

**PERFORMANCE AND EMISSION CHARACTERISTICS
OF DIESEL ENGINE USING KARANJA OIL METHYL
ESTER AND EUCALYPTUS OIL BLENDS**

Thesis

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Pantnagar
July, 2018


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CERTIFICATE – I

This is to certify that the thesis entitled “**PERFORMANCE AND EMISSION CHARACTERISTICS OF DIESEL ENGINE USING KARANJA OIL METHYL ESTER AND EUCALYPTUS OIL BLENDS**” submitted in partial fulfilment of the requirements for the degree of **Master of Technology** in Mechanical Engineering with major in **Thermal Engineering** of the College of Post-Graduate Studies, G.B. Pant University of Agriculture and Technology, Pantnagar, is a record of *bonafide* research carried out by **Mr. Harikrishna Nagwan**, Id. No. **51120** under my supervision and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation and source of literature have been duly acknowledged.

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We, the undersigned, members of the Advisory Committee of **Mr. Harikrishna Nagwan**, Id. No. **51120**, a candidate for the degree of Master of Technology in Mechanical Engineering with major in **Thermal Engineering**, agree that the thesis entitled **“PERFORMANCE AND EMISSION CHARACTERISTICS OF DIESEL ENGINE USING KARANJA OIL METHYL ESTER AND EUCALYPTUS OIL BLENDS”** may be submitted in partial fulfillment of the requirements for the degree.



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%	:	Percent
°C	:	Degree Celsius
API	:	American Petroleum Institute
ASTM	:	American Society of Testing and Materials
bhp	:	Brake Horsepower
BIS	:	Bureau of Indian Standard
BP	:	Brake Power
BS	:	Bharat Stage
BSFC	:	Brake Specific Fuel Consumption
BTE	:	Brake Thermal Efficiency
Cal	:	Calories
cc	:	Centimeter Cube
CI	:	Compression Ignition
CO	:	Carbon Monoxide
CO ₂	:	Carbon Dioxide
cSt	:	Centi Stoke
DI	:	Direct Injection
EGT	:	Exhaust Gas Temperature
etc.	:	And the rest
et al.	:	And Others
EU	:	Eucalyptus Oil
FFA	:	Free Fatty Acid
Fig.	:	Figure
g	:	Gram
g/cm ³	:	Gram per Centimeter Cube
HC	:	Hydrocarbon
h	:	Hour
HSU	:	Hartridge Smoke Unit
IC	:	Internal Combustion
IOCL	:	Indian Oil Corporation Limited
IS	:	Indian Standard
K	:	Absorption Coefficient

kg	:	Kilogram
kJ	:	Kilojoules
KOME	:	Karanja Oil Methyl Ester
kW	:	Kilo Watt
l/h	:	Litre per Hour
m	:	Meter
Me	:	Methyl Ester
min	:	Minutes
MJ/kg	:	Mega Joule per Kilogram
ml	:	Millilitre
mm	:	Millimeter
MMT	:	Million Metric Tonnes
MPa	:	Mega Pascal
N-m	:	Newton Meter
NO _x	:	Nitrogen Oxides
ORG	:	Orange Oil
rpm	:	Revolution per Minute
Rs	:	Indian Rupee
s	:	Second
SAE	:	Society of Automotive Engineers
UHC	:	Unburned Hydrocarbon
v/v	:	By Volume Ratio
W	:	Watt



Introduction



Energy is a primary requirement of a developing and developed country. In mid eighteenth and early nineteenth century industrial revolution took place in the European countries like Great Britain. The necessity of energy was identified and petroleum based fuel became the major source of energy. Petroleum based fuel was consumed by industrial as well as transportation sector in parallel way, which was the main cause of decreasing the petroleum sources. Amount of gasoline and diesel consumed by transportation sector in 2014 was 70% and 99.6% in India. (**Press Information bureau, Government of India, 2014**).

Diesel and gasoline fuels are obtained from crude oil by the distillation process are in high demand in global economy but there are limited reserves available so these are called non-renewable sources of energy. Crude oil price history depends upon available reserves. This is the sign of future oil crisis which has an impact on the transportation as well as industrial sector. India is one among the fastest growing countries as far as industrialization is concerned, and crude oil is the backbone of growth. Petroleum Planning and Analysis Cell, ministry of petroleum reported 213.93 million metric tonnes (MMT) of crude were imported by India during 2016-17 which is worth Rupees 4.7 lakh crore and 82% of total oil requirement (**energy.economictimes.indiatimes.com**). Thus it is the necessity of today that finding some alternative and renewable sources of petroleum products to reduce the dependency on petro fuel.

Global warming has become a global issue today. This change in global temperature has impact direct on climate change which is seen worsening day-by-day. If there is temperature rise by 2°C, near about 7 million people would be affected by submergence of coastal land worldwide. In urban zone of Mumbai and Chennai there would be higher loss of economy. Fuel emission contributes the largest amount in environmental pollution (**Sharma and Sharma, 2014**). Direct pollution caused by fuel emission which contains CO, SO_x, CO₂ and NO_x are great contributors to smoke formation and disturb the biodiversity and ecosystem too. The emission by rail, road, and air are responsible by 80%, 13% and 6% respectively to pollute the environment

(Tata Energy Research Institute, 2006). Most of the Indian vehicles are often made by older technologies which are outdated in the developed world and also responsible for emission of hazardous gases. To reduce the emission BS-IV emission norms had been enforced for the entire country by the Government of India on April 2017. BS III norms stipulate 350 parts per million (ppm) sulphur, which decreased to 50 parts per million (ppm) in BS IV standards. HC, NO_x, and particulate matter emission are also lower in these norms. Besides, in many highly populated cities like New Delhi, BS-IV emission norms have been already enforced since April 2010. Upgrading the fuel standards will help to reduce the air pollution too. **(thehindubusinessline.com)**

Scientists, researchers and environmentalists are working in coordination to conserve the fossil fuels like petroleum products, coal and natural gases etc. They are trying to explore the renewable energy resources all over the world. It has been realized that the further energy needs of the transportation sector may not be filled by any other fuel in view of the tremendous research effects perused all over the world, developing useful future fuels. Ultimately the choice of alternatives will depend upon the availability and economics of the resources in a particular region. In this connection the interest shown in oxygenated fuels such as Karanja oil, Eucalyptus oil, Mahua oil and Tamanu oil as potential fuels for transportation and agriculture sector in India needs serious and quick attention. **(Grahm and Sprei, 2015)**

1.1 Biofuel an Alternative of Fossil Fuel

Biofuels appear to be a promising source in current energy-environment difficulties which are extracted from biomass. Along these lines, biofuels can likewise make a great open door for neighbourhood employments and markets. India is the nation with high capability of biomass and Government of India is additionally looking firmly to discover substitute of petroleum fuel for its transportation sectors, to decrease the dependencies on fossil fuels. Biofuels can be classified based on their physical state as:

1. Solid biofuels (wood and charcoal)
2. Liquid biofuels (alcohols, biodiesel and vegetable oils)
3. Gaseous biofuels (biogas)

1.2 Vegetable Oils: A Renewable Source of Energy

Vegetable oils are renewable sources extracted from plants or trees. Since 1930 research has been conducted on fatty acid methyl esters which are a converted form of vegetable oils. Before World War II the availability of petroleum fuel was widespread and the cost of fuel was low. But after the World War II oil crisis took the attention of researchers towards vegetable's oil again and became a valuable alternative of diesel fuel.

Ethanol blending with gasoline is a good alternative to save fossil fuels as well as environment. Till 2022, government has set the target to bring down total petro fuel requirement to 67% from 77% in the year 2016-17 by replacing it with ethanol, biodiesels and renewable energy sources (**Ministry of petroleum and natural gas, 2016-17**). Indian government had already been planning to blend 20% of ethanol in gasoline since 2008 which became an optimized step in this field. Biodiesel is an important step in this scenario. Indian biodiesel policy is different from policy other countries because it is mainly based on non-edible sources of oil such as palm oil, jatropha oil, Tamanu oil, Mahua oil, Karanja oil, Eucalyptus oil and Pine oil etc. which contains 30% of oil in their seeds, nut or fruit (**Altenburg, 2009**). In India there are 75 non-edible plant species found till now in which fruits or nuts contain 30% or more oil.

1.3 Problems in Engine, Running with Vegetable Oils

Although, vegetable based non-edible oils are good alternative of diesel fuel but due to the physical and chemical properties of vegetable oils, it require slight modification in diesel engine (**Hunke and Barsic, 1981**). Biodiesels are full of energy contents but have high viscosity and density in comparison to commercial diesel fuel. Thus it is not acceptable to use pure or virgin vegetable oil directly in CI engines (**Burwer et al., 1991**).

Because of the high thickness of vegetable oils the engine affected with some problems such as gum deposition, flow atomization, high smoke and particulate emission. These effects further become the cause of reduction in brake thermal efficiency and reduce the life of engine because of carbon deposition. Thus, certain

modifications are required in pure vegetable oils to use it for direct injection in CI engine.

1.4 Biodiesel: A replacement of diesel

Biodiesels are non-petroleum based fuel consisting of long chain of fatty acids. These fuels are derived from renewable sources such as plants and animal fats. Biodiesels are produced by the chemical reactions of vegetable oils and animal fats with ethanol or methanol. These fuels are also called methyl or ethyl esters.

Keeping in mind the end goal to defeat the problems of direct use of vegetable oils in diesel engine, it must be converted into biodiesel by four different ways which are blending, pyrolysis, microemulsion, esterification and transesterification (**Bhattacharyya and Reddy, 1994**) for smooth operation of the engine. Transesterification process after esterification is one the best method suggested by various researchers. It is the method to remove fatty acids present in vegetable oils in the form of glycerol. It improves various properties of the vegetable oils such as viscosity, density, calorific value, flash point, fire point, cloud point and pour point so that it can be utilized in CI engine without any major engine modification.

Vehicle powered by biofuels became predominant before fossil fuels when Rudolph Diesel invented engine in 1892 and was first run on peanut oil just after Henry Ford designed his original 1908 Model T engine which ran on ethanol. Henry Ford also predicted in the year 1925, “The fuel of the future is going to come from fruit like sumac, or from apples, weeds, sawdust almost anything”. But due to its limited supply, less economical and lower efficiency fossil fuels became more practical and use of biofuels almost disappeared.

1.4.1 Advantages of biodiesel

Biodiesels are sustainable power sources and some critical natural advantages can be accomplished out of the usage as fuel in CI engine. There are various advantages of using biodiesel in CI engine such as

1. Biodiesel is free from toxicity, sulfur, lead and aromatics compounds.

There is 8% to 10% oxygen by volume present in biodiesel which leads to complete and proper combustion of fuel so that emission of harmful pollutants

such as CO and smoke get reduced. It also reduces the emission of carbon dioxide which is mainly responsible for greenhouse effect.

2. Longer chain of hydrocarbons is the main cause of HC emission. Biodiesel contains shorter chain of hydrocarbons than diesel. So HC emissions get reduced.
3. Biodiesel also helps in reducing friction as lubricants because it has higher viscosity than diesel.
4. It has higher flash point than diesel which make its storage safer than diesel fuel.

1.4.2 Disadvantages of biodiesel

Biodiesel has following disadvantages also.

1. Biodiesel contains higher pour point which results in starting problems during cold weather.
2. Injectors, filters get choked during long run with biodiesel.
3. Carbon is deposited on piston head of the engine during long run.

1.5 Objectives

From the above discussion, it is evident that there is a need of exploring more novel biofuels for every country to attain self-sufficiency on fuels and to protect the environment. So, in this context a research work undertaken on single cylinder compression ignition engine operating on Karanja oil methyl ester and Eucalyptus oil fuel blends with following objectives.

1. To study the different physical and chemical properties of pure Eucalyptus, Karanja oil and diesel fuel.
2. Transesterification of pure Karanja oil to convert it into Karanja oil methyl ester (KOME).
3. To study the chemical composition present in Karanja oil methyl ester and Eucalyptus oil and comparing it with neat diesel fuel.
4. To determine the different properties such as miscibility, viscosity, density, Gross calorific value, flash point, fire point, cloud point and pour point of different fuel blends of Karanja oil methyl ester and Eucalyptus oil.

5. Evaluate the performance characteristics such as fuel consumption, brake specific fuel consumption and brake thermal efficiency of diesel engine using Karanja oil methyl ester and Eucalyptus oil.
6. Estimation of emission characteristics of diesel engine such as Exhaust gas emission and exhaust gas temperature using different fuel blends of Karanja oil methyl ester and Eucalyptus oil.
7. Comparison of the obtained results with diesel fuel.

1.6 Organization of Research Work

The research work has been divided into five chapters which are following.

1. Chapter 1 presents introduction of research work.
2. Chapter 2 presents literature review related to the research work. In this section research work done by researchers on the use of Karanja oil biodiesel, Eucalyptus oil and full replacement of diesel by biofuels in diesel engine have been explained.
3. Chapter 3 presents materials and methods. In this section an overview of materials, apparatus, fuel used, preparation of Karanja oil biodiesel from crude Karanja oil, chemical composition of fuels and methods used to determine of various test fuel properties, performance parameters and engine exhaust emissions measurement presented.
4. Chapter 4 consist of results and discussion. In this section experimental results of fuel properties tests, engine performance and exhaust emission tests have been discussed.
5. Chapter 5 presents summary and conclusions based on the previous chapters, recommendations and suggestions for future research work.



*Review
of
Literature*



Different vegetable oils and animal fats are being examined by many researchers as an alternative of diesel fuel, due to limited resources of fossil fuels, increasing crude oil prices and increasing environmental pollution. In this chapter the review of some previous researches on alternative of fossil fuels has been discussed.

2.1 Use of Biodiesel in Diesel Engine

Hribernik and Kegl (2007) analyzed the performance and emission characteristics of two different engines, one was naturally aspirated and another was turbocharged diesel engine. They analyzed the influence of different test conditions on performance and emission characteristics of diesel engines using of 100% biodiesel as well as neat diesel. They found that combustion and emission characteristics of engine were different for a particular engine under same atmospheric conditions but operational parameters were similar for both of the engine using biodiesel. They concluded that engines brake power was reduced by 5%, fuel consumption was increased by 8% and BTE remained constant using biodiesel compared to diesel.

Agarwal and Agarwal (2007) performed an experiment on diesel engine using the blends of Jatropha oil and diesel and revealed that viscosity of Jatropha oil was approximately similar as pure diesel at 100°C. So Jatropha oil should be heated to 100°C before using it into the engine so that property is closer to diesel at 40°C. He also found that in case of 30% Jatropha oil blended with diesel shows same viscosity as diesel at 40°C. Optimum fuel injection pressure was found 200 bar for diesel and preheated Jatropha oil. For Jatropha oil CO₂, CO, HC and smoke opacity were higher compared to that of diesel, but when preheated diesel was used, these emissions were found approximately close to the diesel. The Thermal efficiency of the preheated diesel was found higher than unheated diesel while BSFC was found lower which is desirable. Therefore, Jetropha oil biodiesel can also be directly used in the diesel engine with full replacement of diesel without any major modification.

Bueno *et al.* (2010) performed an experiment on six-cylinder, turbocharged, high speed diesel engine fuelled with selected fuel blends of Soyabean oil ethyl esters in different percentage as 10%, 20% and 30% with neat diesel at fuel injection pressure of 220 and 300

bar with 17.8:1 compression ratio. Brake thermal efficiency was observed 4.16% more than diesel fuel using B20 fuel blend. Reduction in combustion time also observed as 1.81%, 1.87% and 1.97% with B10, B20 and B30 fuel blend respectively.

Nayak and Pattanaik (2014) performed an experiment on single cylinder, 4 stroke diesel engine using different blends of Mahua oil and Dimethyl carbonate as an additive and compared the results with neat diesel. They revealed that brake thermal efficiency increased and BSFC decreased with increasing the ratio of additive in test fuels. All fuel blends show the decrement with respect to diesel in carbon monoxide, hydrocarbon. NO_x and smoke emission was decreased with increased percentage of additive and attain minimum value with 15% additive. They concluded that biodiesel showed improvement in performance and emission characteristics when it mixed with additive.

Chhabra et al. (2016) conducted experiments at different compression ratio with rice bran biodiesel and found the optimum value of compression ratio. They mixed biodiesel in 10%, 20% and 40% with pure diesel at the compression ratio of 12 to 14 and evaluated the performance and emission characteristics. They obtained maximum brake thermal efficiency and minimum fuel consumption at compression ratio 14. Regarding emission characteristics they found minimum CO and CO₂ emission with 10% and 20% biodiesel blends at 12 and 14 CR while, increasing NO_x emission was also reported.

Shukla et al. (2017) used blends of Jatropha oil biodiesel in 20%, 40% and 60% with diesel in CI engine. They obtained maximum thermal efficiency and minimum brake specific fuel consumption by blending of 20% biodiesel with diesel. 20% biodiesel blended with diesel showed 11% reduction in exhaust gas temperature with respect to diesel fuel at 50% loading. CO and CO₂ emission of all three blends were much lower than diesel fuel. At last they concluded that diesel and Jatropha biodiesel combination is a good alternative of pure diesel without any modification in diesel engine as well as without sacrificing the performance of the engine.

2.2 Use of Karanja Oil Methyl Ester in Diesel Engine

Srivastava and Verma (2007) prepared Karanja oil methyl ester from pure Karanja oil and prepared it blends with diesel in various ratios and revealed that thermal efficiency in the case of neat biodiesel was lower than blends of KOME-diesel which is because of lower calorific

value of KOME. HC and CO emissions found lower with Karanja oil methyl ester and diesel blends compared to using KOME as neat fuel. NO_x emission was 12% higher than diesel because of increased temperature of combustion chamber.

Rao (2011) tested diesel engine with Karanja oil methyl ester, preheated Karanja oil methyl ester and diesel and compared the performance and emission results obtained. Author concluded that higher peak pressure was obtained by use of Karanja oil methyl ester than neat diesel fuel which was due to the higher bulk modulus of KOME caused advanced dynamic injection. Peak cylinder pressure was found decrease for preheated KOME because of late injection and higher evaporation rate. Author found 6% increment in NO_x emission than diesel using KOME fuel at full load condition but significant reduction in NO_x emission was also observed using preheated Karanja oil methyl ester fuel.

Bobade and Khyade (2012) prepared the Karanja oil biodiesel by transesterification followed by esterification and concluded that the preparation of biodiesel from edible oil was very costlier than diesel and not fit for Indian requirements. Biodiesel from non-edible oil provided the economic benefits to local and nation too. They also concluded that, it is a requirement of today that there should be a modification in chemical processes to increase the yield of ester produced.

Dhar and Agarwal (2014) studied use of Karanja oil methyl ester in diesel engine and its impact on engine characteristics. They conducted the experiment with variation in load and speed from 1800 rpm as a rated speed to 2600 rpm as a maximum speed and showed the detail results of performance and emission characteristics for different blends. Results revealed that 10% and 20% blends of Karanja oil biodiesel produced maximum torque in the 1700-1800 rpm speed range, which was 0.7 and 0.3% higher respectively in comparison to neat diesel fuel. This may be due to the oxygen content present in biodiesel which leads better combustion but for higher blends of biodiesel reduction in torque observed because of lower calorific value. BSFC is higher for the high content of biodiesel and increased with speed. The Optimized value of BSFC was found at 1800 rpm. Thermal efficiency for higher blends of biodiesel was decreased and lower than that for neat diesel. CO emission was higher at low load and decreased at the higher load while NO_x emission was higher at high load compared to diesel fuel. HC emission was lower than that for neat diesel.

Gangil *et al.* (2016) evaluated performance and emission characteristics of Karanja oil methyl ester in 20%, 40%, 60%, 80% and 100% with diesel fuel blends. They found from experimental results that B40 blend indicated better performance and emission compared to the others blends. They concluded that all Karanja oil methyl ester and diesel blends showed BSFC closer to diesel fuel, while thermal efficiency and brake power increased with lower concentration of fuel blends. This may be because of the improved lubrication properties as well as higher oxygen content present in Karanja oil methyl ester. Exhaust emission such as CO, CO₂ and HC emissions get lowered due to smaller carbon chain present in Karanja oil methyl ester compared to diesel. While, NO_x emission increased by 2.5% for B40 and 7.1% for B100 fuel blends compared neat diesel.

2.3 Uses of Eucalyptus Oil as an Alternative Fuel

Tarabet *et al.* (2012) prepared blends of eucalyptus oil in 75%, 50% and 25% with diesel fuel and test it on single cylinder, air cooled DI diesel engine at different loading conditions. They revealed that there is not any undesirable increment in cylinder pressure was shown during the combustion analysis. Combustion started earlier which resulted increased combustion duration with increasing the concentration of biodiesel. Regarding performance analysis they observed increment in BSFC while decrement in BTE with increasing the volume of biodiesel. Exhaust emission such as carbon monoxide, hydrocarbon and other particulates decreased with increased biodiesel percentage at all loads. Increment was also shown in NO_x emission. At last, they concluded that Eucalyptus oil is a good alternative of diesel with compromise of BTE and NO_x emission.

Anandavelu *et al.* (2014) investigated the potential use of Eucalyptus oil in diesel engine in the low heat rejection condition of the engine. They blended Eucalyptus oil at different percentage with neat diesel and compared the performance and emission characteristics of coated and uncoated diesel engine. Low heat rejection was achieved by thermal barrier of combustion chamber using yttria stabilized zirconia coating. Result shows reduction in fuel consumption and increased brake thermal efficiency. CO and NO_x emissions were reduced but smoke density and unburned hydrocarbon increased in the case of coated engine comparing with uncoated engine.

Senthur *et al.* (2014) prepared biodiesel from Eucalyptus oil by transesterification process and mixed it at 10%, 20% and 30% with neat diesel and prepared fuel blends. They concluded that there is significant reduction of hydrocarbon and carbon monoxide emission using prepared fuel blends. While fuel consumption and brake thermal efficiency is similar or slightly higher and lower respectively than neat diesel. Thus, it is a good alternative to reduce the emission of diesel engine with negligible compromise in performance of engine.

