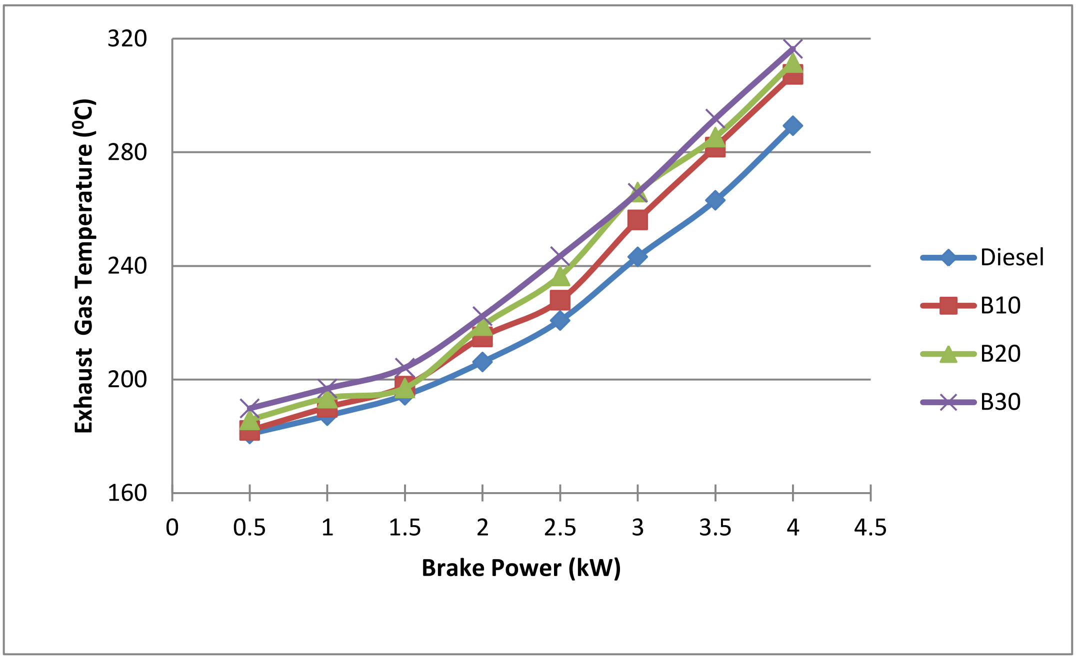


Fig. 17. Variation of Exhaust Gas Temperature with Brake Power

Table 13: Exhaust Gas Temperature at different Brake Power

Brake Power (kw)	Diesel (^0C)	B10 (^0C)	B20 (^0C)	B30 (^0C)
0.5	180.79	182.02	185.75	189.78
1	187.21	190.16	193.42	196.78
1.5	194.41	197.61	196.98	204.12
2	206.14	214.97	218.95	222.26
2.5	220.74	227.89	236.45	243.41
3	243.16	256.17	266.01	265.71
3.5	263.09	281.81	285.34	291.83
4	289.34	307.42	311.58	316.42

5.5 Pressure v/s Crank Angle

The pressure-crank angle curves of different blends of karanja biodiesel and pure diesel are shown in the fig 18. In the fig 18 shows that the pressure to crank angle curve of karanja biodiesel blends are almost resembles to the petroleum diesel's curve. At various crank angle pressure observed for B10, B20, B30 and petroleum diesel. As the pressure increases maximum crank angle value 365^0 at 56.20538 bar is observed and after this point though the crank angle increases but the pressure starts decline, but at the end of 720^0 it increases in fraction that is almost constant for 4kW brake power.

It can be seen that the peak pressure is slightly higher for karanja biodiesel blends when compared to that of diesel. This is due to the lower ignition delay of karanja and its blends. The oxygen content of karanja biodiesel, which results in better combustion, may also result in higher peak pressure compared to petroleum diesel. The maximum rate of pressure rise is shown in Fig. 19 for the all blends of karanja compared to petroleum diesel.