Varma *et al.* (2015) explained the practicality of Eucalyptus oil and its influence on performance and emission of the diesel engine. They take two different sample of oil (named as Sample A and Sample B) containing different properties like density, viscosity, Boiling point, low heating value, Flash point and cetane number. The results of experiment which was performed on diesel engine (5 kW) and showed that BSFC decreased by 2.34% and 2.93% by using B10 blend, but by increased volume of biodiesel in blend ratio the calorific value decreased and specific gravity increased which leads to higher mass flow rate of fuel than diesel for similar power production. Thermal efficiency decreased by 0.52% and 0.94% because of poor atomization and vaporization of the biodiesel-diesel blends. As the ratio of biodiesel increased in blend thermal efficiency reduced consequently. The blending of biodiesel improved the emission characteristics. HSU for B10 blend was decreased by 64.5% and 62.5% respectively for blend A and B. At last, they concluded that use of Eucalyptus biodiesel is an environment friendly step with very less effect on engine performance.

Subramanian *et al.* (2016) compared the engine performance and emission characteristics of different dual fuel blends at part load as well as full load. They mixed different low carbon fuel such as Eucalyptus oil, Pine oil, Camphor oil and Orange oil with Karanja oil methyl ester in 50% and compared the obtained results with diesel fuel. They observed that all low carbon fuel with Karanja oil methyl ester showed lesser carbon dioxide emission than diesel fuel. KOME-ORG fuel blend showed maximum reduction (13%) in CO₂ emission compared to KOME while, 6% reduction observed in HC emission compared to diesel at 100% loading condition. KOME-ORG fuel blend also showed increment in BTE, NO_x and CO emissions. At last, they concluded that KOME-ORG fuel blend is the best fuel among all blends tested.

2.4 Concept of Dual Fuel and Complete Replacement of Diesel

Devan *et al.* (2008) investigated the concept of complete replacement of diesel fuel by the combination of the methyl ester of Paradise oil and Eucalyptus oil. They revealed that, low cetane value of Eucalyptus oil could be compensated by high cetane number of Paradise oil. Brake thermal efficiency was increased by 2.4% for the Me50-Eu50 blend due to the approximate equal delay time of Eucalyptus oil to diesel and there was fast burning also observed which leads to increased brake thermal efficiency. There was better fuel economy also observed in the case of Me50-Eu50 blend in the comparison of other blends. The result also showed 49%, 34.5% and 37% decrement in smoke, HC and CO emissions respectively but due to the lower cetane number of Eucalyptus oil, the air-fuel mixture accumulates more which result in increase of exhaust gas temperature, further it was also evident in increase of NO_x emission. They concluded that Me50-Eu50 blend showed better performance and lower emission than diesel fuel so that Me50-Eu50 fuel blend was the optimum and successful replacement of diesel fuel.

Krishnasamy *et al.* (2011) performed an experiment on turbocharged truck diesel engine using methanol and Karanja oil biodiesel. The experimental results reported that ignition delay was increased by using of methanol comparing with 100% biodiesel while, peak cylinder pressure was decreased. Thermal efficiency of methanol-biodiesel blend was increased by 4.2% at 80% load with adding 10% methanol in biodiesel relative to 100% biodiesel. The CO and UHC emission were higher for B90M10 blend compared to 100% biodiesel at low load, but HC emission was comparable at higher load and CO emission decreased. Maximum decrease in CO emission was 46.5% at full load condition compared to pure biodiesel. Smoke and NO_x emission also decreased with biodiesel-diesel blends and followed the trend as CO emission. Maximum decrement in smoke and NO_x emission was found as 96.4% and 37.3% relatively at 80% loading condition with methanol-biodiesel blend compared to pure biodiesel.

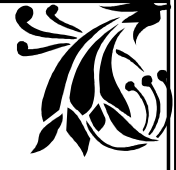
Senthilraja *et al.* (2014) studied the engine performance and exhaust emission by response surface methodology using dual fuel Pongamia oil methyl ester (0 to 30%) and CNG (0 to 20%). In this study a single cylinder, four stroke water cooled diesel engine was converted into a dual fuel system operated with either diesel fuel or blend with CNG using an electronically controlled solenoid actuated valve mechanism. The experimental results showed

significant effect on the engine performance by all the process variables. The emission characteristics (CO, CO₂, NO_x, and Smoke emission) were found significantly lower than the diesel fuel emissions. They developed second order polynomial models from the experimental results to predict the response variables.

Vijayabaskar *et al.* (2015) investigated experimentally the double fuel concept in diesel engine instead of pure diesel by prepared the blends of Karanja oil as a base fuel in 25%, 50%, 75% with Pine oil and studied the performance and emission characteristics of a diesel engine. The viscosity of Pine oil is lower than diesel fuel which can be compensating the undesirable effect of higher viscosity of the Karanja oil. They concluded that, the fuel blend 50% of Karanja oil and 50% of Pine oil could be optimum combination comparing to other blends. Although, in the case of B25P75 blend the thermal efficiency increased by 8% and HC, CO and smoke emission decreased by 14.9%, 43.2% and 33.4% respectively but due to the high rate of heat release the NO_x increased and there is also a knocking problem at higher loads. BTE and BSFC for B50P50 blend were close to diesel and the emission of HC, smoke, and CO was 12.5%, 8.1%, 18.9% lower than pure diesel. At last they also recommended the use of an additive which may prevent the engine from harmful effects like carbon deposition, injector clogging and the formation of soot particles of biodiesel.

Srinivas *et al.* (2016) studied the emission and performance characteristics of the diesel engine with replacing diesel fuel completely by biodiesels. In the experiment 5%, 10% and 15% by volume of Eucalyptus oil have been taken with Palm kernel oil and compared it with neat diesel oil. They revealed that all the fuel blends show the reduction in CO, Smoke intensity when it was compared to neat diesel fuel. 41.09% reduction in CO emission while Smoke intensity was reduced by 37.05% for B15 blend when operating at full load. B15 blend exhibited highest NO_x emission compared to diesel and other fuel blends because of higher oxygen content availability in biodiesel and complete combustion leading increasing in combustion chamber temperature. Regarding performance test, they studied that the low cetane number of Eucalyptus oil can be compensated by high cetane number palm kernel oil biodiesel. They also conclude that rate of combustion is influenced by peak pressure. When the load is increased cylinder peak pressure also increased due to lower cetane number of Eucalyptus oil than diesel.

Senthil *et al.* (2016) performed an experiment on diesel engine using Annona-Eucalyptus oil blends and antioxidant additive and reduced the gases formed in exhaust emissions. They prepared the blends of Annona biodiesel in 10%, 20%, 30%, 40% and 50% with Eucalyptus oil and noted that the Eucalyptus oil has lower viscosity and cetane number as compared to Annona biodiesel so blends became highly volatile. But during the use of 100% Eucalyptus oil a problem was encountered in the starting of the engine at low temperature because the pour point of Eucalyptus oil is higher than diesel. The results showed higher brake thermal efficiency and lower BSFC by using A50-EU50 blend than other fuel blends and neat diesel which is because of low density and higher calorific value of Eucalyptus oil leading to better atomization. BSFC is lower because of higher content of oxygen present in Eucalyptus oil which results better combustion. Regarding emission characteristics they concluded that using A50-Eu50 blend emitted lower CO and HC compared to diesel and other blends. The NO_x emission was high in the case of the A50-Eu50 blend because of high oxygen content present in fuel blend which leads to complete combustion and increased combustion temperature. Further the NO_x emission was reduced by using the additive. It was observed that the reduction in NO_x emission was found 21% less by the use of additive.



*Materials
and
Methods*



Experimental tests were performed in the IC engine laboratory of Department of Mechanical Engineering, College of Technology, G.B. Pant University of Agriculture and Technology, Pantnagar. In this chapter preparation of biodiesel from pure oil, experimental details and methodology used in testing of fuel blends, procedure to perform the experiments on engine to obtain performance and emission characteristics are described.

3.1 Test Fuels

Different blends of Karanja oil methyl ester and Eucalyptus oil were taken for experiment. Both oils were purchased from local distributor of Pantnagar. Karanja oil biodiesel or Karanja oil methyl ester was prepared by the esterification and transesterification process. Karanja oil methyl ester was taken in 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80% and 90% with Eucalyptus oil to prepared different fuel blends such as K10EU90, K20EU80, K30EU70, K40EU60, K50EU50, K60EU40, K70EU30, K80EU20 and K90EU10. Properties of different fuel blends like viscosity, density, calorific value, cloud point and pour point were obtained from different instruments in IC engine laboratory.

3.1.1 Karanja tree

Karanja oil derived from the seeds of Karanja (*pongammia pinnata*) tree which grows in tropical region and temperate climate of Asia at 1200 m above from sea-level. It generally requires 0 to 50°C temperature and sandy and rocky soil.



Fig. 3.1(a): Karanja seeds



Fig. 3.1(b): Karanja flowers

It grows slow in early stage and annual weed control is necessary till three years from plantation. It is 15-25 meter in height and equally wide canopy. It has hemispherical crown leaves which are dark green in colour. After 3 to 4 years white, purple and pink flowers blossom on the tree. Seeds are contained inside the flat elliptical curved pods which is generally 1.5 to 2.5 cm long and brittle in nature. It provides dense shade which leads to slow surface water evaporation. Pictures of Karanja seeds and flowers are shown in figures 3.1(a) and 3.1(b). Karanja tree has also a nitrogen fixation nature by its root nodules. Nitrogen fixation is the process by which nitrogen gas present in air convert into ammonia.

3.1.2 Eucalyptus tree

Eucalyptus regnans, predominantly occur in Australia. It grows tall and known as the plant of blooms. It has a pleasant scent and intriguing bark and foliage and goes under the group of Myrtaceae. Pictures of Eucalyptus tree and blossomed flowers are shown in figures 3.2(a) and 3.2(b). There are 700 species of this tree and in excess of 300 species contains volatile oil in their leaves. It grows in tropical and temperate places for example Europe, Africa, America, centre east, China, and India. Diverse alluring properties like quickly developing, source of wood, oil maker, allopathic impacts draw in the consideration of scientists. It additionally attracts the attention of horticulture, global development and environment researchers.



Fig. 3.2(a): Eucalyptus tree



Fig. 3.2(b): Flowers and seeds of Eucalyptus

Different species of Eucalyptus have different height which varies from 10 m to 200 m and complete 60 percent of their growth within 10 years. It is single stem tree and may be in the form of shrub or a very large tree (**Karnick, 1994**). Ayurvedic pharmacopoeia pointed out the medicinal purpose of Eucalyptus oil and noted that there is a contemporary application of Eucalyptus oil for headache due to cold and cough.

3.1.3 Extraction of oils

Eucalyptus and Karnaja oil are extracted from the seeds of Eucalyptus and Karanja by a mechanical expeller, solvent extraction and cold percolation method using normal hexane as a solvent. Eucalyptus seeds contain about 60% oil which is in the form of cineole content. It is the colourless and water soluble ether whereas a Karanja seed contains 25-30% oil. (**Mehar *et al.*, 2004**).

3.2 Preparation of Biodiesel

Oil extracted after mechanical extraction process is not suitable for direct use in diesel engine due their inappropriate properties such as high viscosity, low pour point, longer molecular chain, low vapour pressure low calorific value and higher flash point. These features cause many problems such as poor atomization, fuel injector damage, incomplete combustion, low pressure and unburned solid particle deposition inside the engine. These factors result in poor engine performance. Thus, it is necessary to enhance the properties of oils so that engine could perform well and for long period. In present work properties of Eucalyptus oil is under the limit of American Standard of Testing Material (ASTM). Therefore it can be directly used in the diesel engine without any pre-treatment but Karanja oil's properties are not within ASTM range, so it is necessary to convert it into Karanja oil methyl ester. There are various methods to produce biodiesel or Karanja oil methyl ester from the Karanja oil such as:

1. Method of direct use and blending
2. Micro-emulsion method
3. Thermal cracking technique
4. Esterification and Transesterification method

Esterification and transesterification methods are very common methods used by researchers previously and also employed in this thesis work. Method used to make biodiesel is discussed in detail below.

3.2.1 Esterification and transesterification methods

Methyl ester of Karanja oil produced from crude Karanja oil by chemical reaction of crude Karanja oil with alcohol and catalyst as shown in figure 3.3. H_2SO_4 (98% pure) used as an acid catalyst (0.5% of oil weight) is mixed with preheated (50°C) crude oil. After that 13% of methanol is added with it and stirred at 500-700 rpm at 57°C for 90 minutes inside a closed vessel. After 90 minutes, free fatty acid contents in oil will separate and proceed to further step which is called transesterification reaction.

In transesterification process Sodium hydroxide is used as a catalyst in the amount of 1% of oil weight which is then added to methanol (13% of oil weight). This alcohol-catalyst (methoxide) solution is prepared in 20 min by stirring it at 700 rpm. The solution should be prepared freshly to keep catalyst active and prevent the moisture absorbance. The solution is then slowly mixed with preheated esterified oil and then sealed immediately to prevent the loss of alcohol and moisture absorbance. The temperature of reaction is maintained at 60 to 65°C which is near to the boiling point of methanol. There is 70 min time and 500-700 rpm stirring speed is recommended for this reaction (**Jerry, 2016**).

Methyl ester which is formed after transesterification process is transferred to separating funnel after cooling it and allowed to settle for 24 hours. Two layers of oil form inside the funnel after 24 hours. Upper layer which is a desirable product called methyl ester or biodiesel is lighter than the lower layer called glycerol. Glycerol is higher density product which can be used in making glycerine, paint and soap. Excess alcohol presence in biodiesel can be removed by distillation process, and residual catalyst or soap presence in biodiesel removed by washing it with warm water.

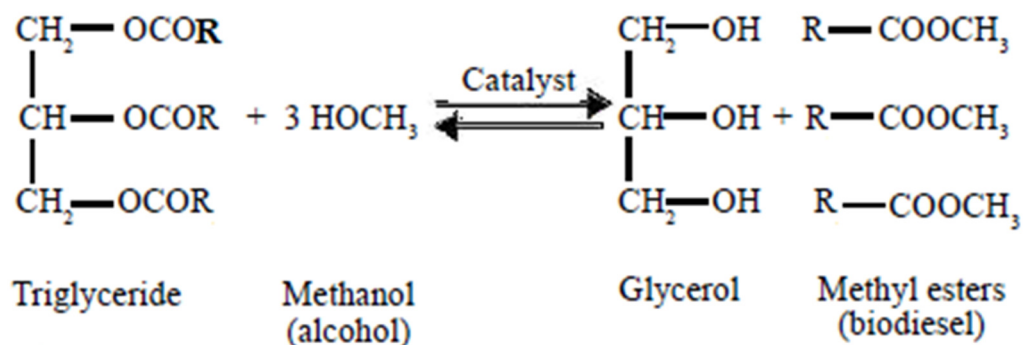


Fig. 3.3: Esterification reaction (Source: Jerry, 2016)

3.2.2 Procedure Used to Prepare Biodiesel

Biodiesel was prepared by crude lab graded Karanja oil in mechanical department's laboratory. Magnetic stirrer of 500 ml capacity, conical flask, thermometer and electronic weighing machine were the equipment used. Figure 3.4(a) shows the experimental setup used for the esterification and transesterification of the Karanja oil. 250 ml oil was filtered and its weight was measured before being poured into conical flask. Then water was taken in an aluminium pot and heated to 50°C. Conical flask containing oil was then lowered into the water slowly. When the temperature of oil also reached 50°C, H₂SO₄ and methanol of 0.5% and 13% of oil weight were mixed with it. Flask was then immediately closed with cork after putting magnetic stirrer bar inside it. Then mixture was stirred from 500 to 700 rpm with maintaining the temperature at 57±2°C. Reaction was stopped after 90 minutes. Then solution of methanol and Sodium hydroxide called Sodium methoxide was prepared separately by shaking with hands till 20 minutes or until catalyst dissolve completely in methanol.

After that Sodium methoxide was charged in the oil and then flask was closed immediately to prevent the vaporization of methanol. Mixture was put in the water again and stir for 70 minutes with the temperature maintained at 64±2°C. Now, mixture was poured into separating funnel and left inside for 24 hours to complete separation of oil. After 24 hours, upper layer called biodiesel was separate from lower layer and washed by distilled water and then heated again to remove moisture and excess amount of alcohol. Methyl ester or biodiesel obtained by above procedure was then contained in separate container. Biodiesel separation in separating funnel is shown in fig. 3.4(b).



Fig. 3.4(a): Preparation of biodiesel



Fig. 3.4(b): Biodiesel floated up in separating funnel

Weight and volume of Karanja oil, methanol and different catalyst taken in the experiment.

Volume of Karanja oil taken = 250 ml

Mass of Karanja oil = 222.8 g

Mass of methanol taken = $28.96 \times 2 = 57.928$ g

Mass of NaOH taken = 2.228 g

Mass of H_2SO_4 taken = 1.114 g

Biodiesel obtained by this process was 90 to 92% of weight of crude Karanja oil used initially. Procedure was repeated eight times to obtain approximately 1.8 litre oil.

3.3 Analysis of Functional Group

Analysis of Karanja oil methyl ester and comparison with Eucalyptus oil and diesel has been done with the help of infrared spectroscopy which is very helpful to predict the functional group present in methyl ester.

3.3.1 Infrared spectroscopy

Infrared belongs to electromagnetic waves having large wavelength, much bigger than the visible wavelength. Infrared light is very beneficial for understanding the structure of different chemical compounds specially the structure of different functional groups present in

the molecules. Infrared spectroscopy is also known as vibrational spectroscopy. It works on the basic principle of behaviour of bonds between different atoms. Bonds between atoms are not permanent or fixed they are always involved with different type of motions. These bonds can be stretched or dragged towards each other which results in oscillation between the atoms and known as stretching effect. There is also another effect which is known as wagging. So a chemical compound contains both effects stretching and wagging at on certain specific frequency. There is different kind of stretching and wagging for different bonds and functional groups. Those variations of frequencies among the chemical compounds gives so many varieties of data of frequency in the form of wavenumbers which helps to find out the kind of chemical compound present in the sample.

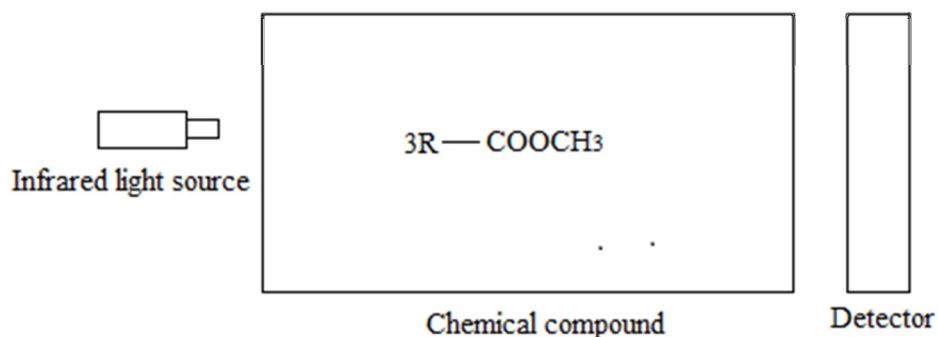


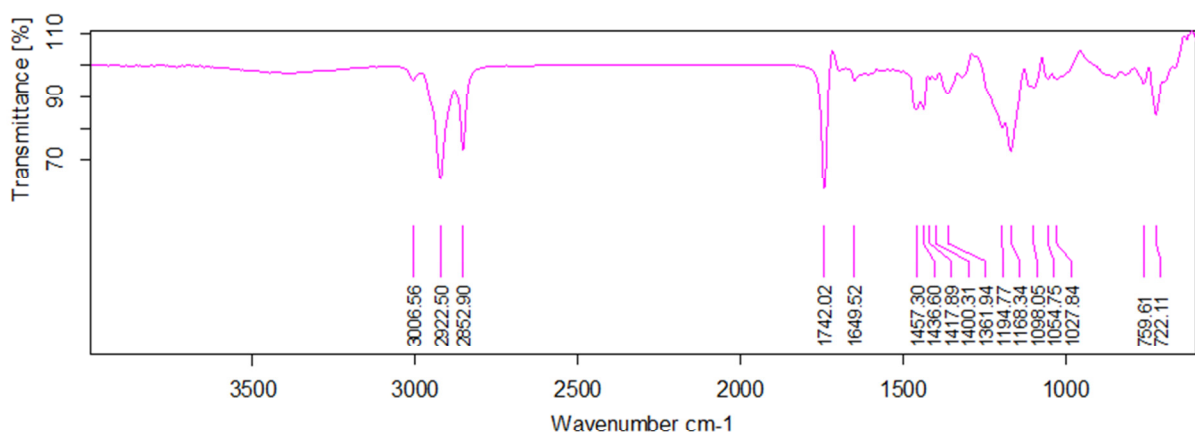
Fig. 3.5: Block diagram of infrared spectroscopy setup

Infrared spectroscopy was done in the laboratory of, department of environmental science, College of basic science and humanities. A simple block diagram of infrared spectroscopy is shown in fig 3.5. The sample of chemical compound was kept inside the chemical compound chamber where the infrared light falling on it. The frequency of infrared light was controlled manually. Light beam of different frequency was absorbed or transmitted by the compound. Percentage of different frequencies of light was detected on the detector which is placed after chemical compound chamber. Detector attached with a computer to plot the transmittance of different frequencies in the form of wave number ranging 3997.34 to 599.907 cm^{-1} .

3.3.2 Peak analysis

Transmittance versus wavenumber variation of Karanja oil methyl ester, Eucalyptus oil and diesel has been plotted on figures 3.4(a), 3.4(b) and 3.4(c). It represents notable differences in wavenumbers of KOMe and diesel fuel which is due to the presence of ester groups in biodiesel. The ester groups are described as R-COOCH₃ in biodiesel. Where, R is the representation of hydrocarbon chain which can be easily identified in the range of 2700-3300 cm⁻¹. Wave number ranges of different functional group are shown in table 3.1.