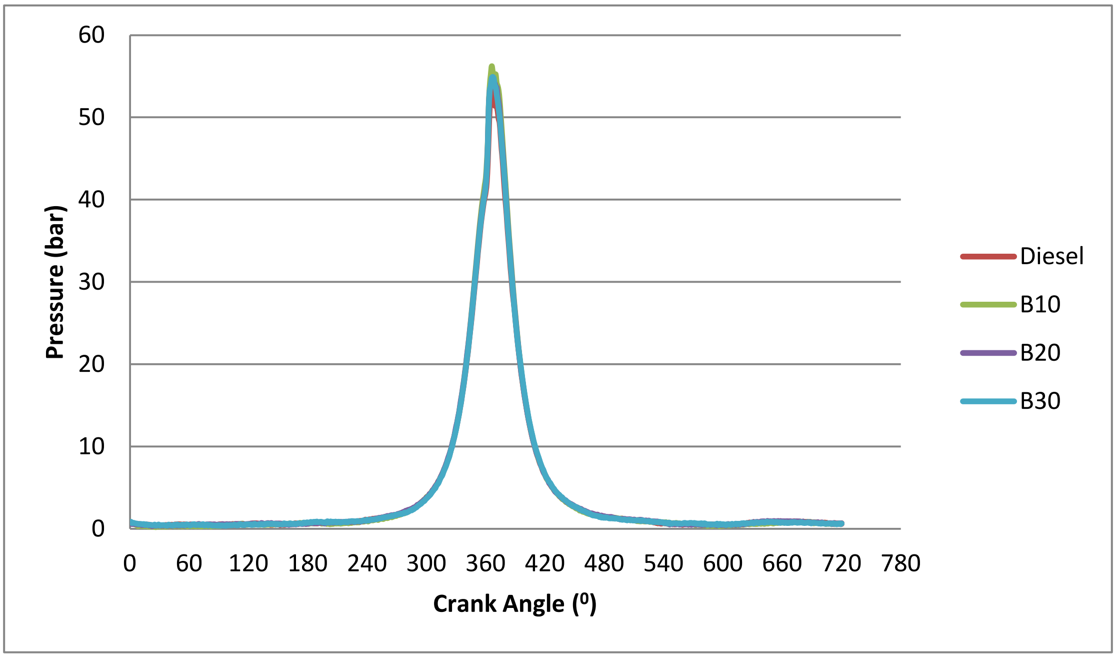


Fig. 18. Variation of Pressure with Crank Angle for 0-720

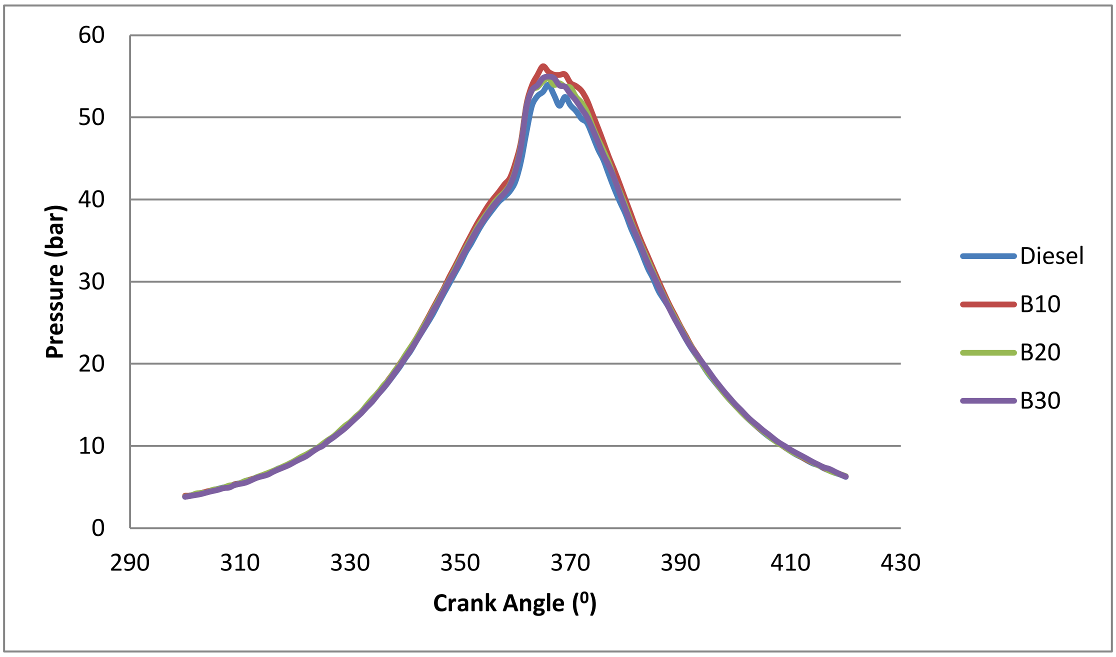


Fig. 19. Variation of Pressure with Crank Angle for 300-400

5.6 Torque v/s Brake Power

The variation of torque with the brake power is shown in Figure.20 for the karanja blends and petroleum diesel. There is a decrease in torque with increase the percentage of karanja biodiesel. It is 25.82 Nm for diesel at 4kW and for B10, B20 and B30 the value of torque is 25.04, 24.60 and 24.11 respectively at the full load i.e., 4kw. For the diesel fuel, the torque is the highest among all the tested fuels. This is mainly due to higher specific heat of petroleum diesel. The trend of the curve for the blends is almost nearer to that of petroleum diesel.

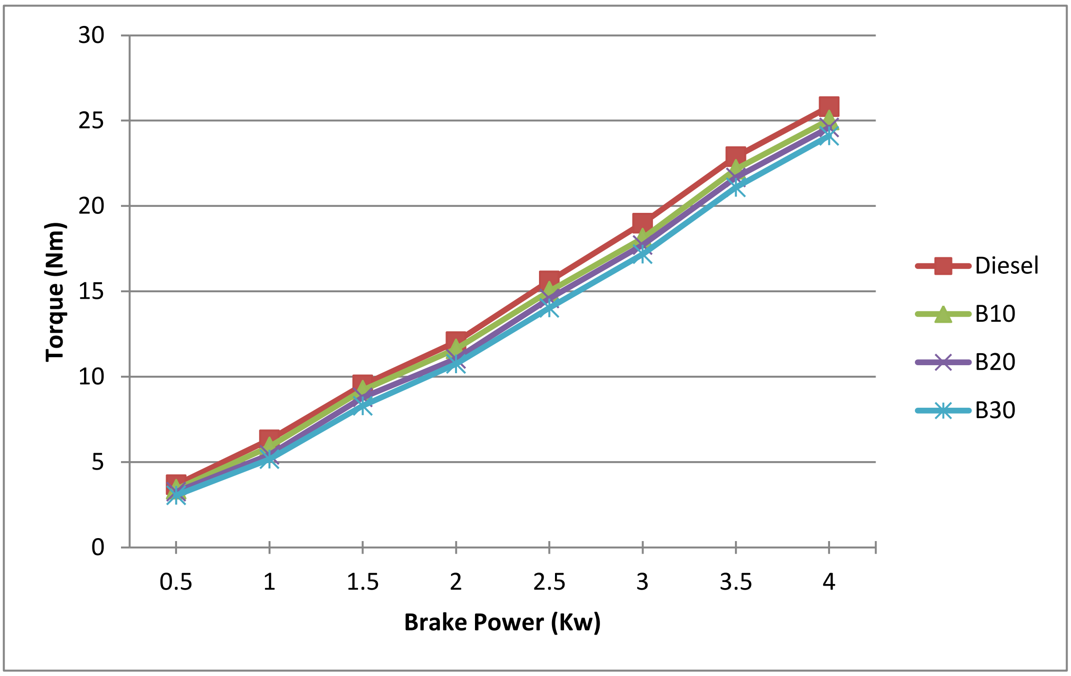


Fig. 20. Variation of Torque with Brake Power

Table 14: Torque at different Brake Power

Brake Power (kW)	Diesel (Nm)	B10 (Nm)	B20 (Nm)	B30 (Nm)
0.5	3.67	3.41	3.26	3.05
1	6.3	5.89	5.42	5.17
1.5	9.52	9.21	8.79	8.29
2	12.05	11.63	11.04	10.75
2.5	15.61	15.01	14.58	14.03
3	18.99	18.12	17.71	17.18
3.5	22.89	22.15	21.67	21.09
4	25.82	25.04	24.6	24.11

5.7 Air-Flue Ratio v/s Brake Power

Air/fuel ratio of the blends fuel such as B10, B20 and B30 observed at various brake power compared to diesel are shown in the fig.21. The A/F ratio forB10, B20 and B30blends of karanja biodiesel at maximum brake power 4kW achieved is 26.4, 26.98 and 27.42 respectively which are slightly lower than the pure diesel maximum value i.e., 29.12 at full load. From the fig 21 shows that as the brake power increases the A/F ratio decreases. The trends obtained for B10, B20 and B30 are almost similar to the pure diesel performed on the same engine, but with a lower magnitude of a given power output the trend is much different in between pure diesel and the karanja blends.

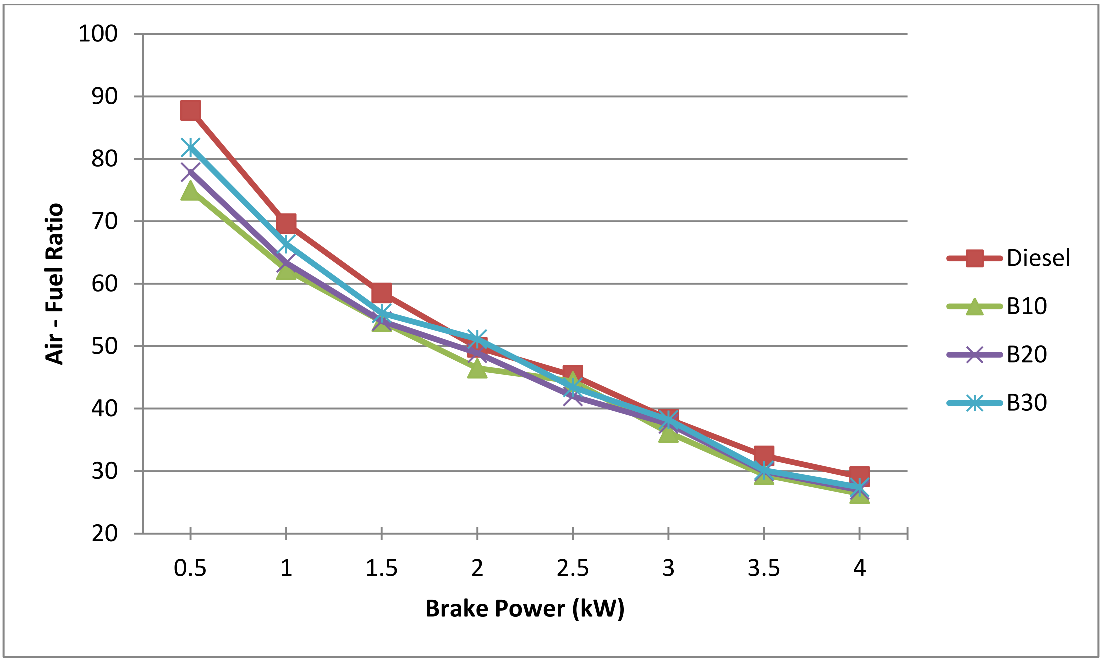


Fig. 21. Variation of Air-Fuel Ratio with Brake Power

Table 15: Air-Fuel Ratio at different Brake Power

Brake Power (kW)	Diesel	B10	B20	B30
0.5	87.75	74.96	77.87	81.82
1	69.61	62.24	63.36	66.34
1.5	58.52	53.94	54.02	55.27
2	49.82	46.48	48.88	51.14
2.5	45.32	44.36	41.96	43.41
3	38.32	36.19	37.55	38.21
3.5	32.43	29.43	29.94	30.13
4	29.12	26.4	26.98	27.42

5.8 Mechanical Efficiency v/s Brake Power

The mechanical efficiency of the fuel mixtures is plotted in figure 22 with the variation of brake power. The variation of mechanical efficiency is increase with the increase of power output of the engine. The trend of the curve is found to be almost same for all tested fuels (blends of karanja biodiesel and petroleum diesel). The mechanical efficiency for the diesel at 4kW brake power is 70.09 and for the karanja blends B10, B20 and B30 are 71.55, 71.2 and 70.19 respectively. It can be seen that the mechanical efficiency for B20 is better than diesel fuel and other blends of karanja biodiesel at all range of brake power conditions.