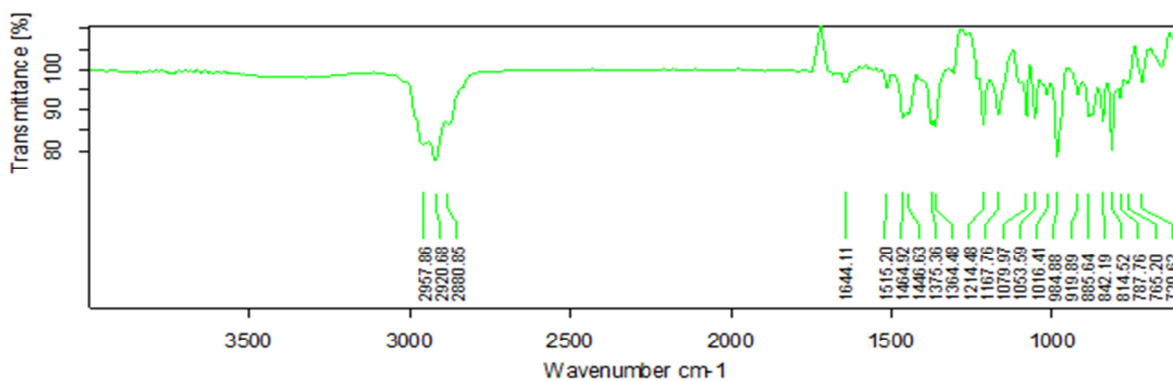
In the spectroscopy of all three fuels there is presence of a long hydrocarbon chain. The main difference can be observed on wave numbers 1742.02 cm⁻¹ and 1649.52 cm⁻¹ which is only present in Karanja oil methyl ester. It signifies the presence of carbonyl group or ester. Presence of esters means presence of oxygen, which evident to good combustion of fuel in diesel engine. The slight shifting frequency of carbonyl group is because of electron donating effect of methyl ester (Naureen *et al.*, 2014).



5/19/2018

Data Parameters TR	Values
Data Point Format	1
Number of Data Points	1666
Frequency of First Point	3997.340575
Frequency of Last Point	599.907161
Y - Scaling Factor	1.000000
Y - Maximum	1.108424
Y - Minimum	0.607688
Date of Measurement	19/05/2018
Time of Measurement	11:12:17.180 (GMT+5)
X Units	Wavenumber cm-1

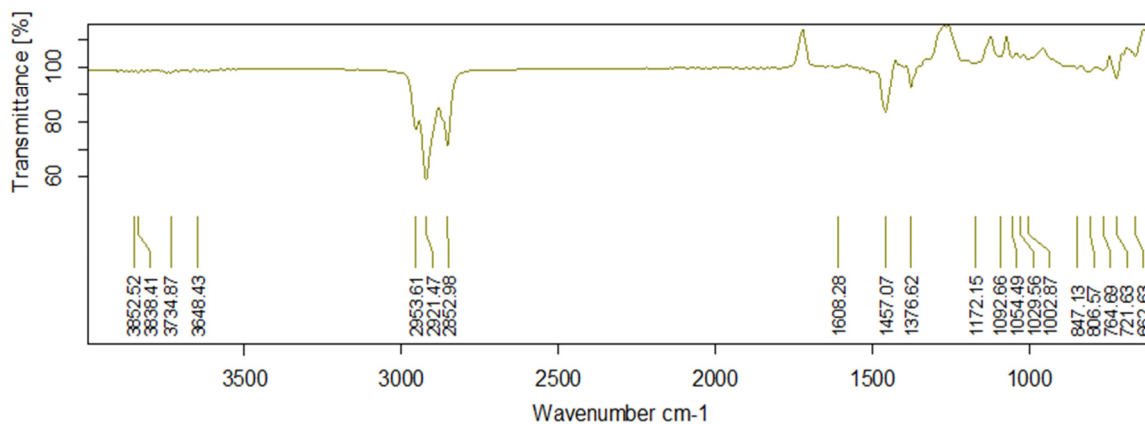
Fig. 3.6(a): Infrared spectroscopy of Karanja oil methyl ester



5/19/2018

Data Parameters IR	Values
Data Point Format	1
Number of Data Points	1666
Frequency of First Point	3997.340575
Frequency of Last Point	599.907161
Y - Scaling Factor	1.000000
Y - Maximum	1.106486
Y - Minimum	0.775567
Date of Measurement	19/05/2018
Time of Measurement	11:14:59.600 (GMT+5)
X Units	Wavenumber cm-1

Fig. 3.6(b): Infrared spectroscopy of Eucalyptus oil



5/19/2018

Data Parameters IR	Values
Data Point Format	1
Number of Data Points	1666
Frequency of First Point	3997.340575
Frequency of Last Point	599.907161
Y - Scaling Factor	1.000000
Y - Maximum	1.156716
Y - Minimum	0.585652
Date of Measurement	19/05/2018
Time of Measurement	11:17:22.880 (GMT+5)
X Units	Wavenumber cm-1

Fig. 3.6(c): Infrared spectroscopy of diesel

Table 3.1: Wave number range of functional group (Source – NPTEL spectroscopic technique)

Bond	Wave number
O-H	3650-3200
C-H	3300-2700
N-H	3500-3100
C-N	1350-1000
C=N	1650-1550
C=O	1750-1650
C-O	1250-1050

The sharp peak is not found in Eucalyptus oil and diesel spectrum. Spectra of Eucalyptus oil and diesel are almost similar which justifies its use in diesel engine directly. Both Eucalyptus oil and methyl ester of Karanja oil contain the peak at 1168 cm^{-1} wave number which represent the presence of C–O stretching vibration. The bending vibration of methyl group is represented by 1457.97 cm^{-1} and 1361.30 cm^{-1} wave numbers in biodiesel.

3.4 Test Fuel Blends Preparation

Fuel blends of Karanja oil methyl ester-Eucalyptus oil prepared in different selected percentage and terminology used in present study is shown in table 3.2. The pictures of fuel blends are shown in fig. 3.7(a) and 3.7(b). It was observed that fuel blends get dark colour by adding of KOMA in excess amount.

In the initial stage of work, the fuel blends were kept in the room temperature 30°C for 24 hours for testing of miscibility and stability. Then all the properties of different fuel blends

like kinematic viscosity, relative density, calorific value, flash point, fire point, cloud point and pour point are measured and plotted. All the properties determined according to Bureau of Indian standards.

3.5 Reference Fuel

The high-speed diesel marked by Indian Oil Corporation limited (IOCL) in accordance with IS: 1460-1974 is taken as reference fuel for comparison of test results. Diesel is a hydrocarbon fuel which contains carbon molecule in a number varying from 12 to 25. Diesel is mostly a heavy vehicle fuel and it is produced by distillation of crude oil. Diesel is not miscible with water and its relative density varies from 0.82 to 0.95. Diesel cetane rating varies from 40 to 55. It has negligible amount of oxygen molecule. On burning, diesel produces black smoke which is highly toxic in nature. For present study, IOCL marketed diesel is obtained from the University's filling station.

Table 3.2: Blends prepared for engine

S. No.	KOME Biodiesel (%)	Eucalyptus oil (%)	Terminology used
1.	10	90	K10EU90
2.	20	80	K20EU80
3.	30	70	K30EU70
4.	40	60	K40EU60
5.	50	50	K50EU50
6.	60	40	K60EU40
7.	70	30	K70EU30
8.	80	20	K80EU20
9.	90	10	K90EU10



Fig. 3.7(a): K10EU90, K20EU80, K30EU70 and K40EU60 test fuel blends



Fig. 3.7(b): K50EU50, K60EU40, K70EU30, K80EU20 and K90EU10 test fuel blends

3.6 Fuel Blends Properties

Fuel blends properties are measured in IC engine lab of mechanical department according to Bureau of Indian standards (**IS: 1448**), New Delhi. Following apparatus are used to measure the properties of fuel blends as well as diesel.

3.6.1 Kinematic viscosity

The property of resistance to flow when shear stress is applied between two adjacent layers of a liquid is called viscosity. It opposes the relative motion between two surfaces due to friction between the molecules of fluid. Ideal or inviscid fluid has zero shear resistance. It means different fluids with different viscosity flow at different speed when a force is applied on them. Force required to induce movement of fluid will be larger in case of more viscous fluid. So viscosity is a key for any process involving fluid flow. Kinematic viscosity is the ratio of dynamic viscosity and fluid density and expressed in stokes or centistokes (St or cSt).

Viscosity of the fuel is influenced by the temperature. It decreases with increasing the temperature of fluid. Viscosity affects the engine performance due to variation in atomization of different fuel's droplets. Higher viscous fuel droplets are poorly atomized which leads to incomplete combustion and injector chocking which further reduces the efficiency of engine. Engine is also affected by carbon deposit after long run period due to higher viscosity.

Redwood viscometer is an apparatus which is used to measure the kinematic viscosity shown in Fig. 3.8. Measurements were carried out at 40°C. This method of measurement is accepted for Newtonian fluid, in which shear stress is directly proportional to shear strain and possess linear relationship among them. In the experiment 50 ml fuel was collected in glass beaker under the virtue of gravity and time is noted between 30 to 2000 seconds. The fuel was filled in the cup up to a specific level, which is surrounded by water jacket having an immersed heater. Water is heated to 40°C by voltage regulator. The silver metal ball used for open and close the agate jet, fixed orifice made in an agate piece as per **IS: 1448 [P: 25] 1976**. A 50 ml glass beaker was held below the jet to collect the oil from oil cup and time was noted using stopwatch. Accurate Redwood seconds were obtained by repeating the experiment three times. Kinematic viscosity in cSt was evaluated by using the following empirical relationship (**Nakra and Chaudary, 1985**).



Fig. 3.8: Redwood viscometer

$$V = At - \frac{B}{t}$$

Where,

A and B are constants

V = Kinematic viscosity in centistokes, cSt

t = Flow time of 50 ml sample, s

For Redwood viscometer values of A and B are 0.26 and 172 respectively.

3.6.2 Relative density and API gravity

Density is the measure of compactness of the mass in a substance or object and relative density is the density of liquid relative to the density of water. In other words relative density is the ratio of density of liquid to the density of water. It also gives the information whether one liquid will sink or float in other fluid if they are not miscible. Relative density depends on pressure and temperature of fluid.

API gravity is part of the most basic test for fuel qualities. It is a great tool for fuel diagnostics in industries such as fuel producers as well as fuel stores and stand by generators.

API gravity is the inverse of relative density means if one fuel has lower density than other then it has higher API gravity. The relative density and API gravity was found according to **IS: 1448[P: 32]:1992.**

API gravity of fuel blends are calculated by following relation:

$$\text{API gravity} = \frac{141.5}{\text{Relative density}} - 131.5$$

For, water API gravity is 10. This means if API gravity of any fuel is greater than 10 it will lighter than water and float on the surface of water.

Relative density is measured by hydrometer as shown in fig. 3.9. The hydrometer works on the Archimedes principle which states that when a body suspended in a fluid, a buoyant force is exerted on it which is equal to the weight of the fluid displaced by the submerged part of the body. Fix weight of hydrometer displaced the fluid which is equal to the weight of hydrometer.

To measure relative density of fuel it was filled inside 100 ml clean measuring cylinder. Then hydrometer of fuel gravity range has been selected. Hydrometer was put inside the measuring cylinder by holding it top. Just before it let go, it was twisted slowly spin to ensure that no bubbles cling to the hydrometer and dropped, if bubbles do happen to be a problem in test sample just pours the sample back and forth between the test cylinder and another sanitized container until the bubble dissipates.

It should be make sure that the test cylinder is in level so the hydrometer does not touch the sides of measuring cylinder. The surface of the liquid will be concave which is called meniscus. Take the reading by keeping eye horizontal to the bottom of the meniscus.



Fig. 3.9: Hydrometer of different ranges

3.6.3 Gross calorific value or heating value

Amount of heat produced (J or kJ) by complete burning of 1 g or 1 kg fuel is called calorific value. It is an important property in the engine operation to calculate the heat produced inside the engine by complete combustion of fuel in presence of oxygen to do useful work. Calorific value of fuel is determined by bomb calorimeter as per **IS: 1448[P: 6]: 1984**. Photographic view of bomb calorimeter is given in fig. 3.10.

Fuel sample of 1 g was taken in a crucible to measure its calorific value. Then wire of nickel-chromium (0.16 mm to 0.20 mm in diameter) fastened between the two electrodes. Crucible contained fuel sample placed between the electrode loops and tag a thread at the center of wire which should touch the surface of fuel. Then electrode loop head slide in cylinder slowly. Head cap of cylinder set and turned down to close it properly. After that, bomb pressurized with excess oxygen by oxygen cylinder. Then pressurized bomb is placed inside the distilled water. Stirrer fitted on the top of the closed system switched on after constant temperature shown by Beckmann thermometer. Then sample was ignited electronically. Heat flow by the burning of fuel sample increases the temperature of surrounding water jacket which was shown on the screen of thermometer.



Fig 3.10: Bomb calorimeter

Heating value is calculated by following relation

$$H_c = \frac{W_c}{M_s} \times \Delta T$$

Where,

H_c = Heat of combustion of the fuel samples, Cal/g

W_c = Water equivalent of the calorimeter, Cal/ °C (2172.5 Cal/°C)

ΔT = Rise in temperature, °C

M_s = Mass of sample burnt, g

Water equivalent of calorimeter was calculated by repeating the above procedure for benzoic acid as fuel.

3.6.4 Flash point and fire point

Flash point is the lowest temperature of fuel at which vapour of fuel will ignite but vapour produced might not be sufficient to fire the fuel. Fire point is the temperature of fuel at which vapour of the fuel continuously burn after ignited by some source. So, the fire point is higher than flash point. The vapour pressure of liquid is the function of the temperature of liquid. Vapour pressure increases by increasing the temperature which leads to increase in concentration of combustible fuel particles in air.

The sample was poured into cup which is on the top of apparatus to measure its flash point and fire point. Fuel should be filled to a specified level of cup and stirred at a constant speed. After that turn on heater and heat the air. A thermocouple placed inside the cup which indicates the rise in temperature of oil (should be 5°C per minute). A flame was passed over the surface of oil continuously at sufficient height. A spontaneous flame was generated at certain temperature (123°C for biodiesel and 56°C for Eucalyptus oil) which was the flash point of the oil. After 5 to 10°C rise in the temperature, the fuel was ignited and continuously burn, which is known as fire point. Cleaveland open cup flash point and fire point apparatus shown in the fig. 3.11. Flash point and fire point measured as per **IS: 1448[P: 32]: 1992**.



Fig. 3.11: Flash point and fire point apparatus

3.6.5 Cloud point and pour point

Cloud point and pour points both are low temperature phenomena. Cloud point is the temperature below which wax appears in the fuel called biowax in the case of biodiesel. Wax formation in fuel indicates the starting of solidification and cloud formation of fuel at the particular temperature. Wax formation in fuel leads to clogging of injector and fuel filter of diesel engine because oil thickness increases. The pour point is the temperature at which fuel completely solidifies and loss its flow characteristics. These cold flow properties are determined as per **IS: 1448 [P: 10]: 1970**. Apparatus used to determine the cloud and pour point is given in fig. 3.12.

There are two tubes of specific dimensions are contained inside the apparatus of cloud point and pour point measurement which are covered with air jacket. The air jacket was filled with smashed ice and Sodium chloride which is called the freezing mixture.



Fig. 3.12: Cloud point and pour point apparatus

Fuel sample was filled inside the tubes and kept inside ice and was recorded every 1°C fall in the temperature until cloud appear. Temperature noted at which fog or cloud was seen. For pour point fuel is heated to 48°C and then cooled to 35°C . Cooled samples are laid inside apparatus and withdrawn to record every 1°C fall in temperature.

3.7 Performance of Engine

Engine performance test was carried out in the internal combustion engine laboratory after studying the physical and chemical properties of fuel blends. Comparison of different fuel blends with diesel fuel is also done. Diesel fuel also called a reference fuel in this study.

4.4 kW, single cylinder, 4-stroke diesel engine made by Kirloskar was used as an experimental engine setup which is shown in Fig. 3.13. Engine consist fuel consumption measurement unit and eddy current dynamometer for loading which is connected with an electronic controller. Detail specification of engine is given in table 3.3.

The engine is basically used in agriculture to supply torque to irrigation pumps, stationary and milling power source as a prime mover. Some other applications are following.

1. Diesel generator to generate electricity
2. Bus and truck application
3. Construction equipments
4. As a power source in industries

Table 3.3 Engine specifications

Parameters	Specifications
Made	Kirloskar
Model	TAFI
Rated BP (bhp/kW)	6/4.4
Rated Speed (rpm)	1500
Number of Cylinder	1
Bore x Stroke (mm)	87.5 x 110
Displacement volume (cc)	662
Compression Ratio	17.5:1
Cooling System	Air Cooled
Starting System	Manual hand start (with handle)

3.8 Engine Performance Test

The engine performance tests were conducted on 4.4 kW single cylinder 4-stroke diesel engine shown in fig 3.13, as per **IS: 10000 [P: 8]: 1980**. Following engine parameters were measured during performance test.

1. Brake power, (kW)
2. Fuel consumption, (l/h)
3. Brake specific fuel consumption, (kg/kW-h)
4. Brake thermal efficiency, (%)
5. Exhaust gas temperature, ($^{\circ}\text{C}$)



Fig. 3.13: Diesel engine with eddy current dynamometer

3.8.1 Brake power

Brake power is the power which is developed by the engine on crankshaft. It is directly proportional to the engine speed and torque. Brake power was measured for different fuel blends of Karanja-Eucalyptus oil biodiesel and diesel on different loading conditions. Engine was initially run to 20 minutes under no load condition for stabilization and smooth operations. Speed of engine is measured with the help of non-contact digital laser tachometer which displayed speed in rpm. Speed was measured on different load such as no load, 25%, 50%, 75% and 100% of the rated load. Brake power is calculated by following relation.

$$\text{Brake power (kW)} = \frac{2\pi \times N \times T}{60000}$$

Where,

T = Torque, N-m

N = Engine speed, rpm

3.8.2 Fuel consumption

Fuel consumption measurement unit has a fuel tank and graduated glass burette of 50 ml capacity. The fuel blend sample was filled in 50 ml burette and allowed to pass in the engine. The total time required to consume 50 ml fuel is noted. Same procedure is repeated for different loading condition to find out the fuel consumption at every load.

The hourly consumption calculated using following equation.

$$f_c = \frac{V_{cc}}{t} \times C$$

Where,

f_c = Fuel consumption, l/h

V_{cc} = Volume of the fuel consumed, ml

T = Time, s

C = Unit constant, 3.6

3.8.3 Brake specific fuel consumption

The brake specific fuel consumption was calculated using the following relationship.

$$\text{bsfc} = \frac{\text{Fuel consumption rate}}{\text{Brake power}} = \frac{V_{cc} \times \rho \times 3.6}{\text{bp} \times t} = \frac{f_c \times \rho}{\text{bp}}$$

Where,

bsfc = Brake specific fuel consumption, kg/kW-h

V_{cc} = Volume of fuel consumed, 50 cc

ρ = Density of fuel, g/cc

bp = Brake power, kW

t = Time taken to consume 50 ml fuel, s

3.8.4 Brake thermal efficiency

The brake thermal efficiency of the engine at the different load was determined by using the equation as given below.

$$\eta_{th} = \frac{\text{Brake power}}{\text{Fuel power}} = \frac{K_s}{\text{bsfc} \times \text{HV}} \times 100$$

Where,

η_{th} = Brake thermal efficiency, %

K_s = Unit constant, 3600

HV = Gross heating value, kJ/kg

bsfc = Brake specific fuel consumption, kg/kW-h

3.9 Exhaust Gas Emission Test

The measurement of various exhaust gas emission parameters such as exhaust gas temperature, smoke density and absorption coefficient of all blends were measured at different brake load ranging from no load condition to full load conditions.

3.9.1 Exhaust gas temperature

Exhaust gas temperature (EGT) was measured by connecting a thermocouple wire in the exhaust gas pipe. Thermocouple wire connected to a digital temperature scanner shows temperature in degree Celsius. Exhaust gas temperature was measured for different fuel blends as well as for pure diesel fuel.

3.9.2 Smoke density and absorption coefficient

Smoke density and absorption coefficient is the estimation of the thickness of smoke created by the engine. A thick cloud of smoke is delivered because fuel is pushed from the engine without totally consumed, and afterward leaves dark ash which is called black soot. The smoke thickness is the quantity of smoke molecules introduced in per unit volume of gas. It is also called "Light absorption coefficient" and communicated in term of m^{-1} . Another unit to express smoke density is Bosh, Hartridge smoke unit which shows smoke opacity in percentage.



Fig. 3.14: Photographic view of Exhaust gas monitor

Automotive exhaust gas monitor is shown in fig. 3.14. Automotive exhaust gas monitor model OMS 101 manufactured by INDUS scientific is used in present work which measure smoke opacity by following the test standard of SAE J255a for diesel engine. Technical data of automotive exhaust gas monitor are given in table 3.4. This system consist two units. One is smoke chamber where exhaust gas is passed to measurement zone and another unit processed analog signal and display it on the screen and proceed to print under the control of software. Smoke chamber consist a smoke tube at the centre which has a light source and detector placed in opposite sides. It measures the visible opacity by using light transmission technique. Light intensity decreases due to presence of any smoke particle in exhaust gas which is detected by detector and displayed on screen.