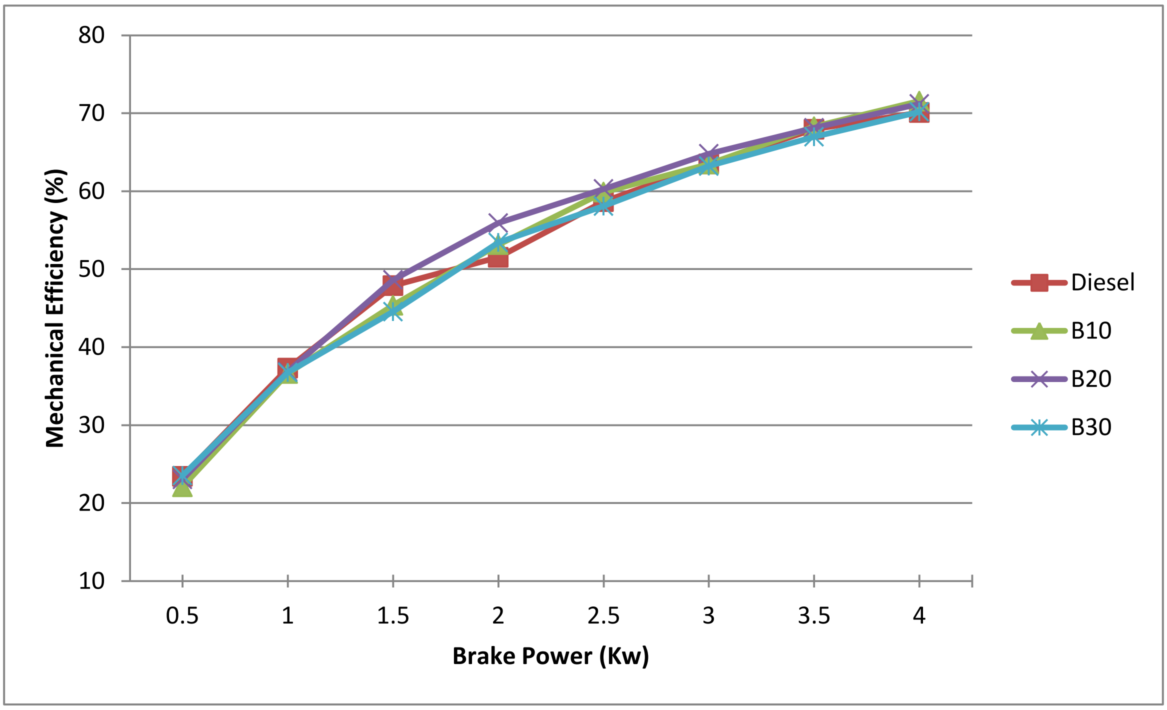


Fig. 22. Variation of Mechanical Efficiency with Brake Power

Table 16: Mechanical Efficiency at different Brake Power

Brake Power (kW)	Diesel (%)	B10 (%)	B20 (%)	B30 (%)
0.5	23.43	22.09	23.04	23.53
1	37.31	36.62	36.87	36.75
1.5	47.89	45.37	48.64	44.55
2	51.52	53.15	55.92	53.43
2.5	58.66	59.89	60.3	58.09
3	63.5	63.49	64.81	63.22
3.5	67.94	68.27	68.13	66.98
4	70.09	71.55	71.2	70.19

6. CONCLUSIONS

A single cylinder compression ignition engine was operated successfully on karanja biodiesel and neat diesel. Karanja biodiesel seems to have a potential to use as alternative fuel in diesel engines. Blending with diesel decreases the viscosity considerably. The following conclusions are drawn based on the experimental results at 4 kW brake power:

- SFC for B-30 is higher than diesel and other karanja blends at higher load.
- The karanja blends B10, B20 and B30 shows an increase in brake thermal efficiency, which is very close to diesel. This is due to the reduction in viscosity, density and improved atomization, fuel-air mixture formation and increase in the heating value as the proportion of diesel in the blend increases.
- Significant decrement in smoke level with preheated B30 and karanja blends compared to neat diesel is observed.
- The exhaust emission from karanja biodiesel blends is lower than that of petroleum diesel.
- The exhaust gas temperature is higher for B30 compared to diesel. This is due to the late burning of karanja biodiesel.
- For the diesel fuel, the torque is the highest among all the tested fuels.
- The mechanical efficiency for the diesel at 4kW brake power

It is concluded that the blending of karanja biodiesel in the petroleum in different ratios may be the good option for fuel in CI engines and is the effective method to reduce emission and improving performance of a diesel engine.

7. FUTURE SCOPE & RECOMMENDATIONS

This study covers the production process of Karanja biodiesel, performance, combustion and emission characteristics of pure petroleum diesel and blends of karanja biodiesel with petroleum diesel in different ratios. Results obtained from the study shows that the karanja biodiesel can be used in compression ignition (CI) engine without major modification in the engine.

But still there are certain reasons for encouraging the development of biodiesel and further development in this field are:

- For the long term use of biodiesel in an engine, high maintenance required is need to be investigate.
- Viscosity for biodiesel is an issue, while using in a diesel based engine and can be reduced by increasing the injector pressure.
- Further research in dynamic response of fuel is required. As the biodiesel fuel has excellent lubricating property, so either some modification is required in the fuel injector of the engine or some additive should be search to make it easily viable for a diesel based engine.

8. RECOMMENDATION FOR DEVELOPMENT OF BIO FUELS[46]

- As the stock of fossil fuel is getting depleted, emphasis should be given to renewable sources of fuel such as Bio-Fuel crops and tree brone oilseeds.
- DST funding is required for land resources management water resources, mineral, fossil fuels.
- Design, develop and popularize appliances and equipments specifically for rural application.
- Prima facie, bio-diesel seems to have significant potential to contribute to Indian's energy security, the need of the hour is to undertake R&D on sustainable plantation management, oil extraction and use environmental and social impact assessment and build institutional models.
- To develop fuel wood and bio-diesel plantation to reduce drudery in collecting fuel wood for meeting house hold energy equipment.
- A common plate form for interaction with farmers extension personnel, researchers and technologists with media personnel must be created.
- Contact training programmers to sensitize media personnel on latest technologies and developments related to rural development.
- Creating awareness regarding loan, insurance facilities subsidies, etc.

8.1. Need for a Policy Initiative [47]

- Initiate dialogue on classification of non-edible vegetable oils based on their origin and practices, from that of natural forest/ social forestry/avenue plantations.
- Cultivated vegetable oils can be dedicated/diverted to agricultural operations to source energy requirements.
- Tree borne oils of forest origin can go for central pool for blending as a transportation fuel.

- Need for a long term National Policy on utilization of these oils as per their allocations.
- Sustain this concept till it is socially reproduced, and becomes an agricultural activity by the farmers.
- Energy recovery from de-oiled cakes is encouraged as an on farm activity, for fertilizer, and for duel fuel mode engine applications.
- Arriving at a bench mark on the engine capacity, subsidize the interest rates, as an incentive.