Table 3.4 Technical data of automotive exhaust monitor

Principle of operation	Attenuation of light beam
Measurement	Smoke density in Hartridge smoke unit (HSU) / Absorption coefficient (K)
Range	0 to 100% opacity in HSU and 0 to ∞ absorption in m^{-1}
Light source	Halogen bulb, 12 V DC/20W
Colour temperature	3050 K
Detector	Photocell with filters
Display	Backlit LCD display, 16 digit a) Light Absorption coefficient (K) in m^{-1} b) Temperature ($^{\circ}C$)
Keyboard	Membrane keypad with 18 keys
Stabilization	30 min
Time constant	a) Physical: 0 to 1 second b) Electrical: < 1m second

Temperature sensor	1. RTD, PT100 for smoke column temperature 2. 'J' Type Thermocouple for oil temperature
Printer	24 column dot matrix, paper of 56mm
Probe	A probe with synthetic rubber connecting hose (4 m)
Calibration	Using calibration filter of known intensity
Cabinet	Power coated MS enclosure
Measuring unit	650 x 285 x245 mm, 20 kg
Control unit	340 x240 x130 mm, 4 kg
Operating temperature	0 to 50 ⁰ C
Power supply	190-250V AC/11-12 V DC
Power consumption	500 W (overall equipment)
Smoke column temperature	70-100 ⁰ C
Heating time	20 min
Software version	INDUS DiesX

This system has built-in heating facilities and the temperature at the time of measurement was approximately 80⁰C. The equipment can be used to check and measure emission of all kinds of diesel vehicles and measure the opacity and absorption coefficient from the vehicle being tested for approval.



*Results
and
Discussion*



Karanja oil methyl ester and Eucalyptus oil in different percentage were mixed in IC engine laboratory and prepared fuel blends such as K10EU90, K20EU80, K30EU70, K40EU60, K50EU50, K60EU40, K70EU30, K80EU20 and K90EU10. Different percentage of fuels in the blends changes the engine performance and emission characteristics under different loading conditions. So it is important to discuss about the properties of fuel blends before using it in the engine for proper explanation of various characteristics.

In this chapter different properties of different fuel blends such as kinematic viscosity, relative density, API gravity, Calorific value, fire point, flash point, cloud point and pour point are analysed and compared with the properties of diesel which taken as reference fuel. The experimental results of diesel engine performance characteristics such as brake torque, brake specific fuel consumption, brake thermal efficiency and emission characteristics such as smoke emission test and exhaust gas temperature measurement also presented and analysed in this chapter. The performance and emission tests were carried out as per **IS:10000[P:8]:1980** and **SAE J255a** respectively.

4.1 Stability Test

Stability test was carried out at room temperature 25°C to 30°C. 10 ml sample of each blend was prepared and kept at room temperature for 30 days. Stability was analyzed by observation of phase separation after a period of 24 hours regularly till 30 days. All fuel blends are stable and no phase separation was found in 30 days at room temperature (from 25°C to 30°C).

4.2 Properties of Test Fuel Blends

Properties of Karanja oil biodiesel and Eucalyptus oil blends which influence the engine performance and emission characteristics are given below.

4.2.1 Kinematic viscosity

Kinematic viscosity of fuel affects injector holes, fuel pipes and nozzle of the engine at specific temperature. According to American standard, ASTM D 6751 kinematic viscosity for biodiesel should be between the ranges of 1.9-6 mm²/s while, 3.5-5.0 mm²/s range was

recommended in European standard EN 14214:2012. Kinematic viscosity of diesel was found 2.067cSt in present experiment, whereas it was 6.1 and 2.16 cSt obtained for Karanja oil methyl ester and Eucalyptus oil respectively. All the values of kinematic viscosity for different fuel blends were obtained at 40°C. **Tüccar *et al.* (2014)** reported that kinematic viscosity of diesel as 2.37 cSt at 40°C. **Srivastava and Verma (2007)** stated that, kinematic viscosity of Karanja oil methyl ester as 5.72 cSt. Experimental results of **Srinivas *et al.* (2016)** show that the kinematic viscosity of Eucalyptus oil is 2.024 cSt. Kinematic viscosity of KOME and Eucalyptus oil and its blends are shown in fig. 4.1, which increase with increase in percentage of KOME.

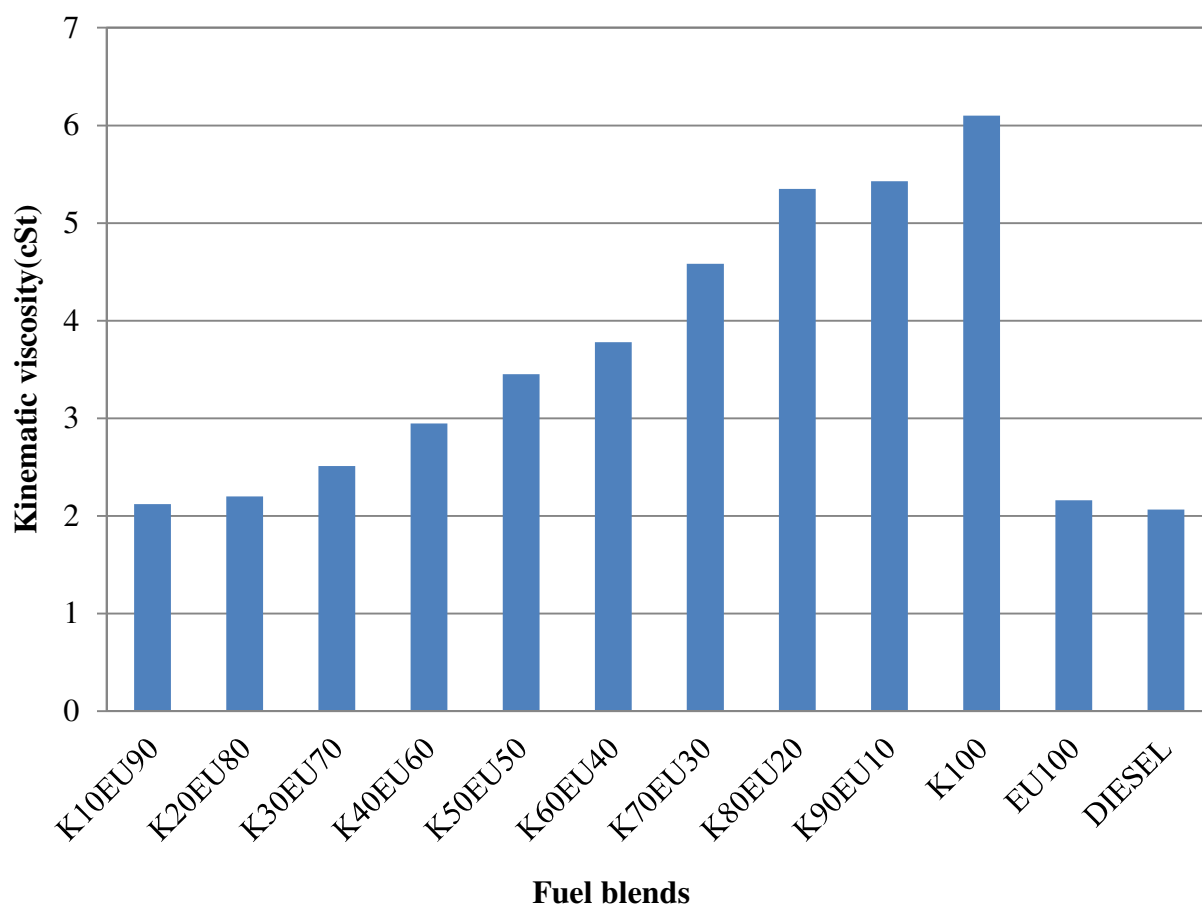


Fig. 4.1: Variation in Kinematic viscosity of different fuel blends

4.2.2 Relative density and API gravity

Relative density is a very important fuel property which impacts engine performance and emission. It also influences the atomization of fuel, which is splash into the compressed or

packed air. A higher estimation of relative density, as well as viscosity, drives poor efficiency of combustion in the engine.

Relative density of diesel was obtained 0.846 experimentally, which is less than that of fuel blends as well as neat blends constituents. According to **Devan and Mahalakshmi (2009)** density of Eucalyptus oil and diesel is 0.8955 and 0.84 respectively. **Srivastava and Verma (2007)** prepared Karanja oil methyl ester by crude Karanja oil and obtained the value of relative density of Karanja oil methyl ester is 0.885. Figure 4.2(a) represents the variation in relative density of the different fuel blends. It increases with increase in the percentage of KOME in test fuel blends.

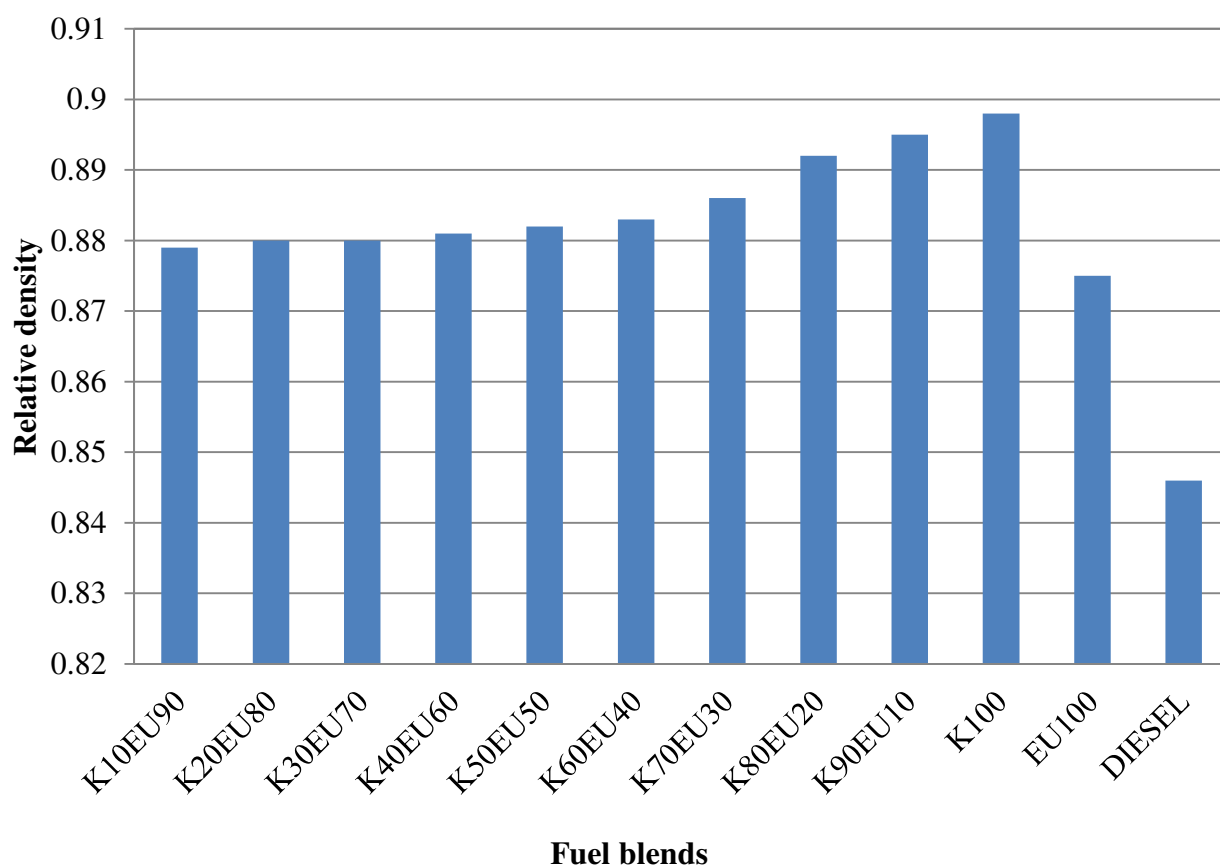


Fig. 4.2(a): Variation in relative density of different fuel blends

API gravity of diesel, Eucalyptus oil and Karanja oil methyl ester calculated as 35.75° , 30.21° and 26.07° respectively. API gravity was found decreasing by increasing the percentage of

Karanja oil methyl ester in blends. Figure 4.2(b) shows variation in API gravity of different blends of fuels.

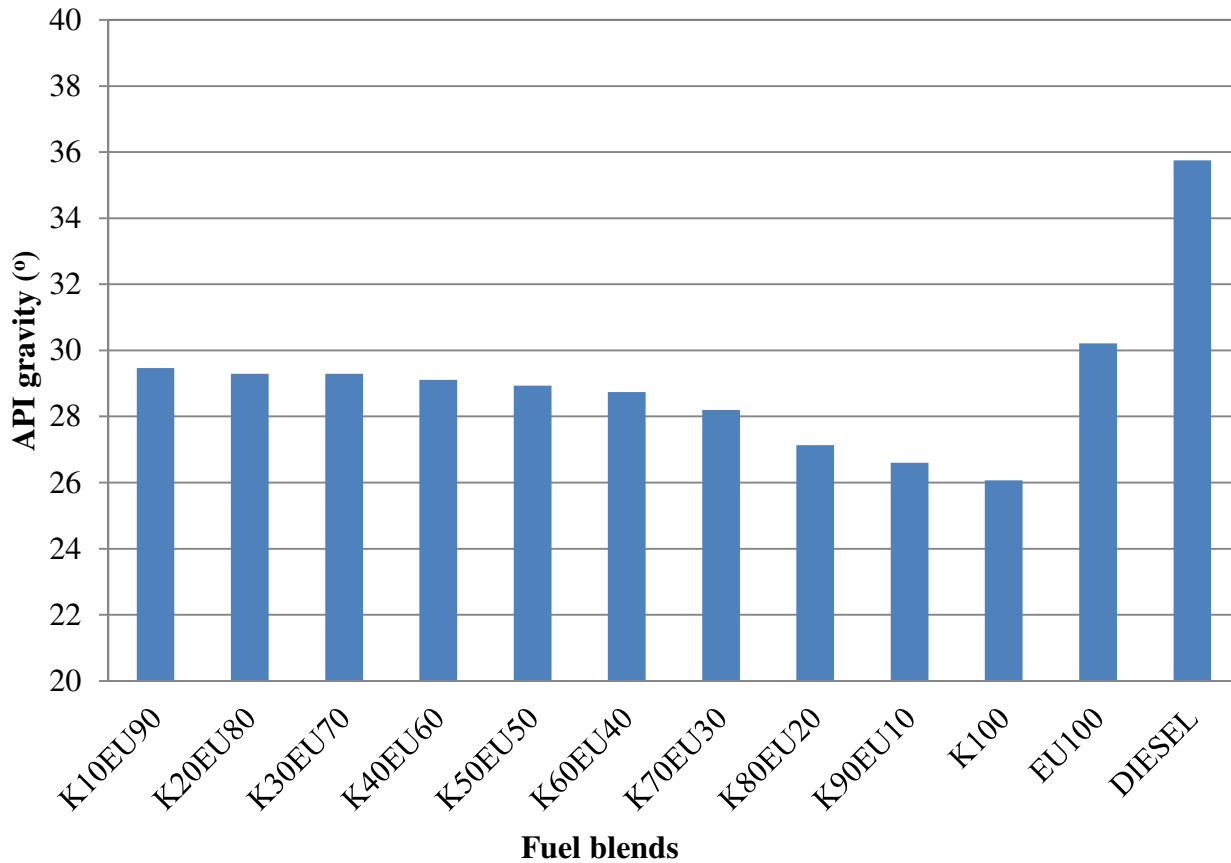


Fig. 4.2(b): Variation in API gravity of different fuel blends

4.2.3 Gross calorific value

Gross calorific value of different selected fuel blends is shown in fig 4.3. Gross calorific value of diesel was calculated as 44.567 MJ/kg in this work which is 2.67% higher than Eucalyptus oil and 19.47% higher than Karanja oil methyl ester. Gross calorific value of different fuel blends was found decreasing with increasing percentage of KOME. **Devan and Mahalakshmi (2009)** found the calorific value of diesel and Eucalyptus oil is 42.7 and 43.27 MJ/kg respectively. **Senthil et al. (2016)** and **Srinivas et al. (2007)** also found the same values. **Dhar and Agarwal (2014)** calculated the heating value for KOME which is equal to 37.98 MJ/kg. According to ASTM D 6751-02, minimum value of calorific value should be 37 MJ/kg.

Biodiesel prepared by mixing of Karanja oil methyl ester and Eucalyptus oil having calorific value fully satisfied the ASTM standard.

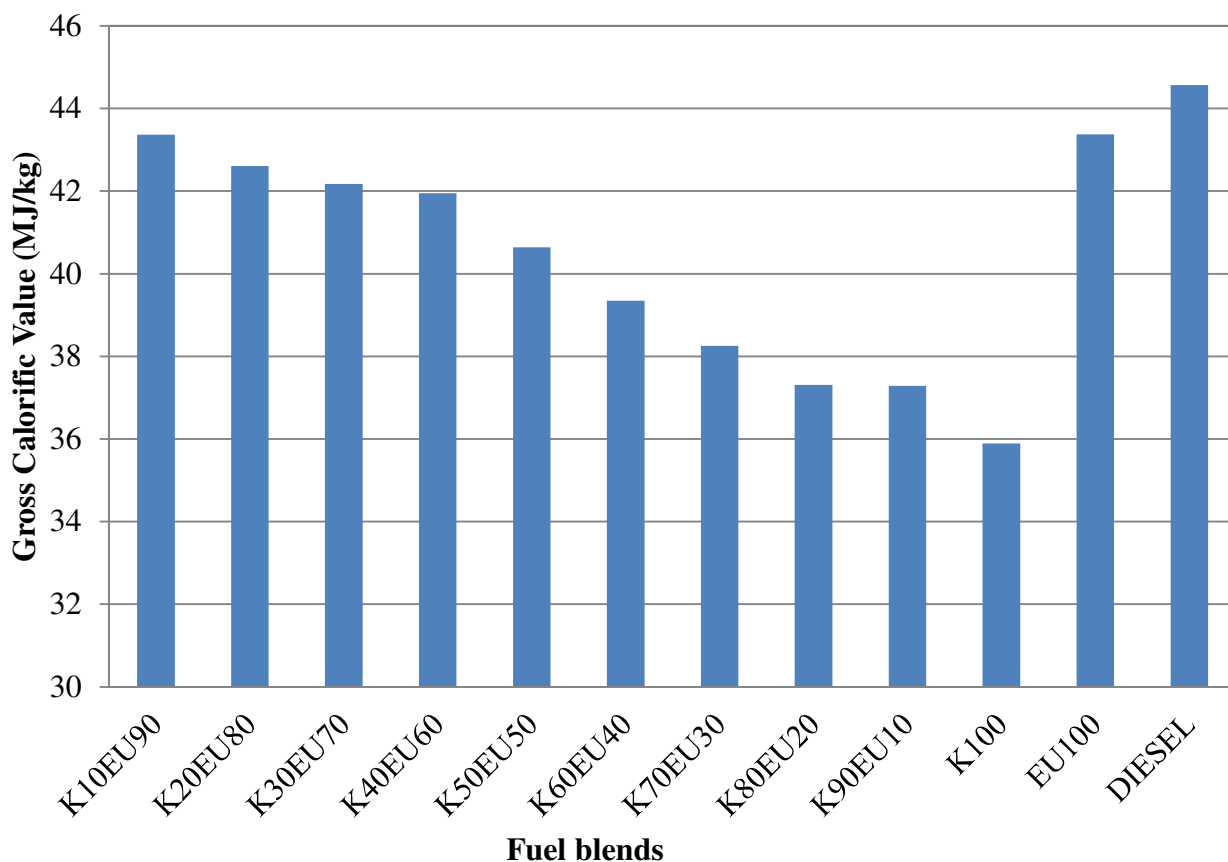


Fig. 4.3: Variation in gross calorific value of different fuel blends

4.2.4 Flash point and fire point

The combustibility of the material is given by flash point and fire point. These are important properties of a fuel for safety during storage and handling.

Flash point and fire point of diesel fuel were attained as 62.5 and 65.78°C respectively in the present research work. BIS specifies the minimum limit of flash point of diesel to 35°C (IS 1460 [P: 10]: 1974). **Velappan et al. (2015)** obtained flash point of diesel was 65°C. Flash point obtained for Eucalyptus oil and Karanja oil methyl ester is 54.5°C and 121.1°C respectively in this work. **Bobade et al. (2012)** found the value of flash point for Karanja oil methyl ester is 144°C. Flash point and fire point of different fuel blends are plotted in Fig. 4.4. These

temperatures were found rising with increasing the percentage of KOME due to higher flash point of KOME.

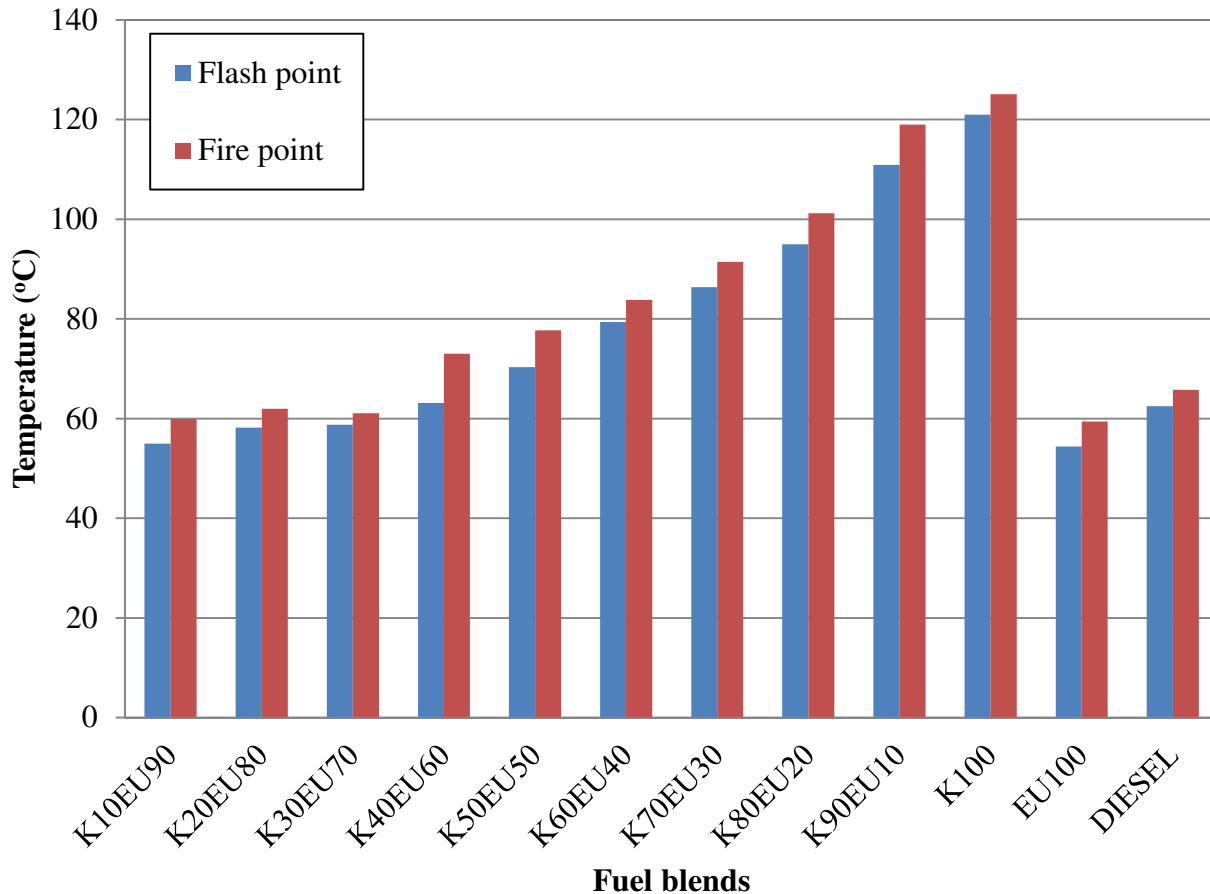


Fig. 4.4: Variation of flash point and fire point of different fuel blends

4.2.5 Cloud point and pour point

Cloud point and pour point of different fuel blends Karanja oil methyl ester and Eucalyptus oil have been shown in fig 4.5, which are compared with neat diesel too. Cloud point and pour point of KOME were found 19°C and 11.4°C respectively, obtained higher than neat diesel and show poor cold flow behavior. It is because of 51.59% oleic acid ($C_{18}H_{34}O_2$) presence in KOME. It is a fatty acid which is also a reason for higher density (Mehar *et al.*, 2004). Therefore, use of pure KOME is not suitable for cold places.

Cloud and pour point of Eucalyptus oil is -4°C and -9°C respectively, which are approximately similar to diesel fuel. Thus, blending of Eucalyptus oil compensates the poor cold

flow behaviour of KOME, as shown in fig. 4.5. According to **Srivastava and Verma (2007)** cloud point and pour point of diesel are -10°C and -16°C respectively. **Devan and Mahalakshmi (2009)** found the value of pour point of Eucalyptus oil as -5°C . According to **Mehar et al. (2004)** cloud point and pour point for KOME were 22°C and 15.8°C .

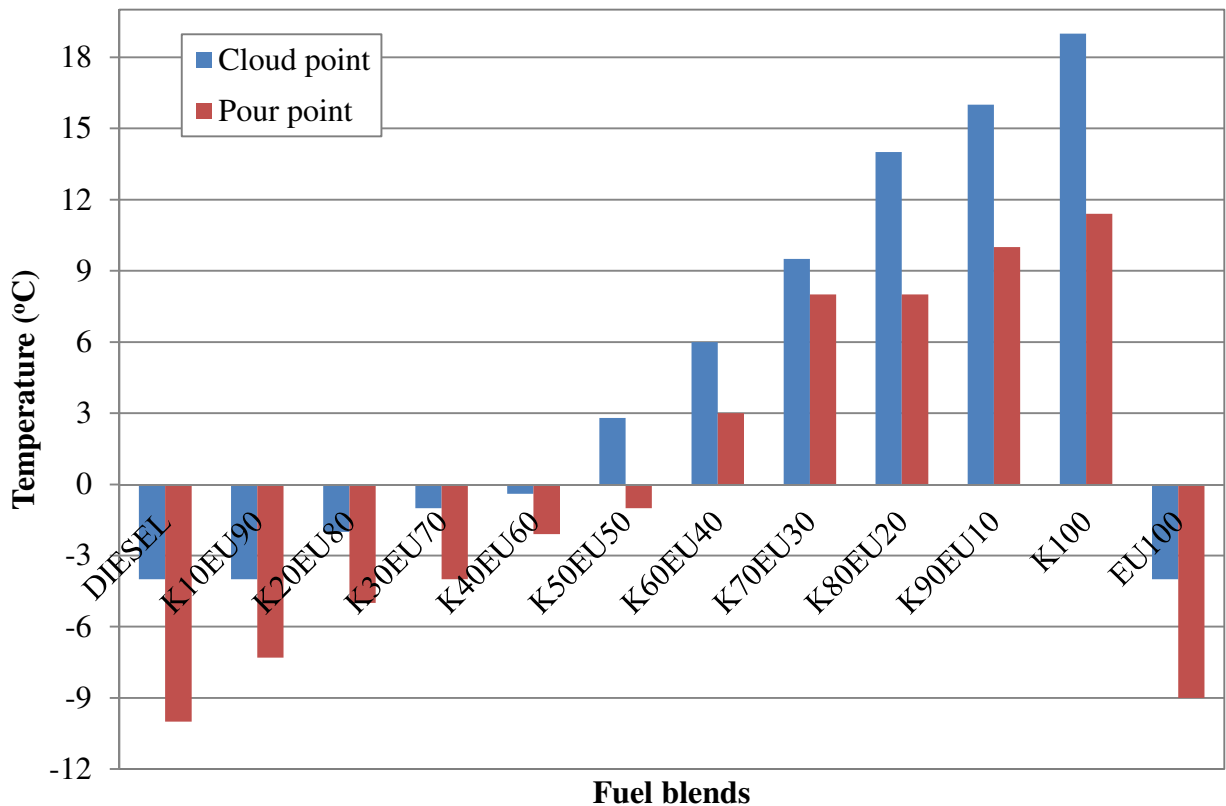


Fig. 4.5: Variation of cloud point and pour point of different fuel blends

4.3 Engine Performance Characteristics

Engine performance characteristics such as fuel consumption, brake specific fuel consumption and brake thermal efficiency are carried out in this section. These important engine characteristics of engine were tested with different selected fuel blends, under the variation of torque with eddy current dynamometer and keeping constant speed on 4.4 kW diesel engines. All the characteristics were also compared with the characteristics obtained using neat diesel fuel. Tests were conducted according to **IS:10000[P:8]: 1980**.

Engine brake power was calculated by measuring the engine speed at variable loads as 0, 25%, 50%, 75% and 100% which is further used for calculation of brake specific fuel consumption of selected fuel blends. The variation of engine brake power found approximately same for all the fuel blends as well as diesel fuel at specific load because the work is performed on constant speed CI engine. Although, slight speed variation has been observed from 1510 to 1435 rpm at no load to full load condition but it can be considered negligible. It was also observed that increases in the braking load increases the braking power, for all selected fuels, because the brake power is directly proportional to the brake load. The engine developed maximum braking power of 4.258 kW with K30EU70 as fuel blend, at full load condition and 1458 rpm.

4.3.1 Fuel consumption

Fuel consumption in l/hr of 4.4 kW diesel engine using selected fuel blends and diesel under different loading condition is shown in fig 4.6(a), 4.6(b) and 4.7. The fuel consumption of engine gradually increases with increasing brake load and was observed maximum at full load condition for all selected fuel blends and pure diesel.

Fuels containing rich quantity of KOME than Eucalyptus such as K60EU40, K70EU30, K80EU20 and K90EU10 show continuously increasing trend and maximum fuel consumption shown by K90EU10 that was 1.978 l/h at full load condition, which is because of lower energy content and higher viscosity of KOME than Eucalyptus oil as well as diesel. Minimum fuel consumption was found during use of K40EU60 blend as 1.552 l/h at full load condition, which is 1.7% less than diesel fuel. K30EU70 blend and diesel show approximately same fuel consumption per hour.

Fuel consumption increased for K10EU90 and K20EU80 blends because less oxygen content present in these fuel blends, which may be responsible for improper combustion of fuel.

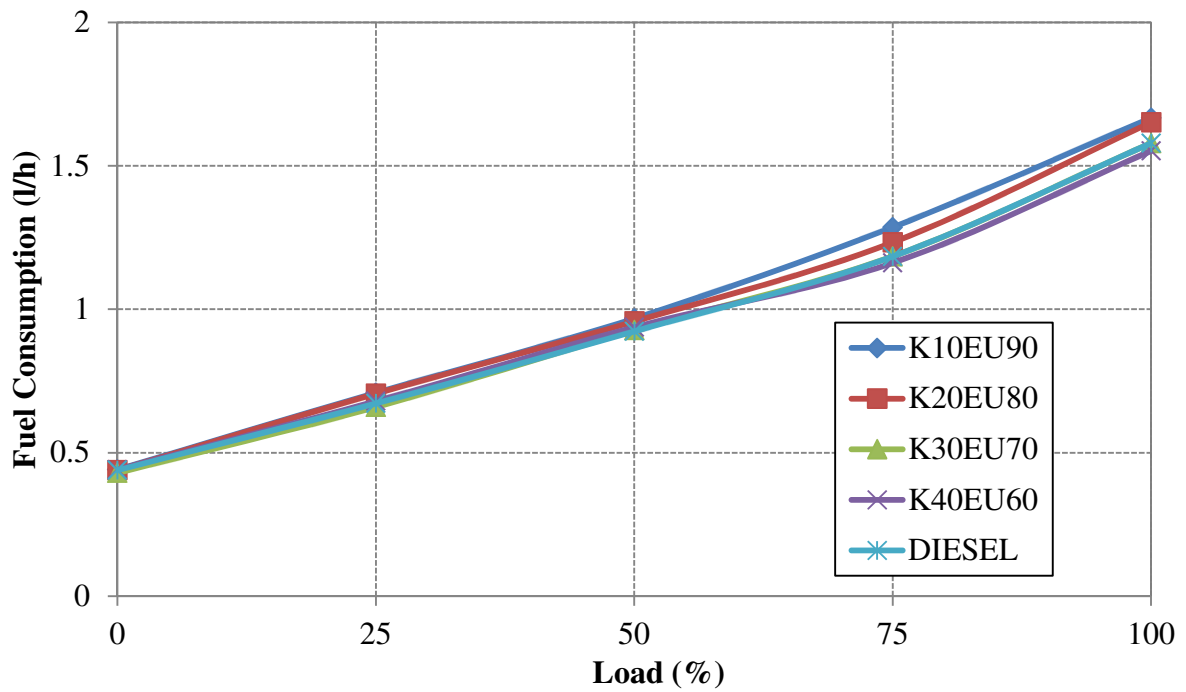


Fig. 4.6(a): Load v/s fuel consumption of K10EU90, K20EU80, K30EU70, K40EU60 and diesel

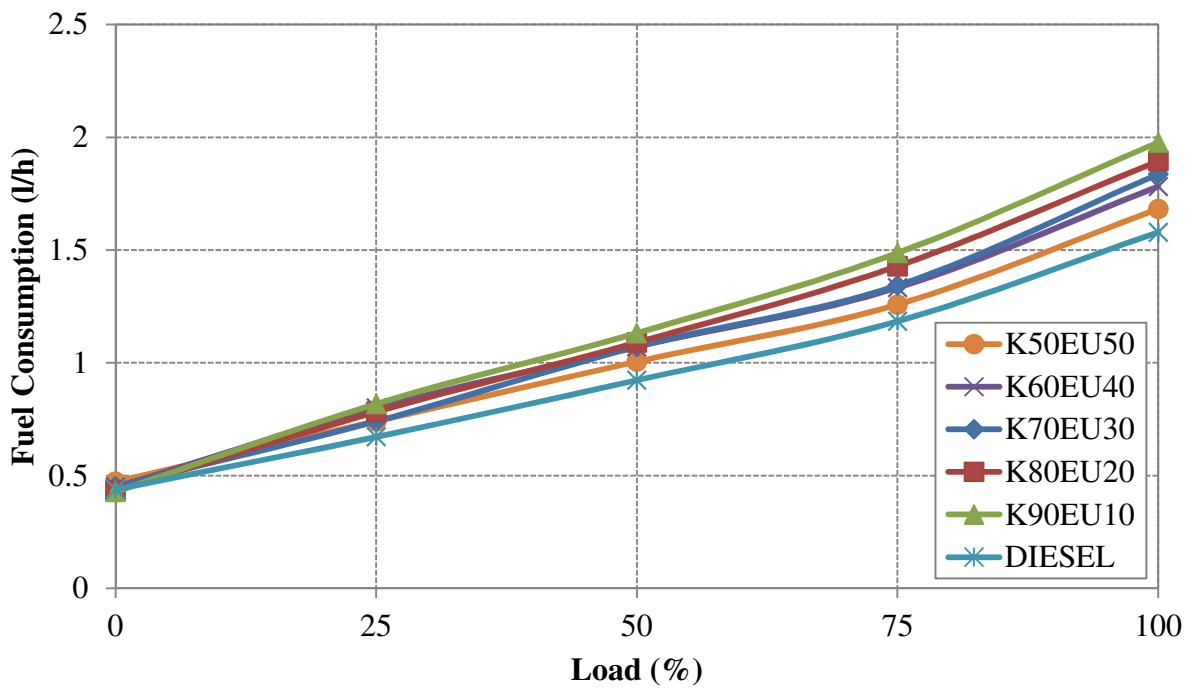


Fig. 4.6(b): Load v/s fuel consumption of K60EU40, K70EU30, K80EU20, K90EU10 and diesel

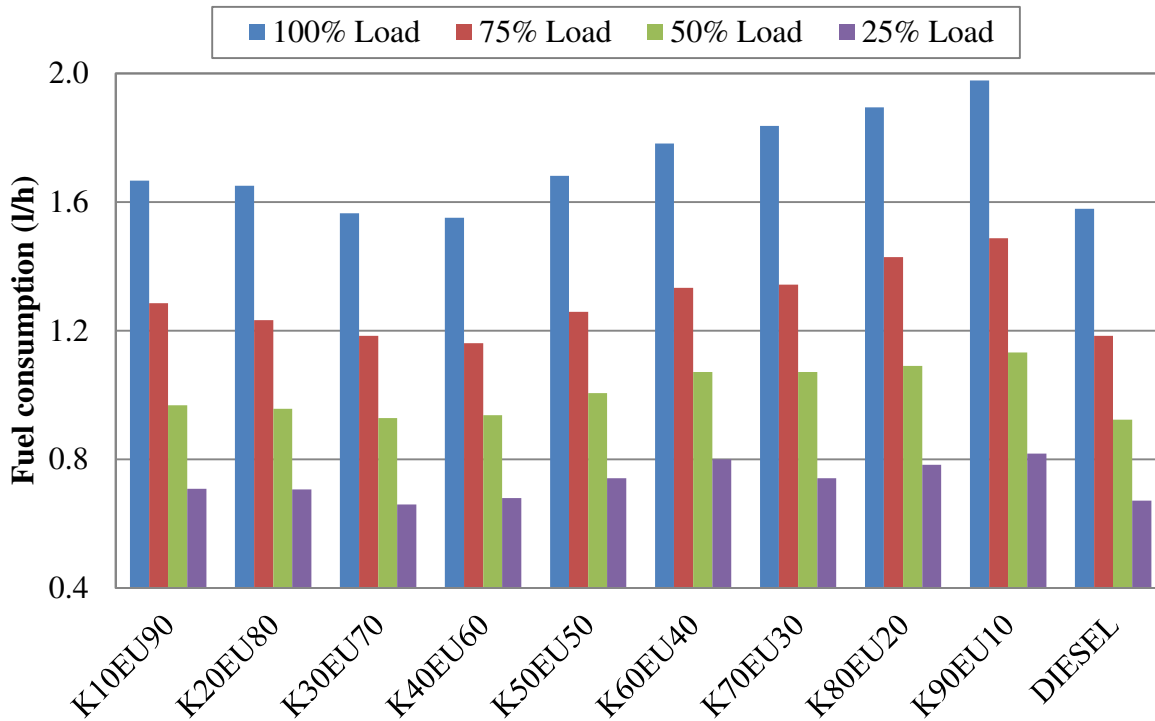


Fig. 4.7: Fuel consumption of all selected fuel blends

4.3.2 Brake specific fuel consumption (BSFC)

Brake specific fuel consumption is calculated using dividing fuel consumption by brake power. So, it is fuel consumption per unit brake power. Figures 4.8(a), 4.8(b) and 4.9 show the variation in BSFC at different loads. BSFC was found decrease with increasing the load and get it minimum value at 75% load approximately.

BSFC of fuel blends decreased as the concentration of Karanja oil methyl ester increase from 10% to 30% at all loading conditions. Decrement was observed from 0.347 kg/kW-h to 0.326 kg/kW-h. This reduction in BSFC is because of high calorific value of Eucalyptus oil and rich oxygen content present in KOME. K40EU60 and diesel showed approximately equal BSFC at full load. It has 41.947 MJ/kg gross calorific value and 2.947 cSt viscosity, which are optimum values. BSFC increased continuously at all loads from K40EU60 to K90EU10 due to low heating value and high viscosity of KOME. This leads to atomization and vaporization problems, so high fuel quantity is required to complete the combustion.

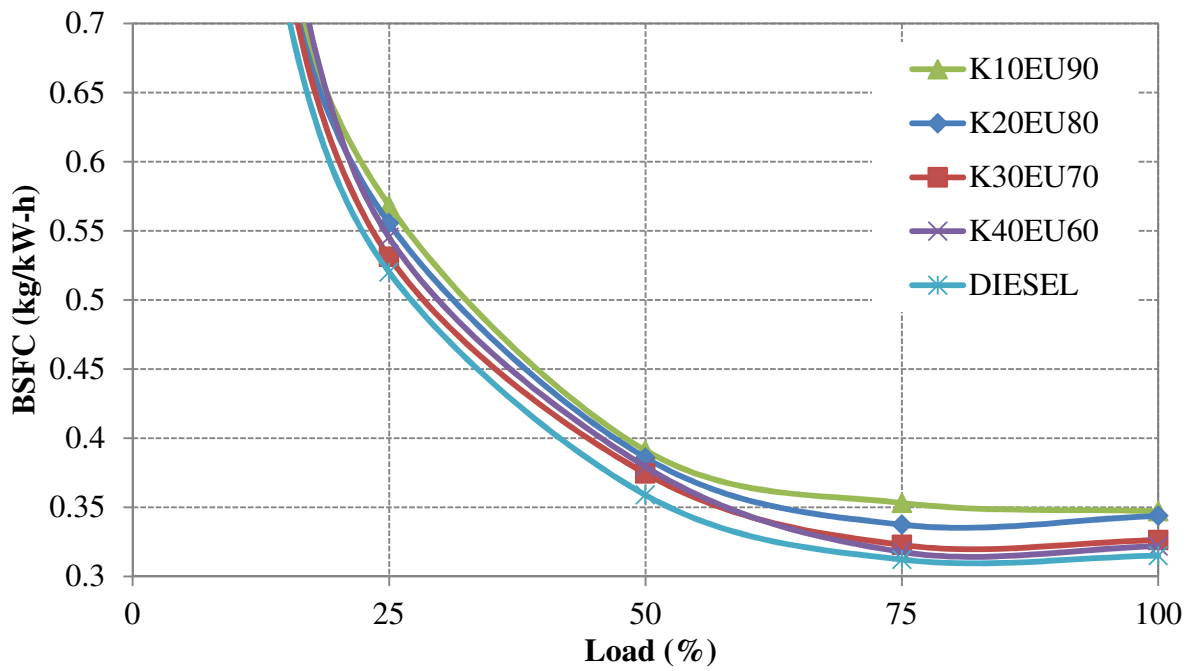


Fig. 4.8(a): Load v/s BSFC of K10EU90, K20EU80, K30EU70, K40EU60 and diesel

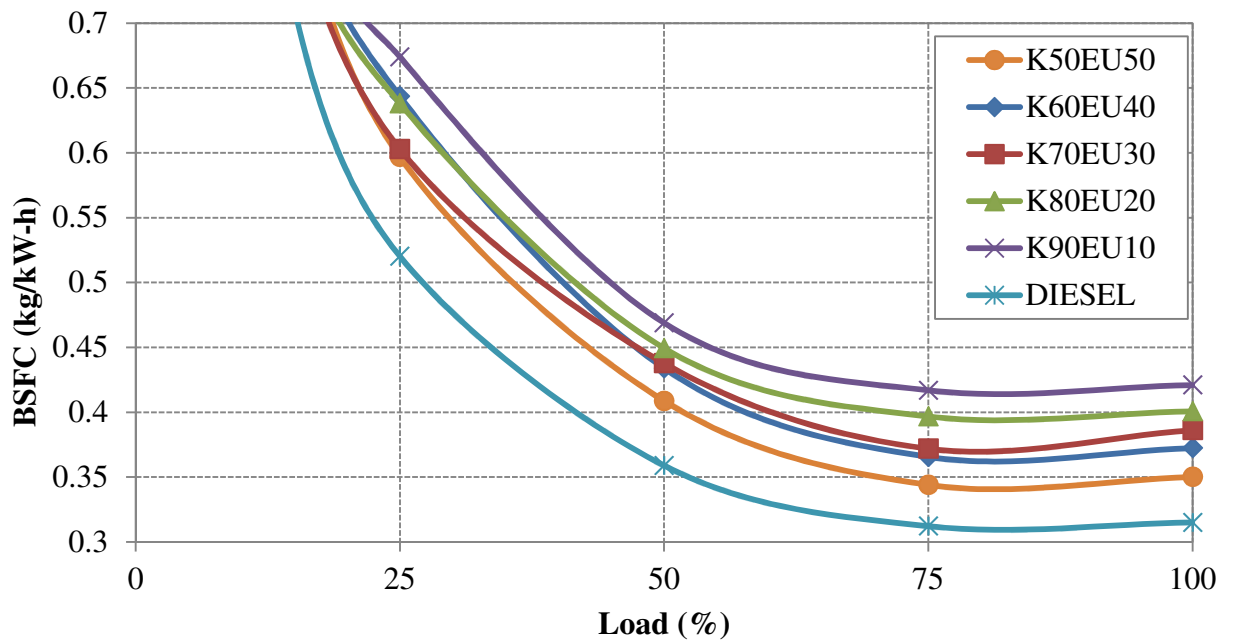


Fig. 4.8(b): Load v/s BSFC of K50EU50, K60EU40, K70EU30, K80EU20, K90EU10 and diesel