8.2. Translation of the Policy Initiative [48]

- Establish a separate permanent board/Directorate of Biofuels strictly for agricultural operations.
- The District – wise agricultural energy requirements be translated, into the extent of crop to be grown.
- Ensure for every 200 ha+ of such crop (ex. Jatropha), at least two processing plants be encouraged.
- In a time frame, to develop and make it available the engines to run on SVO/bio-diesel, based on need, and convenience.
- Additional incentive for dual fuel mode of operation to save vegetable oil for other applications.
- Invite involvement of Local engineering institutions to verify the quality aspects of the fuel by providing infrastructure, to act as a resource centers.
- Necessary training and extension programs be motivated with these centers.
- Ensures rural entrepreneurial/work opportunities, by encouraging small scale industrial activity.
- Put in place the mechanism to deliver energy products available locally, to all the stake holders.
- Transition to bio fuels can be developed based on cropping pattern/site and size specific operations, by measuring the actual energy saved.
- For this exercise state bio fuel boards can engage charted engineering/qualified personnel to make such evaluation once in 3 months.

- Savings on fossil fuels is rewarded, as an incentive to the biofuel boards of the respective states by EB's/states.
- The CDM cash credits/rewards can be distributed, among the stakeholders as a support price for the raw material/to the distribution mechanism.

8.3. Bio-Diesel Policy [49]

Beginning 1 January 2006, the public sector OMCs (oil marketing companies) will be purchasing bio-diesel (B100) at Rs. 25 a liter for blending with diesel (HSD) to the extent of 20% in phases. Unveiling the new bio-diesel purchase policy on 13 October, the former minister for petroleum and natural Gas, Mr. Mani Shankar Aiyar, said that to start with, five percent of bio-diesel a non-edible oil extracted from Jatropha and Pungamia, would be mixed with diesel during trial runs. At a later stage, in phases, the B100 blending with diesel is to be increased to 20%. Mr. Alyar noted that automobile engines would not require any modification for using diesel doped with 20% bio-diesel as fuel. Only those bio-diesel manufacturers who get their samples approved and certified by the oil companies, and get registered as authorized suppliers will be eligible for assured purchase of product, the new policy statement said. Accordingly starting 1 January 2006, the OMCs – IOC, BPCL, and HPCL – would purchase through select purchase centers, bio-diesel that meets the fuel quality standards prescribed by the bureau of industrial standards.

8.4. Environmental Considerations

In view of environmental considerations, bio-diesel is considered Carbon neutral because all the CO2 released during consumption had been sequestered from the atmosphere for the growth of vegetable oil crops. The combustion of bio-diesel has reported to emit lesser pollutants compared to diesel **[50]**. This indicates that the engine exhaust contains no SO2, and shows decreasing emissions of PAH, CO, HC, soot and aromatics. The NOx emission is reported to be in the range between 10% as compared to diesel depending on engines combustion characteristics.

8. REFERENCES

[1] G Tashtoush, M Al-Widyan and A Al-Shyouck, "Combustion performance and emissions of ethyl ester of a waste vegetable oil in a water-cooled furnace", Appl Thermal Eng, Vol.23, 2002, pp.285–93.

[2] Y.C. Denis Leung, Wu Xuan and M.K.H. Leung "A review on biodiesel production using catalyzed transesterification", Applies Energy, Vol.87 (4), 2009, pp.1083-1095.

[3] S Geyer, M Jacobus, and S Letz, "Comparison of diesel engine performance and emissions from heat and transesterified vegetable oils", ASAE, Vol.27 (2), 1984, pp.375–381.

[4] A Yahya and S.J. Marley, "Performance and exhaust emissions of a C.I engine operating on ester fuels at increased injection pressure and advanced timing", Biomass Bioenergy, Vol.6 (4), 1994, pp.297-319.

[5] S Clarck, L Wanger and M Schrock, "Methyl, ethyl and butyl soybean esters as a renewable fuel for Diesel engine", Biomass Energy, Vol.70, 1985, pp.209–212.

[6] L Wanger, S Clark and M Shrouck, "Effects of soybean oil esters on the performance, lubricating oil, and wear of Diesel engines", SAE Paper No. 841385, 1984.

[7] CL Peterson, DL Reece, DL Hammond, R Cruz and JA Thompson, "Comparison of ethyl and methyl esters of vegetable oils as diesel fuel substitute", Alternate Energy, ASAE, Vol.12 (13), 1992, pp.99-110.

[8] AS Ramadhas, C Muraleedharan and S Jayaraj, "Performance and emission evaluation of a diesel engine fuelled with methyl esters of rubber seed oil", Renewable Energy, Vol.20, 2005, pp.1–12.

[9] Planning Commission Report (Govt. of India), Integrated Energy Policy, report of the expert committee, August 2006.

[10] Carmen Stavarache, M. Vinatoru, R. Nishimura, Y. Meedda "Fatty acids methyl esters from vegetable oil by means of ultrasonic energy", Ultrasonic Sonochemistry Vol.12, 2005, pp.367-372.

[11] R Siddalingappa Hotti and Omprakash Hebbal, "Performance and Combustion Characteristics of Single Cylinder Diesel Engine Running on Karanja Oil/Diesel Fuel Blends", Scientific Research Engineering, Vol.3, 2011, pp.371-375.

[12] S. Bajpai, P. K. Sahoo and L. M. Das, "Feasibility of Blending Karanja Vegetable Oil in Petro-Diesel and Utilization in a Direct Injection Diesel Engine", Fuel, Vol.88 (4), 2009, pp.705-711.

[13] A. K. Agarwal and K. Rajamanoharanm, "Experimental Investigations of Performance and Emissions of Karanja Oil and Its Blends in a Single Cylinder Agricultural Diesel Engine," Applied Energy, Vol.86 (1), 2009, pp.106-112.

[14] H. Raheman, A.G. Phadatare, "Diesel engine emissions and performance from blends of karanja methyl ester and diesel", Biomass and Bioenergy, Vol.27 (4), 2004, pp.393–397.

[15] N. Stalin and H. J. Prabhu, "Performance Test of IC Engine Using Karanja Biodiesel Blending with Diesel", ARPN Journal of Engineering and Applied Sciences, Vol. 2 (5), 2007, pp. 32-34.

[16] B. Baiju, M.K. Naik, L.M. Das, "A comparative evaluation of compression ignition engine characteristics using methyl and ethyl esters of Karanja oil", Renewable Energy, Vol.34, 2009, pp. 1616–1621.