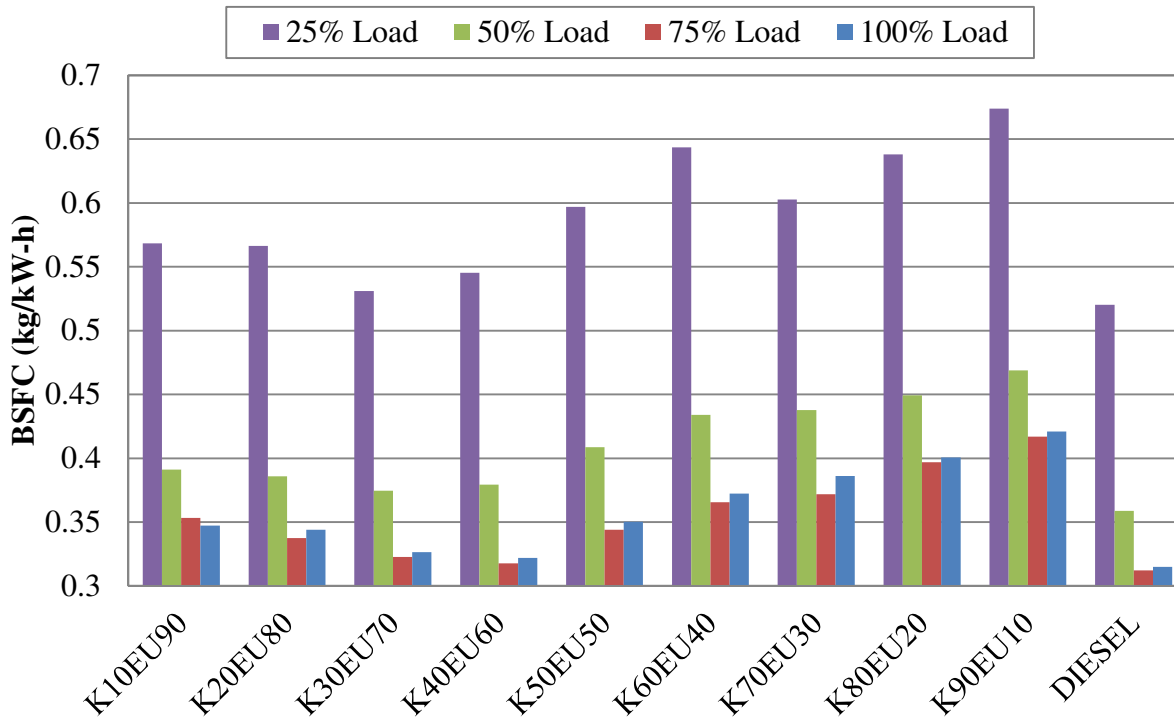


Fig. 4.9: BSFC of all selected fuel blends

From the fig. 4.9 it is observed that BSFC of all fuel blends is higher than diesel fuel under all the loading conditions. This may be due to the fact that fuel consumption of all fuel blends (except K30EU70 and K40EU60 fuel blends) is higher than diesel fuel due to lower calorific value than diesel. BSFC of K30EU70 and K40EU60 fuel blends was also observed higher than diesel because of higher density and small variation in brake power compared to neat diesel. This difference in BSFC is very small and negligible. Therefore, K30EU70 and K40EU60 fuel blends can fully replace diesel fuel with a negligible compromise in BSFC. This was also shown that, any increase in braking load will result in a small increase in braking power. Since the engine produces the maximum energy at full load, which requires more fuel energy, thus, more fuel consumption will occur at high loads, resulting in a slight increase in brake fuel consumption also shown at full load compared to 75% load.

Devan and Mahalakshmi (2009) found an optimum blend Me50-Eu50 regarding BSFC of methyl ester of Paradise-Eucalyptus oil fuel blends, given in fig. 4.10. They also concluded that atomization, vaporization and combustion are improved due to reduction in viscosity and better air entrainment of fuel blend.

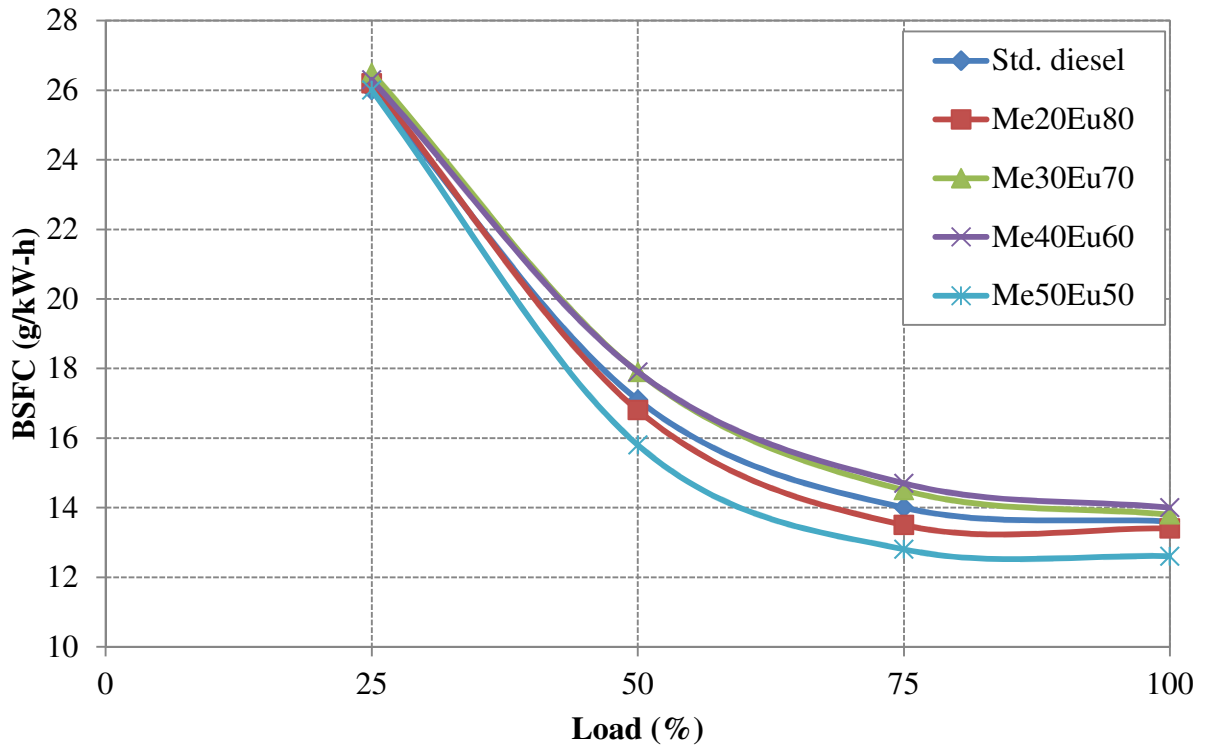


Fig. 4.10: Variation of BSFC with brake load using methyl ester of paradise and Eucalyptus oil biodiesel, given by Devan and Mahalakshmi (2009)

Vijayabaskar *et al.* (2015) found lower value of BSFC with 25% Karanja oil methyl ester and 75% pine oil blend and concluded that higher value of viscosity and lower calorific value of Karanja oil methyl ester were compensated by pine oil. BSFC was observed higher than diesel for K75P25 and K100 blends due to lower heating value of Karanja oil methyl ester which leads to higher amount of fuel consumption than diesel to produce same amount of power output.

4.3.3 Brake thermal efficiency

Brake thermal efficiency of selected fuel blends and diesel are shown in figures 4.11(a) and 4.11(b). These Figures are showing the relationship between brake thermal efficiency and brake load. It is observed that BTE is inversely proportional to BSFC and fuel consumption.

BTE found increase with increasing the load for all fuel blends as well as diesel fuel (except at full load). There was drastically increased fuel consumption was observed Beyond 75% load thus BTE remain constant or decreased beyond that load. **Rahul *et al.* (2018)** showed

similar BTE at full load and 75% load for both cases i.e. neat diesel and biodiesels blend. It may be due to the high fuel consumption rate at full load.

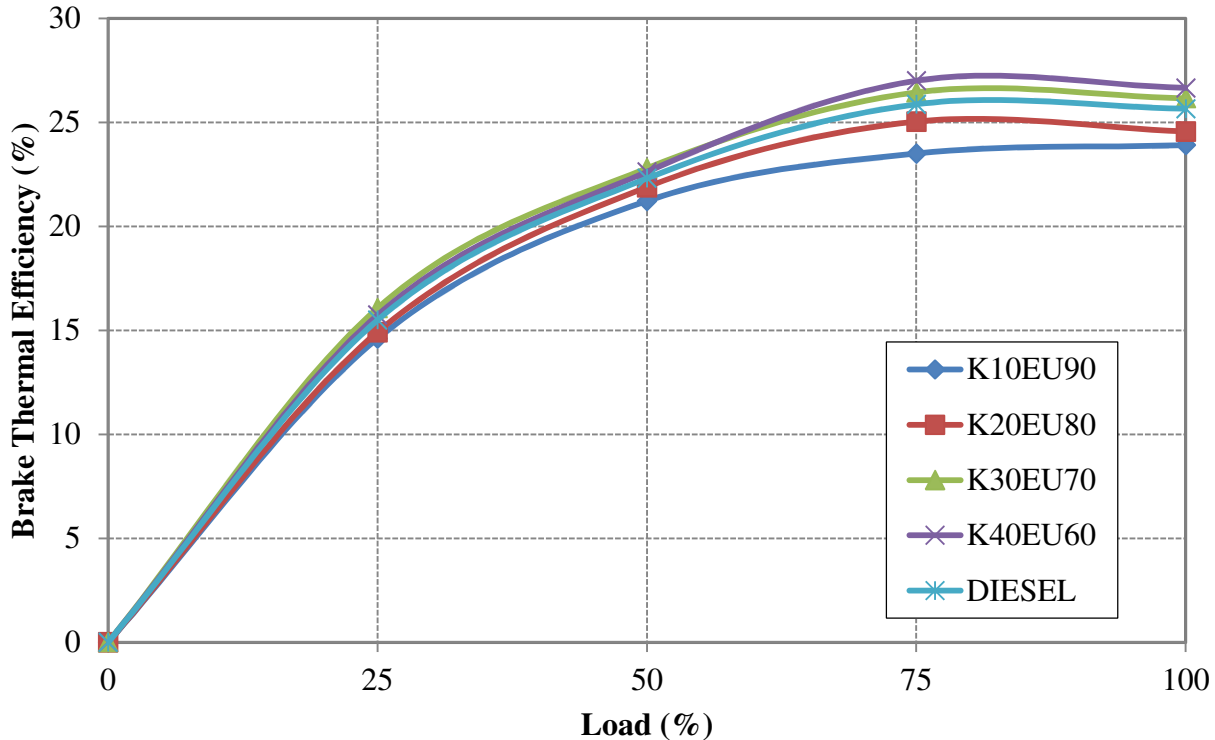


Fig. 4.11(a): Load v/s brake thermal efficiency of K10EU90, K20EU80, K30EU70, K40EU60 and diesel

BTE increased with increasing the load for all loading (except full load). BTE of high concentrated Eucalyptus oil fuel blends such as K10EU90 and K20EU80 found lower than diesel at all the loading condition.

It was shown by **Verma *et al.* (2016)** that brake thermal efficiency decreased with increasing the percentage of Eucalyptus oil in diesel. It is due the presence of low amount of oxygen content presence in Eucalyptus oil tends to improper combustion compared to other fuel blends. Lower calorific value compared to pure diesel also increased fuel consumption rate to generate same brake power and leads to lower BTE than neat diesel.

BTE was improved for K30EU70 and K40EU60 blends due to higher oxygen content and comparable calorific value of fuel blends with diesel. It is 0.52% and 1.02% more than diesel fuel respectively. Although, the calorific value of these fuel blends was lower than neat

diesel but rich oxygen content in fuel take part in combustion and compensated the fuel consumption rate. K50EU50 shows approximately same variation as mineral diesel at full load. All blends from K50EU50 to K70EU30 shows lower brake thermal efficiency at lower engine loads but it improves at higher loads such as 75% and 100% loads. This is because of higher viscosity of blends than diesel which leads to poor fuel combustion and higher consumption rate of fuel. But at higher load brake thermal efficiency of these fuel blends was comparable to diesel because of higher turbulence of fuel at higher load. BTE of K80EU20 and K90EU10 decreased by 1.56% and 2.7% respectively comparing to diesel because higher viscosity of KOME results in poor atomization of fuel which leads to poor combustion so high amount of fuel was consumed by the engine to perform same work output. Moreover, calorific value of KOME is lower so, rich air-fuel mixture required to produce same brake power. Figure 4.12 shows the comparison of brake thermal efficiency between fuel blends and diesel.

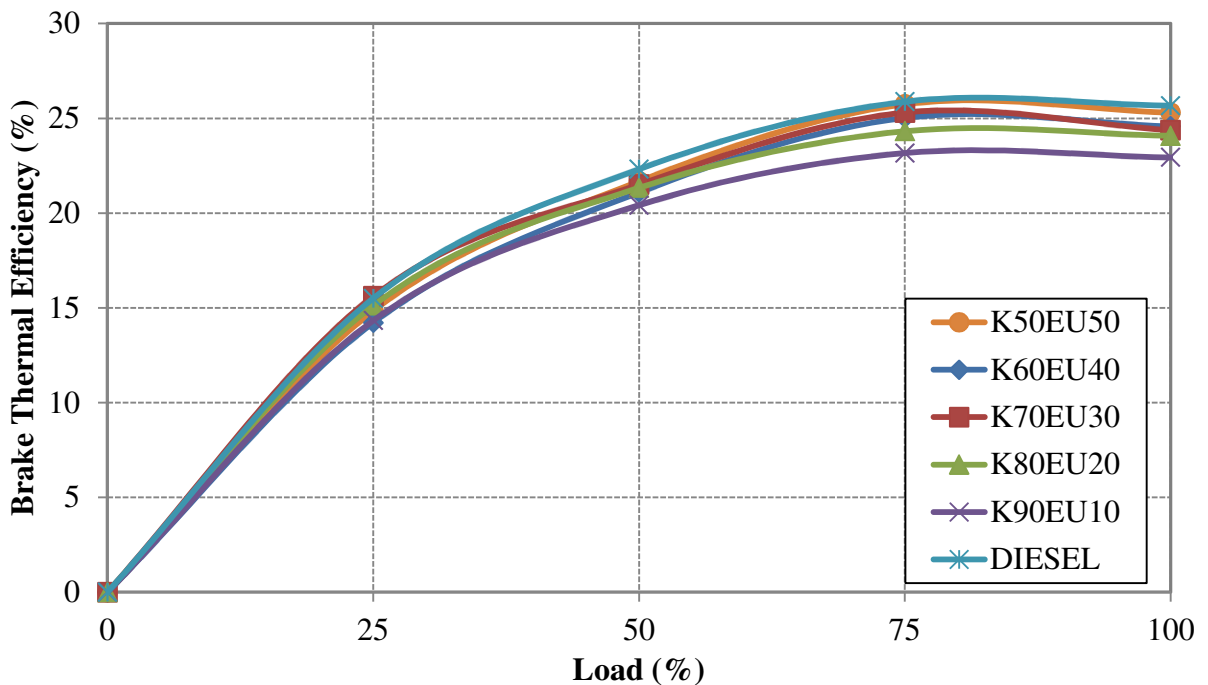


Fig. 4.11(b): Load v/s brake thermal efficiency of K50EU50, K60EU40, K70EU30, K80EU20, K90EU10 and diesel

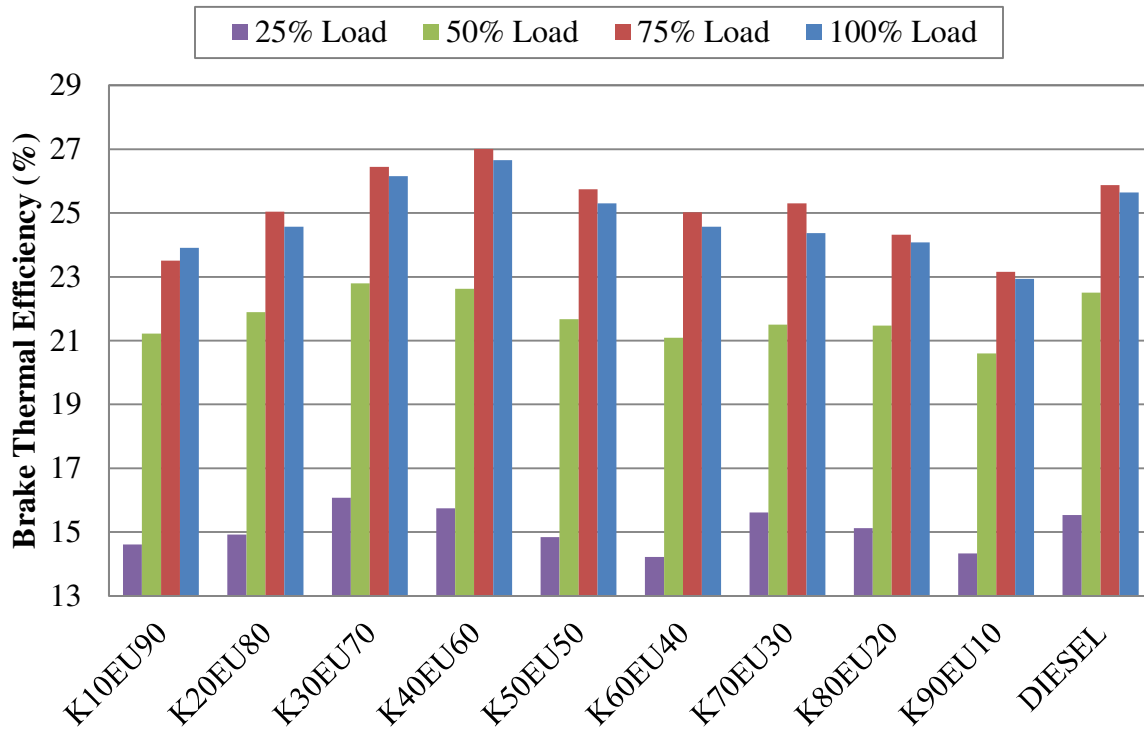


Fig. 4.12: Brake thermal efficiency of all selected fuel blends

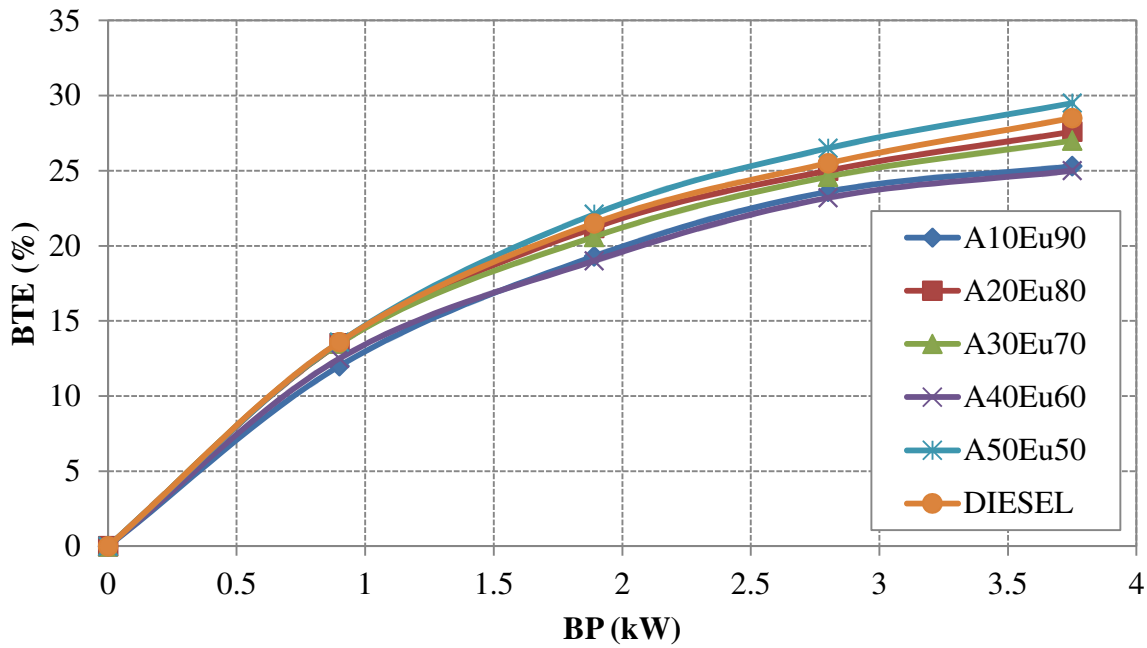


Fig. 4.13: Brake thermal efficiency with brake power using different fuel blends of Annona-Eucalyptus oil, given by Senthil *et al.* (2016)

Senthil et al. (2016) performed an experiment on diesel engine using Annona biodiesel with Eucalyptus oil, dual fuel blends. They obtained higher brake thermal efficiency using A50-EU50 fuel blend than other fuel blends as well as diesel. This is because of equal quantity of biodiesel and Eucalyptus oil contains optimum amount of oxygen for proper combustion fuel. Figure 4.13 shows the variation of brake thermal efficiency with load given by **Senthil et al. (2016)**. **Dhar and Agarwal (2014)** also reported that the higher Karanja oil biodiesel blended diesel shows lower BTE at lower load. **Srivastava and Verma (2008)** found 5.72% decrease in thermal efficiency with Karanja oil biodiesel and diesel blends compared to neat diesel at full load condition.