[17] Nagarhalli M. V., Nandedkar V. M. and Mohite K.C., "Emission and Performance Characteristics of Karanja Biodiesel and its Blends in a C.I. Engine and its Economics", ARPN Journal of Engineering and Applied sciences vol. 5 (2), 2010, pp. 52-56.

[18] K. Sureshkumar, R. Velraj, R. Ganesan, "Performance and exhaust emission characteristics of a CI engine fuelled with Pongamia pinnata methyl ester (PPME) and its blends with diesel", Renewable Energy, Vol.33, 2008, pp. 2294–2302.

[19] P.K. Sahoo, L.M. Das, "Combustion analysis of Jatropha, Karanja and Polanga based biodiesel as fuel in a diesel engine", Fuel, vol.88, 2009, pp.994–999.

[20] Dhinagar S, Nagalingam B., "Experimental investigation on non-edible vegetable oil operation in a LHR diesel engine for improved performance", SAE, 932846, 1993.

[21] Malaya Naik, L.C. Meher, S.N. Naik, L.M. Das, "Production of biodiesel from high free fatty acid Karanja (*Pongamia pinnata*) oil", Biomass and Bioenergy, Vol. 32 (4), 2008, pp. 354–357.

[22] Avinash Kumar Agarwal, Atul Dhar, "Experimental investigations of performance, emission and combustion characteristics of Karanja oil blends fuelled DICI engine", Renewable Energy, Vol. 52, 2013, pp. 283-291.

[23] A. Javidialesaadi and S. Raeissi, "Biodiesel Production from High Free Fatty Acid-Content Oils: Experimental Investigation of the Pre-treatment Step", APCBEE Procedia, Vol.5, 2013, pp. 474 – 478.

[24] Lotero E, Liu YJ, Lopez DE, Suwannakarn K, Bruce DA, Goodwin JG., "Synthesis of biodiesel via acid catalysis", Ind Eng Chem Res Vol. 44, 2005, pp. 5353-5363.

[25] K.V. Thiruvengadaravi, J. Nandagopal, P. Baskaralingam, V. Sathya Selva Bala, S. Sivanesan, "Acid-catalyzed esterification of karanja (Pongamia pinnata) oil with high free fatty acids for biodiesel production", Fuel, Vol.98, 2012, pp.1–4.

[26] M. Canakci, J. Van Gerpen, "Biodiesel Production from Oils and Fats with High Free Fatty Acids", ASAE, Vol. 44(6), 2001, pp. 1429–1436.

[27] R.K. Singh and Saswat Rath, "Performance analysis of blends of karanja methyl ester in a compression ignition engine", IPCBEE, Vol.11, 2011, 187-192.

[28] Nagarhalli.M.V , Nandedkar.V.M, "Performance of diesel engine using blends of esters of jatropha and karanja- a novel approach", IJAET, Vol.3 (3), 2012 pp.51-54.

[29] Dipak Patil, Dr. Rachayya.R. Arakerimath, "Performance analysis of multi-cylinder CI. engine by using karanja bio-diesel", IJERA, Vol. 1 (4), pp.1755-1763.

[30] Mallikarjun M.V., Venkata Ramesh Mamilla, Lakshmi Narayana Rao, and Purushothaman, "Emissions and performance characteristics of diesel engine from blends of karanja methyl ester and diesel", IJRSR, Vol. 3 (1), 2012, pp.25 – 28.

[31] K. Sureshkumar and R. Velra, "Performance and Characteristics Study of the Use of Environment Friendly Pongamia Pinnata Methyl Ester in C. I. Engines", JEE, Vol. 5, 2007, pp. 60-71.

[32] Bryant L. The development of the diesel engine. Technol Culture 1976;17(3):432–46.

[33] Krawczyk T. Biodiesel—alternative fuel makes inroads but hurdle remains, INFORM 7801–815, 1996.

[34] Alton R, Cetinkaya S, Yucesu HS. The potential of using vegetable oil fuels as fuel for diesel engines. Energy Convers Manage 2001;42:529–38.

[35] Ramadhas AS, Jayaraj S, Muraleedharan C. Use of vegetable oils as IC engine fuels—a review. Renew Energy 2004;29:727–42.

[36] Ma F, Hanna MA. Biodiesel production: a review. Bioresour Technol 1999;70:1–15.

[37] Pramanik K. Properties and use of Jatropha curcas oil and diesel fuel blends in compression ignition engine. Renew Energy 2003;28:239–48.

[38] Srivastava A, Prasad R. Triglycerides-based diesel fuels. Renew Sustain Energy Rev 2000;4:111–33.

[39] Meher LC, Vidya Sagar D, Naik SN. Technical aspects of biodiesel production by transesterificationda review. Renewable and Sustainable Energy Reviews 2006;10(3):248‑68.

[40] Naik Malaya, Meher LC, Naik SN, Das LM. Production of biodiesel from high free fatty acid karanja (Pongamia pinnata) oil. Biomass & Bioenergy 2008;32(4):354‑7.

[41] Otera J. Transesterification Chem Rev 1993;93(4):1449–70.

[42] Meher LC, Vidya Sagar D, Naik SN. Technical aspects of biodiesel production by transesterificationda review. Renewable and Sustainable Energy Reviews 2006;10(3):248‐68.

[43] Kalam MA, Masjuki HH. Biodiesel from palm oil an analysis of its properties and potential. Biomass Bioenergy 2002;23(18):471‐9.

[44] Srivastava A, Prasad R. Triglycerides-based diesel fuels. Renew Sust Energy Rev 2000;4:111‐33.

[45] Raadnui S, Meenak A. Effects of refined palm oil (RPO) fuel on wear of diesel engine components. Wear 2003;254(19):1281‐8.

[46] Recommendation of the focal theme Integrated Rural development science and technology of the 93rd Indian science congress. Annual report 2005–2006. p. 54–80.

[47] Dr. P. Radhakrishna, Director (Tech), Ministry of Non-conventional Energy Sources, Chennai. Sustaining and Securing the Agricultural Economy by Dedicated Green Energy Options. Biofuels India, Vol.-IV, Issue II, June 2006. p. 12–4.

[48] International conference on: Bio-fuels 2012 Vision to Reality. Energy & Fuel Users Journal, January–March 2006. p. 6–8.

[49] Dr. C. Ramasamy, Vice Chancellor Tamil Nadu Agricultural University Coimbatore. Jatropha Improvement management and production of Bio diesel. Center of excellence in Biofuels. AEC& RI, Tamil Nadu Agricultural University Coimbatore-641003.

[50] Rosenblum LJ. Feasibility of Biodiesel for rural electrification in India (Draft); June 2000.

APPENDIX I

Since the FFA of the Karanja oil is higher, therefore two-stage process had been adopted for the production of biodiesel from karanja oil. The FFA of the karanja oil initially was 5.1% as found by the process of titration. After the acid esterification (stage I) FFA reduced to 2.2%. And after this process the product of 1st stage was used in alkaline transesterification (stage II).

The effect of various parameters on yield is given below:

(a) Effect of the molar ratio

Both transesterification and esterification are reversible reactions. The amount of methanol must be in excess to force the reaction towards the formation of biodiesel. In this study, the different methanol-to-oil ratios (6:1 and 9:1) and reaction times (30, 45, 60, 75 and 90 mins) were used to investigate their effect on the methyl ester content of biodiesel product. The transesterification was carried out with the catalyst concentration of 2% and 3% and at the reaction temperature of 60 ^{0}C. It can be seen from Fig. (23) and (24) that the conversion of triglyceride increased as the molar ratio of methanol/oil increased from 6 to 9.