4.4 Emission Characteristics

Exhaust emission characteristics such as smoke density and exhaust gas temperature of diesel engine were found using selected fuel blends of Karanja oil methyl ester and Eucalyptus oil at different loading conditions.

4.4.1 Smoke opacity

In general, the smoke density characteristics of diesel engine are the least and highest for vegetable oils. This is due to the lower viscosity and higher volatility that contributes to forming a good mixture for complete combustion. However, in the case of vegetable oil mixtures, low viscosity and high volatility lead to poor combustion due to incorrect atomization of the fuel.

Light beam absorption and scattering phenomena which are optical properties base to detect the smoke particle in smoke detector unit. Different values of smoke for different fuel blends as well as diesel were obtained at no load to full load condition and plotted in Figures 4.14(a) and 4.14(b). Comparison of smoke density of different fuel blends and diesel is shown in fig 4.15. Smoke emission for all the biodiesel blends is lower than diesel except K80EU20 and K90EU10 at higher load (greater than 50% load).

Diesel fuel is a non-oxygenated fuel. It contains very less amount of oxygen. Thus it shows higher smoke emission than biodiesel at part load as well as full load. Smoke opacity of K10EU90 blends also was found close to diesel because of lower oxygen presence in Eucalyptus oil than KOME. It decreased continuously from K10EU90 to K50EU50.

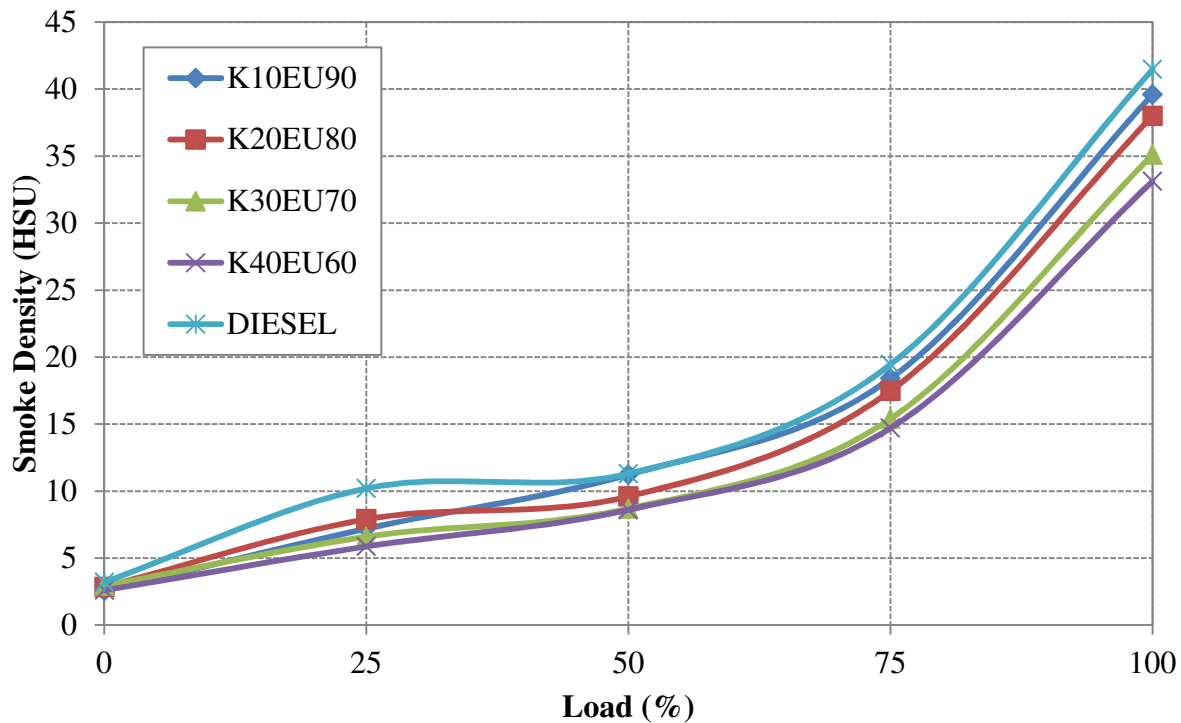


Fig. 4.14(a): Load v/s smoke density of K10EU90, K20EU80, K30EU70, K40EU60 and diesel

Fuels blend K50EU50 produced minimum value of smoke density as 32.1 HSU which is 22.06% lower than smoke produced by diesel fuel. This was because of higher oxygen content presence in the fuel which leads to proper combustion of fuel. Although, K70EU30 to K90EU10 contain enough oxygen content for proper burning of fuel but the viscosity of these fuel blends is higher so they cannot properly be atomized, which results in fuel drops remain unburnt and black smoke particles produced in exhaust emission.

Anand et al. (2011) also found the lower smoke opacity than diesel by methanol and Karanja oil biodiesel blends. They also concluded that smoke emission and carbon monoxide emission from diesel engine follow similar trends for the given fuel.

Figure 4.16 shows the variation of smoke power in different engine brake power given by **Vijayabaskar et al. (2015)**. They found the minimum emission by the combination of 75% Pine oil and 25% Pongamia methyl ester blend at all loading condition or brake power, due to proper combustion leading lower unburnt particles of fuel, so resulted in less soot formation in exhaust.

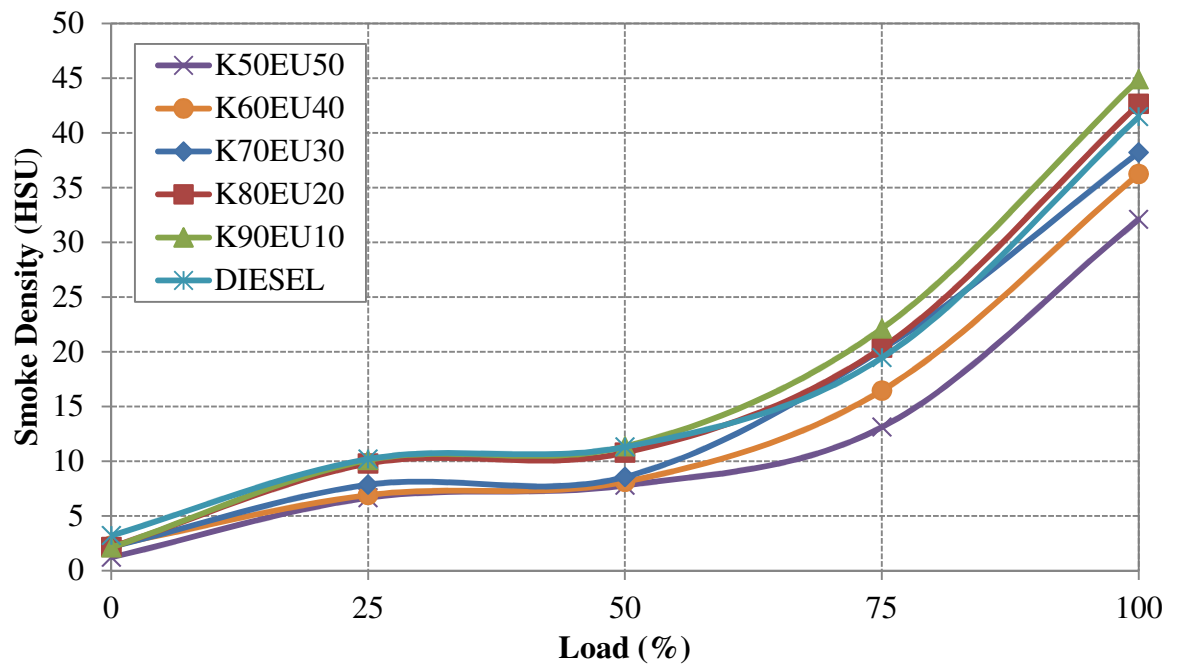


Fig. 4.14(b): Load v/s smoke density of K50EU50, K60EU40, K70EU30, K80EU20, K90EU10 and diesel

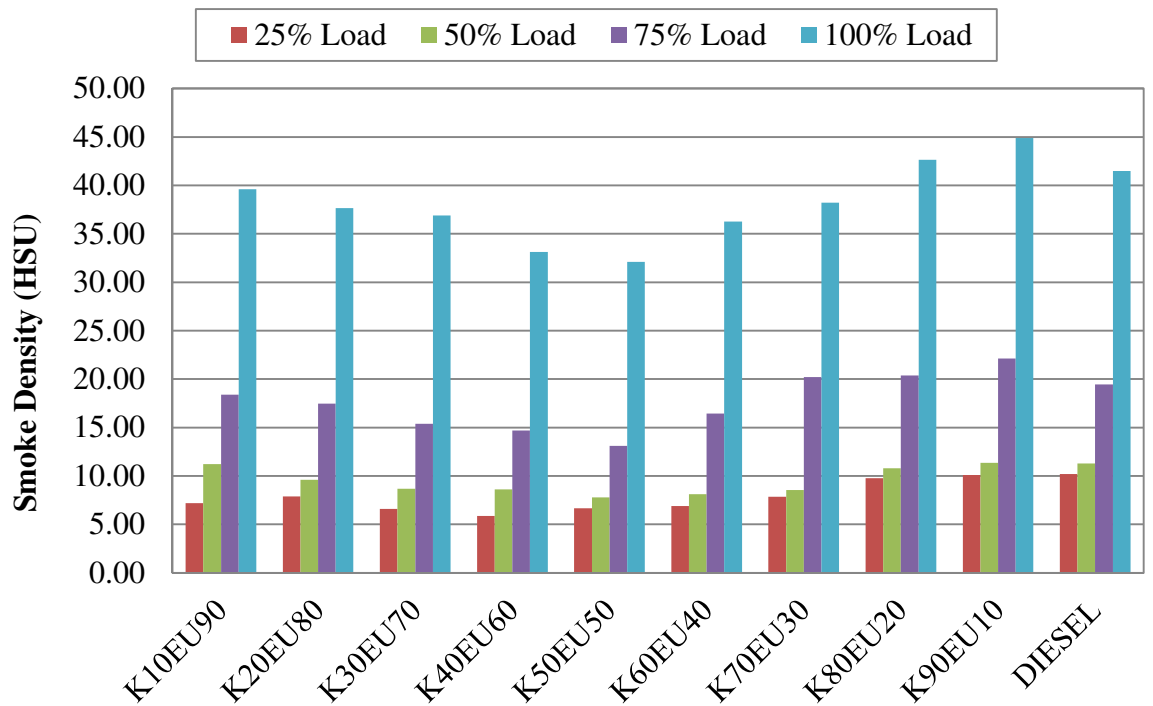


Fig. 4.15: Smoke density of all selected fuel blends

B50P50 fuel blends emits same smoke as emitted by neat diesel at lower loading because the properties of B50P50 such as viscosity, density, calorific values are close to diesel. B75P25 blends show maximum soot formation, may be due the poor atomization because of higher viscosity of pongamia pinnata methyl ester or Karanja oil biodiesel.

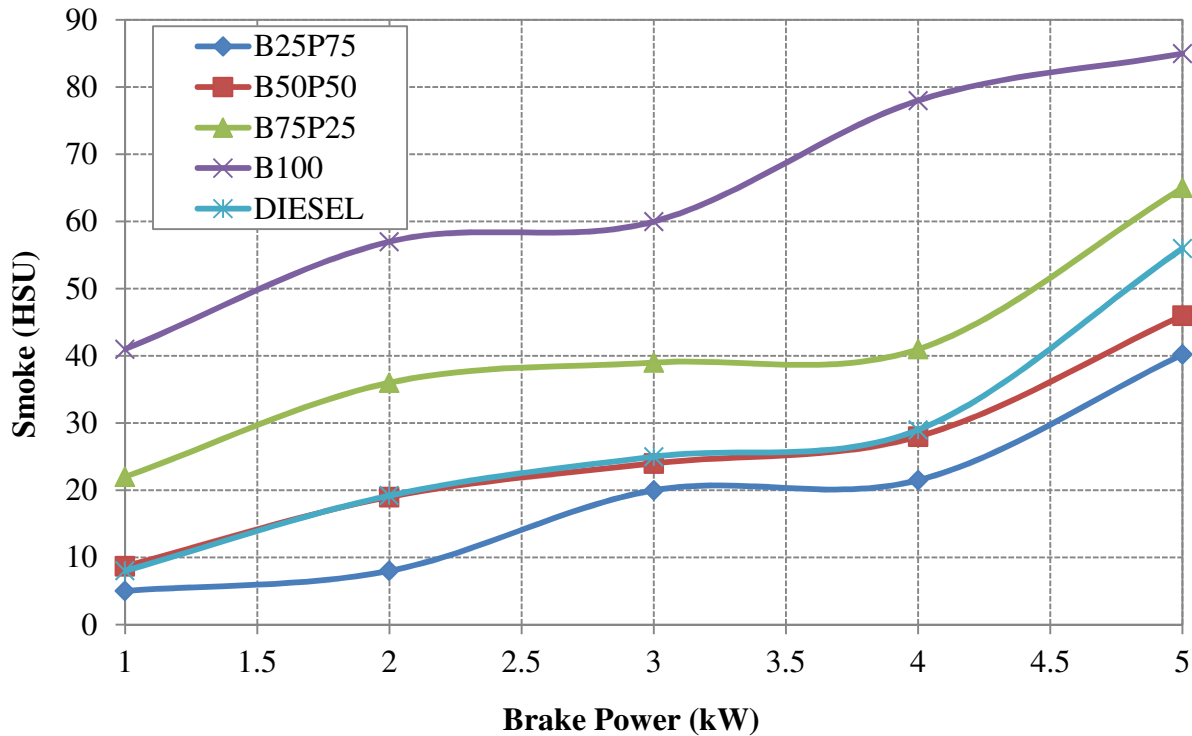


Fig. 4.16: Variation of smoke density with brake power using different blends of pongamia pinnata-pine oil, given by Vijayabaskar *et al.* (2015)

4.4.2 Exhaust gas temperature

The relationship between the exhaust gas temperature (EGT) and load with the combination of various selected fuel and diesel fuel is shown in figures 4.17(a) and 4.17(b). The results show that EGT gradually increased with increasing load for all selected fuel mixtures and diesel. Increase in EGT may be due to the heating of fuel inside the engine by engine cylinder heat and increasing the pressure of combustion chamber which results advanced fuel burning at warmed up condition of engine. It is obtained from fig. 4.17(a) and 4.17(b) that fuel blends contained rich amount of Eucalyptus oil having higher calorific value and less viscosity which results complete or proper combustion and increased the in-cylinder

pressure and temperature. Moreover, Eucalyptus oil has low cetane number which results higher ignition delay which also affected the in-cylinder temperature (Verma *et al.*, 2015). Therefore, EGT of rich Eucalyptus contained fuel is higher than diesel. Except this, rich amount of Karanja oil methyl ester fuel blends energy conversion to work is not proper due to incomplete combustion of highly viscous and poorly atomized molecules of KOMe. Thus, increase in EGT with respect to diesel also observed during analysis.

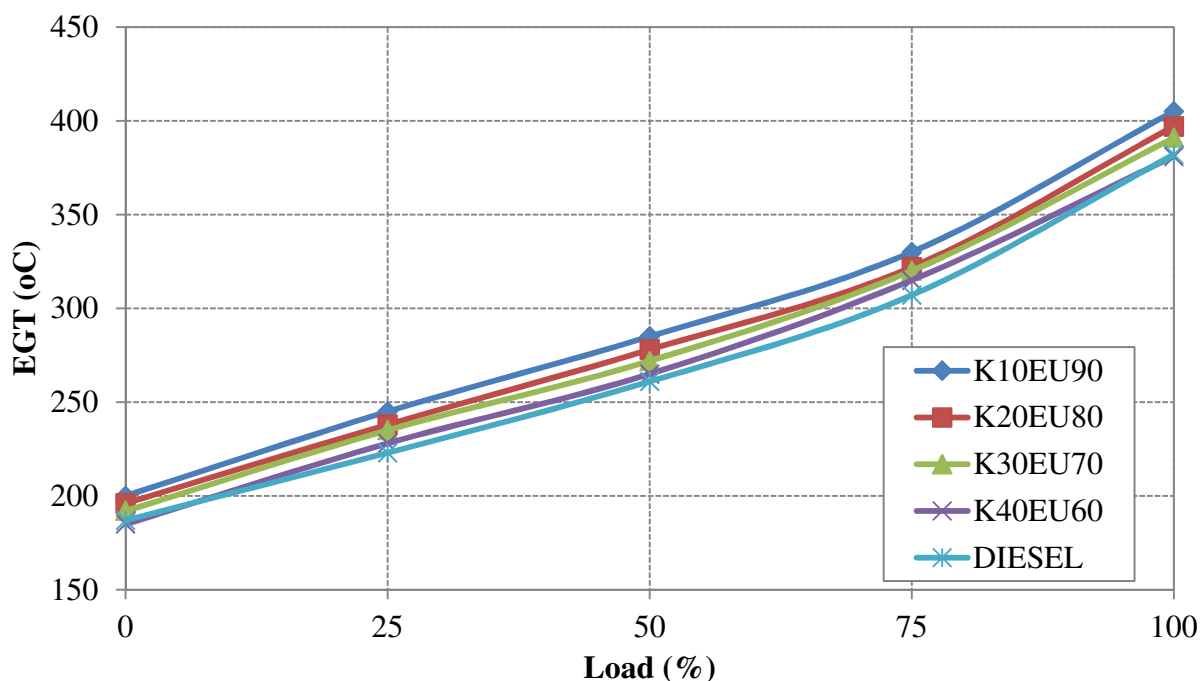


Fig. 4.17(a): Load v/s EGT of K10EU90, K20EU80, K30EU70, K40EU60 and diesel

Figure 4.18 shows the comparison of exhaust gas temperature of different fuel blends as well as diesel. EGT with all fuel blends found higher than diesel at all load except K50EU50 fuel blend. It is observed that EGT with K50EU50 fuel blend is very close to diesel than other fuel blends. It is 255°C at part load and 385°C at full load condition, which is 2.29% lower at lower load and 0.78% higher at higher load, as compared with diesel respectively. K90EU10 blend shows highest exhaust gas temperature among all the fuel blends and diesel too, which is 7.6% higher than diesel fuel. It is obtained from fig 4.18 that exhaust gas temperature was found increased for those fuel blends which has lower or decreasing brake thermal efficiency because less energy input was might be converted to work by those fuel blends.