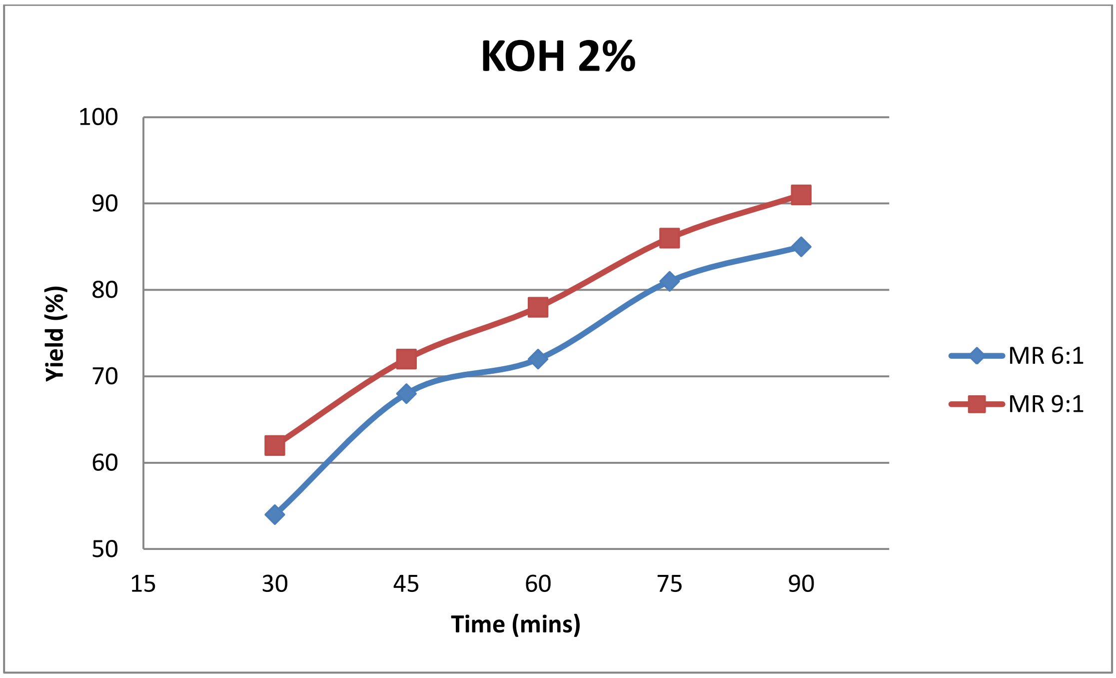


Fig.23. Variation of yield at different molar ratio with KOH 2%

Table 17. Yield Variation at different molar ratio with 2% KOH

Time (mins)	MR 6:1 (%)	MR 9:1 (%)
30	52	56
45	63	70
60	69	74
75	76	82
90	79	84

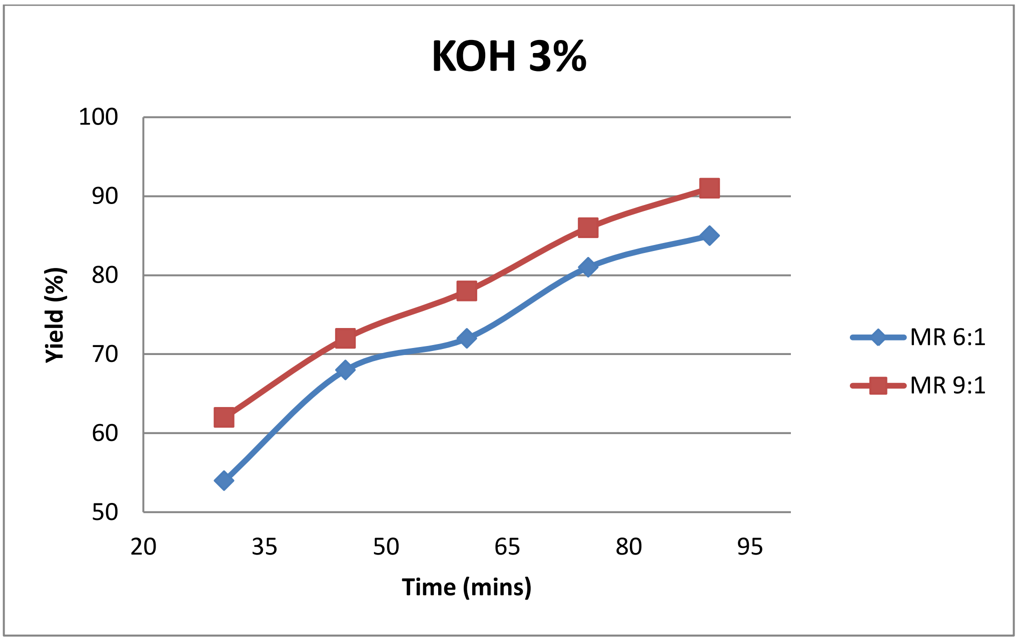


Fig.24. Variation of yield at different molar ratio with KOH 3%

Table 18. Yield Variation at different molar ratio with 3% KOH

Time (mins)	MR 6:1 (%)	MR 9:1 (%)
30	54	62
45	68	72
60	72	78
75	81	86
90	85	91

(a) Effect of the catalyst

The amount of KOH must be in excess but up to a certain limit to force the reaction towards the formation of biodiesel. It can be seen from Fig. (25) and (26) that the conversion of triglyceride increased as the catalyst increased from 2% to 3%.

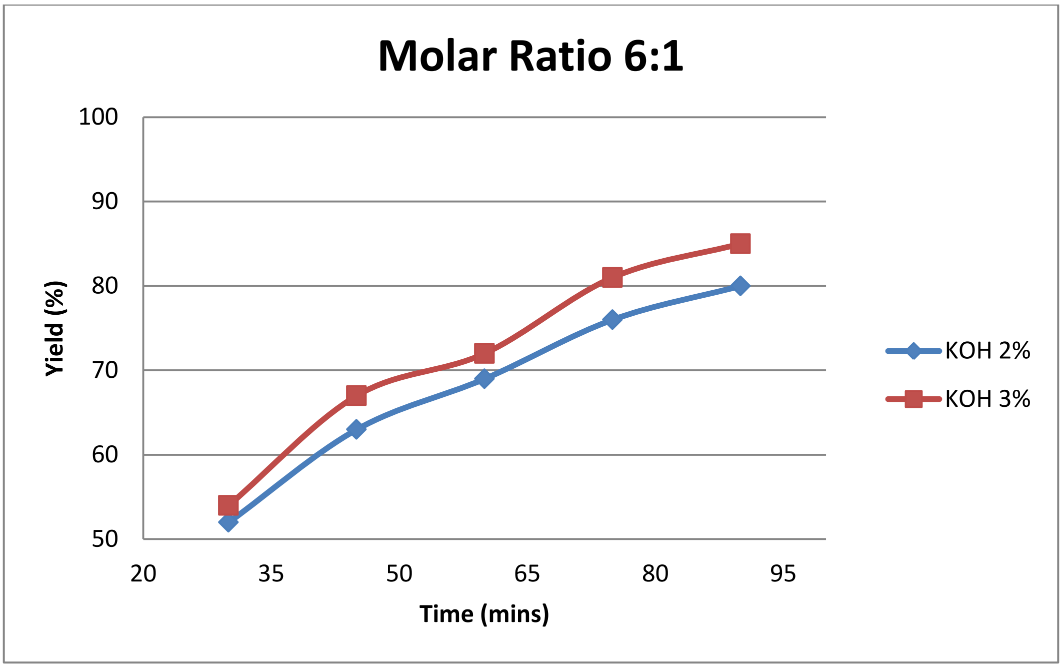


Fig.25. Variation of yield at different KOH with molar ratio 6:1.

Table 19. Yield Variation at different KOH

Time (mins)	MR 6:1 (%)	MR 9:1 (%)
30	52	54
45	63	68
60	69	72
75	76	81
90	79	85

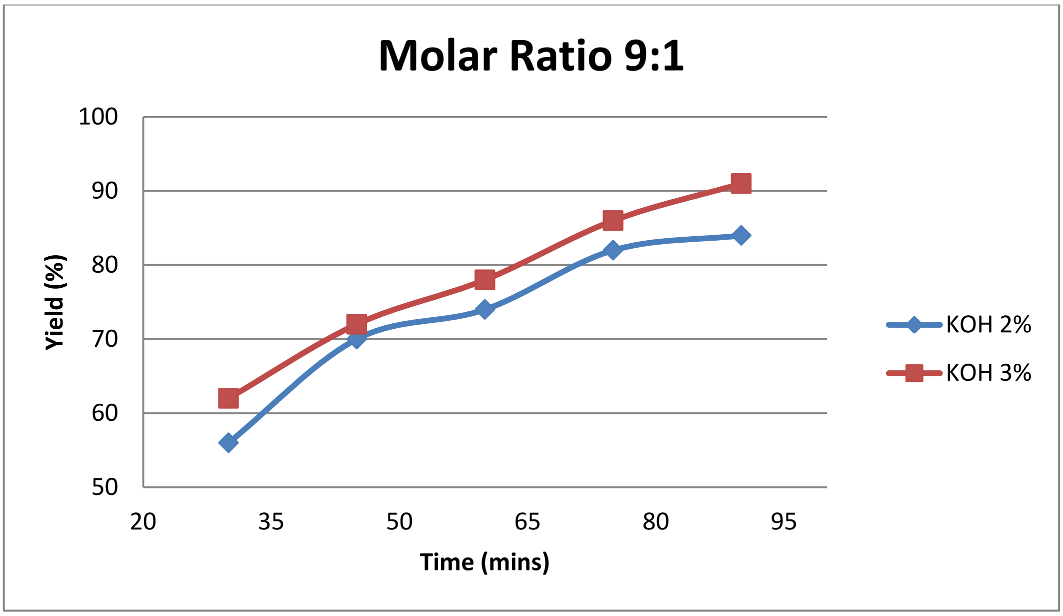


Fig.26. Variation of yield at different KOH with molar ratio 9:1.

Table 20. Yield Variation at different KOH

Time (mins)	MR 6:1 (%)	MR 9:1 (%)
30	56	62
45	70	72
60	74	78
75	82	86
90	84	91