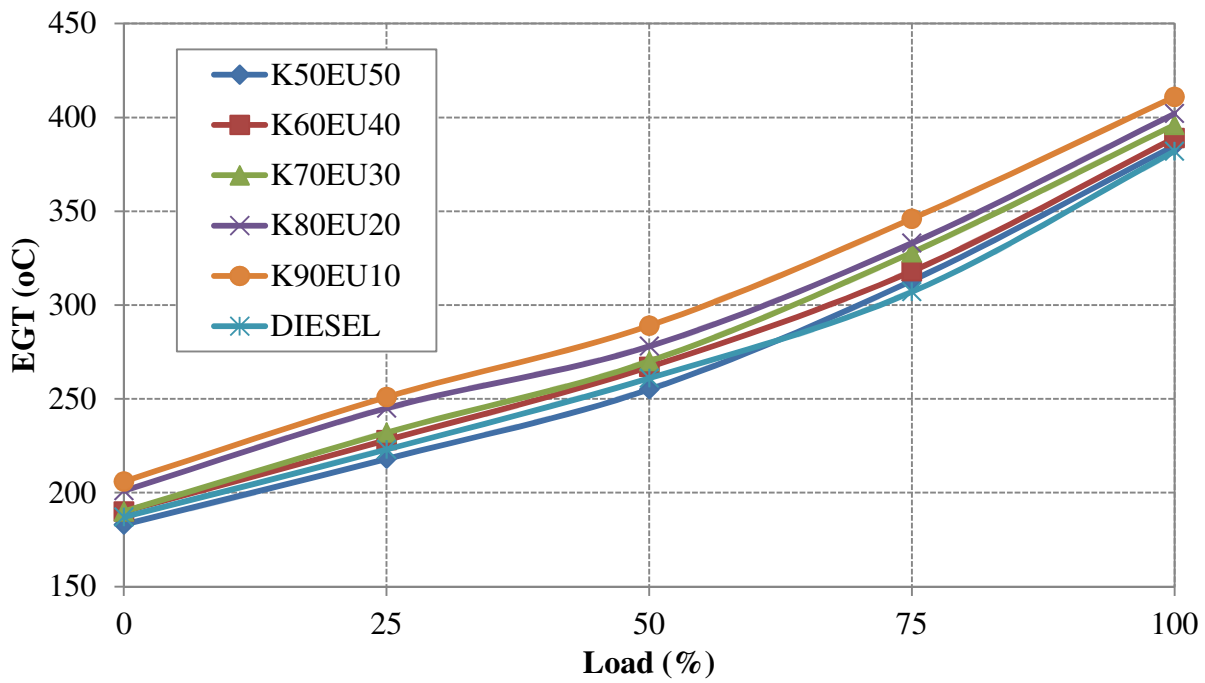


Fig. 4.17(b): Load v/s EGT of K50EU50, K60EU40, K70EU30, K80EU20, K90EU10 and diesel

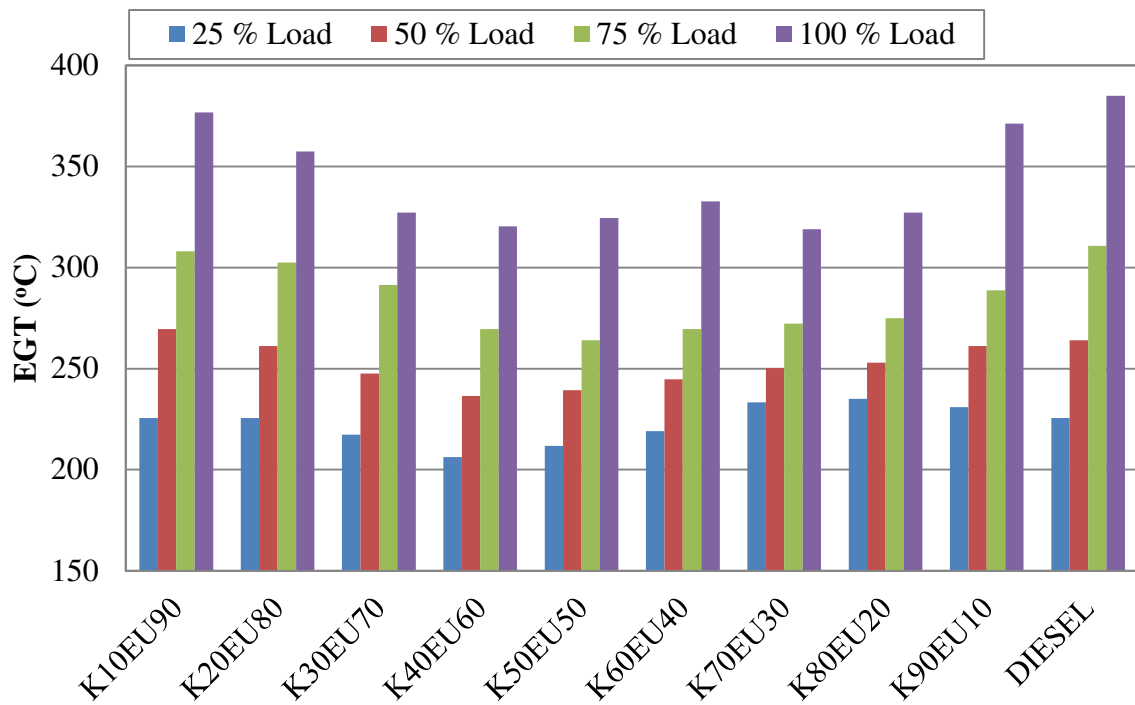


Fig. 4.18: EGT of all selected fuel blends

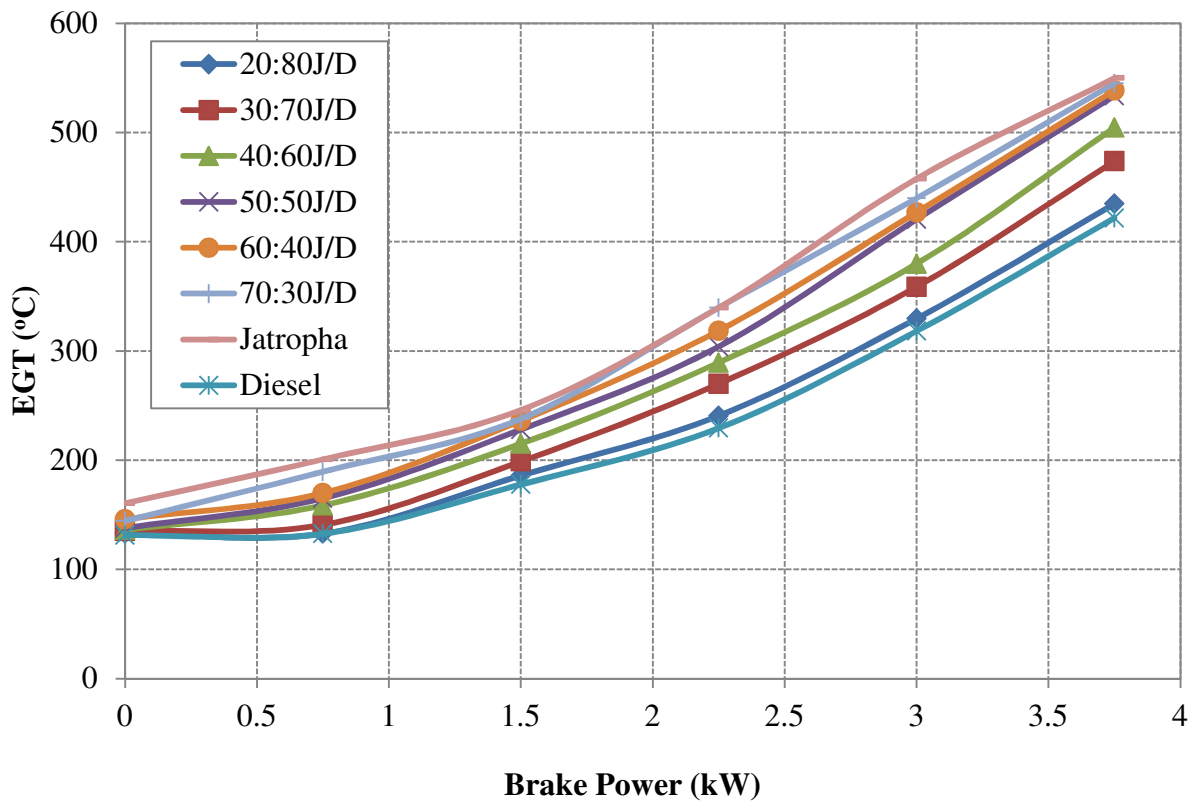


Fig. 4.19: Load v/s EGT for different blends of diesel and Jatropha curcas oil given by Pramanik (2003)

Pramanik (2003) obtained different values of exhaust gas emission using Jatropha curcas biodiesel, diesel and mixture of both at different brake power. Figure 4.19 shows Load v/s EGT for different blends of diesel and Jatropha curcas oil. He mixed Jatropha oil biodiesel with diesel in different percentage such as 20%, 30%, 40%, 50%, 60% and 70%. Results shown by him revealed that EGT increase with increasing brake power. EGT deviation of all blends is higher at higher loads. EGT increased with increasing the percentage of Jatropha biodiesel in fuel blends and attain its maximum value using neat Jatropha biodiesel which is due to poor combustion of Jatropha because of higher viscosity than diesel. He also concluded that, on 20% Jetropha biodiesel engine shows minimum exhaust gas temperature which is closer to diesel comparing other fuel blends.



*Summary
and
Conclusions*



5.1 Summary and Conclusions

Experimental investigation of performance and emission characteristics of 4.4 kW diesel engine using different blends of Karanja oil methyl ester and Eucalyptus oil has been conducted. Before experimental analysis stability on the basis of phase separation of fuel blends was checked at room temperature and selected for engine performance and emission testing. Physical and chemical properties of fuel blends were also obtained experimentally, which were seem to be improved after transesterification of crude Karanja oil. The extraction of biodiesel was carried out successfully in two steps named as esterification and transesterification in which H₂SO₄ in 0.1% and KOH in 1% of crude Karanja oil weight was used as catalyst. Reaction was carried out with 13% methanol by oil weight in first step and second step.

Performance and emission investigation were done using K10EU90, K20EU80, K30EU70, K40EU60, K50EU50, K60EU40, K70EU30, K80EU20, K90EU10 and diesel fuel. Different parameters of engine such as brake power, fuel consumption, brake specific fuel consumption, brake thermal efficiency, smoke density and exhaust gas temperature were tested and summarized. Performance characteristics of diesel engine were checked as per **IS: 10000[P: 8]: 1980**. Moreover, **SAE: J255a** standard was used for the testing of engine emission characteristics.

Based on current analysis the following conclusions are drawn:

1. First the crude Karanja oil was successfully converted into Karanja oil biodiesel with reduced viscosity, density and enhanced properties like calorific value, volatility, flash point and fire point.
2. All selected fuel samples were found suitable for testing in engine without any phase separation at room temperature.
3. Kinematic viscosity and density was increased but calorific value decreased with increasing the percentage of Karanja oil methyl ester in test fuel blends.

4. Kinematic viscosity of most of the fuel blends such as K40EU60, K50EU50, K60EU40, K70EU30, K80EU20 and K90EU10 were found to be higher than diesel fuel but in ASTM range, thus it can be used in diesel engine.
5. Gross calorific value of diesel was calculated as 44.567 MJ/kg in this work which is 2.67% higher than Eucalyptus oil and 19.47% higher than Karanja oil methyl ester. Gross calorific value of different fuel blends were found decreasing with the increased proportion of KOME. This is because of higher density of KOME compared to diesel, which cause more fuel consumption for generating same heat as generated by diesel. GCV of all fuel blends was obtained as per **IS: 1448[P: 6]: 1984**.
6. Flash point and fire point of KOME was 59.32°C higher than diesel because of its low volatile nature than diesel. Simultaneously it is 6.38°C lower than diesel for Eucalyptus oil, which results in easy storage and handling of fuel blends.
7. Cold flow properties such as cloud point and pour point of KOME is higher than eucalyptus oil and diesel fuel which may restrict its direct use in cold weather places. But mixing of eucalyptus oil with KOME decreases the cloud point and pour point to optimum ranges and results in smooth use in any climate.
8. The performance of engine was found satisfactory under the fuel consumption testing of engine using selected fuel blends of Karanja oil methyl ester and Eucalyptus oil. Fuel consumption of K30EU70 and K40EU60 fuel blends are similar to diesel fuel, but fuel consumption using other fuel blends was higher than diesel.
9. Brake power of diesel engine on selected fuel blends was found to be similar and close to diesel.
10. BSFC of fuel blends was found to decrease as the concentration of Karanja oil methyl ester was increased from 10% to 30% at all loading conditions. K40EU60 and diesel show approximately equal BSFC at full load which increases continuously at all loads with increasing concentration of KOME. Thus it can be concluded that K30EU70 and K40EU60 are best fuel blends among all selected fuel blends to obtain BSFC closer to diesel fuel.

11. BTE was found to increase with increasing load for all fuel blends as well as diesel fuel (except at full load). BTE of high concentrated Eucalyptus oil fuel blends such as K10EU90 and K20EU80 was found lower than diesel at all loading conditions. K30EU70 and K40EU60 fuel blends shows 0.52% and 1.02% higher BTE than diesel.

12. Smoke density was found to be lower than diesel for all fuel blends except K80EU20 and K90EU10 blends. K50EU50 fuel blend produced minimum smoke emission which is 22.06% lower than smoke produced by diesel fuel.

The above discussions show that the behaviour of Eucalyptus oil is similar as diesel in test fuel blends. Karanja oil methyl ester is highly viscous and dense biodiesel than eucalyptus oil as well as diesel fuel. So the mixture of Karanja oil methyl ester and Eucalyptus oil can be a full replacement of diesel fuel and an optimum mixture to run diesel engine without any modification in engine. Moreover, results concluded that K30EU70 and K40EU60 fuel blends are optimum mixtures for better performance and lower smoke emission of engine. Although, brake specific fuel consumption of these fuel blends is higher than diesel but brake thermal efficiency is comparable to diesel.

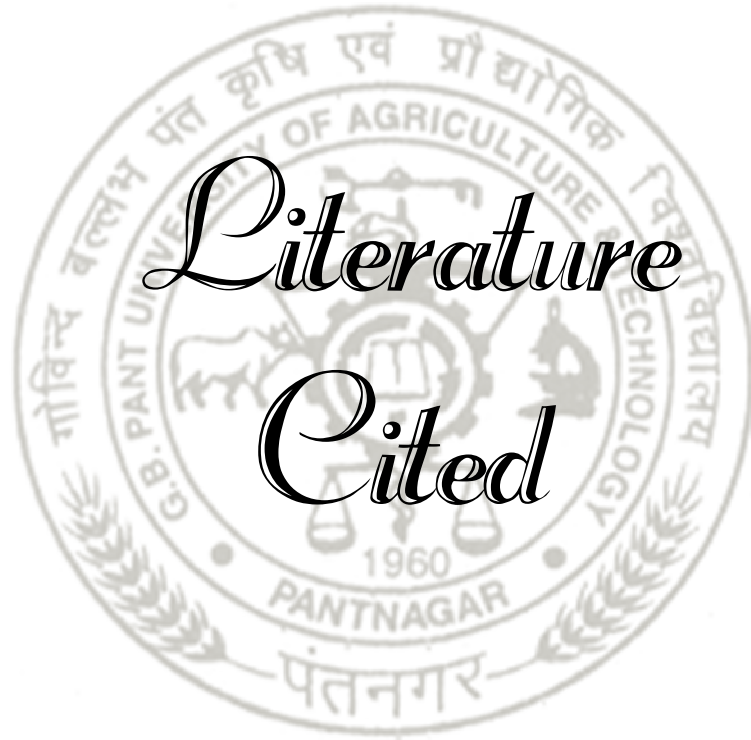
Hence K30EU70, K40EU60 fuel blends can be recommended as diesel engine fuel with better performance and emission characteristics without any engine modification.

5.2 Recommendations for Future Work

The present work leaves a wide scope for future investigators. Some recommendations for future research are:

1. The performance and emission characteristics of these fuels blends can be investigated in variable compression ratio (VCR) engine.
2. Possible use of oxygenated additives, such as Isopropyl ether, Dimethyl carbonate, Diethyl carbonate, Dimethoxy methane etc with fuel blends to reduce the exhaust emission levels.
3. Tests can also be conducted such as calculation of cetane number, to resolve the effect of low cetane number fuel (Eucalyptus oil).

4. Investigation of optimum fuel blends can be performed using the response surface methodology (RSM).
5. Analysis of engine characteristics with model simulation using MATLAB and ANSYS software for a comparative study which can be a good future plan of work.



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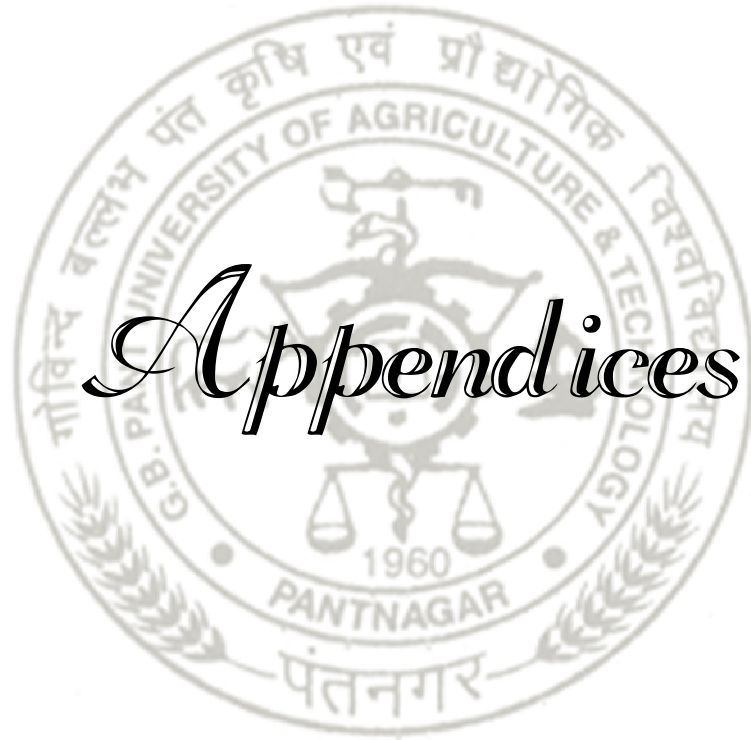
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Appendices



APPENDICES

Appendix A-1 Different measured fuel properties of selected fuel types

Sl. No.	Fuel Type	Kinematic Viscosity (cSt)	Relative Density	Calorific Value (MJ/kg)	Flash Point(°C)	Fire Point (°C)	Cloud Point (°C)	Pour Point (°C)
1	Diesel	2.067	0.846	44.567	62.5	65.78	-4	-10
2	K100	6.1	0.898	35.89	121	125.1	19	11.4
3	EU100	2.16	0.875	43.374	54.4	59.4	-4	-9
4	K10EU90	2.121	0.879	43.366	55	59.9	-4	-7.3
5	K20EU80	2.2014	0.88	42.609	58.2	62	-2	-5
6	K30EU70	2.512	0.88	42.173	58.78	61.11	-1	-4
7	K40EU60	2.947	0.881	41.947	63.12	73	-0.4	-2.1
8	K50EU50	3.451	0.882	40.642	70.32	77.7	2.8	-1
9	K60EU40	3.78	0.883	39.345	79.4	83.78	6	3
10	K70EU30	4.582	0.886	38.257	86.36	91.47	9.5	8
11	K80EU20	5.35	0.892	37.308	95	101.21	14	8
12	K90EU10	5.429	0.895	37.283	110.9	119	16	10

Appendix A-2 Experimental results of the engine operating on diesel

Brake Load (%)	Engine Speed (rpm)	Brake Power (kW)	50ml fuel consumption time (sec)	Fuel Consumption (l/h)	BSFC (kg/Kw-h)	Brake Thermal Efficiency (%)	Exhaust Gas Temperature (°C)	Smoke Density (HSU)
No load	1505	0	6.83	0.439	1.400	0.00	187	3.20
25	1491	1.090	4.47	0.672	0.520	15.53	223	10.20
50	1485	2.157	3.25	0.923	0.359	22.51	261	11.30
75	1460	3.209	2.53	1.184	0.312	25.87	307	19.45
100	1447	4.244	1.90	1.579	0.315	25.64	382	41.47

Appendix A-3 Experimental results of the engine operating on K10EU90

Brake Load (%)	Engine Speed (rpm)	Brake Power (kW)	50ml fuel consumption time (sec)	Fuel Consumption (l/h)	BSFC (kg/Kw-h)	Brake Thermal Efficiency (%)	Exhaust Gas Temperature (°C)	Smoke Density (HSU)
No load	1510	0.000	6.80	0.441	1.200	0.00	200	2.56
25	1496	1.096	4.23	0.709	0.568	14.61	245	7.20
50	1484	2.175	3.10	0.968	0.391	21.22	285	11.23
75	1456	3.200	2.33	1.286	0.353	23.51	330	18.40
100	1440	4.220	1.80	1.667	0.347	23.91	399	39.60

Appendix A-4 Experimental results of the engine operating on K20EU80

Brake Load (%)	Engine Speed (rpm)	Brake Power (kW)	50ml fuel consumption time (sec)	Fuel Consumption (l/h)	BSFC (kg/Kw-h)	Brake Thermal Efficiency (%)	Exhaust Gas Temperature (°C)	Smoke Density (HSU)
No load	1504	0	6.83	0.439	1.400	0.00	196	2.84
25	1497	1.097	4.25	0.706	0.566	14.92	238	7.90
50	1490	2.183	3.13	0.957	0.386	21.89	278	9.60
75	1463	3.216	2.43	1.233	0.337	25.04	322	17.48
100	1442	4.226	1.82	1.651	0.344	24.57	397	37.64

Appendix A-5 Experimental results of the engine operating on K30EU70

Brake Load (%)	Engine Speed (rpm)	Brake Power (kW)	50ml fuel consumption time (sec)	Fuel Consumption (l/h)	BSFC (kg/Kw-h)	Brake Thermal Efficiency (%)	Exhaust Gas Temperature (°C)	Smoke Density (HSU)
No load	1498	0	6.98	0.430	1.400	0.00	192	2.93
25	1491	1.092	4.55	0.659	0.531	16.07	235	6.60
50	1488	2.180	3.23	0.928	0.374	22.80	272	8.69
75	1469	3.229	2.53	1.184	0.323	26.45	320	15.40
100	1453	4.258	1.90	1.565	0.326	26.16	391	36.90

Appendix A-6 Experimental results of the engine operating on K40EU60

Brake Load (%)	Engine Speed (rpm)	Brake Power (kW)	50ml fuel consumption time (sec)	Fuel Consumption (l/h)	BSFC (kg/Kw-h)	Brake Thermal Efficiency (%)	Exhaust Gas Temperature (°C)	Smoke Density (HSU)
No load	1505	0	6.80	0.441	1.500	0.00	185	2.60
25	1498	1.098	4.42	0.679	0.545	15.74	228	5.87
50	1486	2.177	3.20	0.938	0.379	22.63	265	8.60
75	1465	3.220	2.58	1.161	0.318	27.01	315	14.70
100	1449	4.247	1.93	1.552	0.322	26.66	381	33.12

Appendix A-7 Experimental results of the engine operating on K50EU50

Brake Load (%)	Engine Speed (rpm)	Brake Power (kW)	50ml fuel consumption time (sec)	Fuel Consumption (l/h)	BSFC (kg/Kw-h)	Brake Thermal Efficiency (%)	Exhaust Gas Temperature (°C)	Smoke Density (HSU)
No load	1500	0	6.33	0.474	1.600	0.00	183	1.21
25	1494	1.095	4.05	0.741	0.597	14.84	218	6.65
50	1481	2.170	2.98	1.006	0.409	21.67	255	7.78
75	1468	3.227	2.38	1.259	0.344	25.74	313	13.10
100	1446	4.238	1.78	1.682	0.350	25.30	385	32.10

Appendix A-8 Experimental results of the engine operating on K60EU40

Brake Load (%)	Engine Speed (rpm)	Brake Power (kW)	50ml fuel consumption time (sec)	Fuel Consumption (l/h)	BSFC (kg/Kw-h)	Brake Thermal Efficiency (%)	Exhaust Gas Temperature (°C)	Smoke Density (HSU)
No load	1505	0.00	6.68	0.449	1.700	0.00	190	2.30
25	1498	1.098	3.75	0.800	0.644	14.22	228	6.90
50	1488	2.180	2.80	1.071	0.434	21.09	267	8.12
75	1465	3.220	2.25	1.333	0.366	25.03	318	16.45
100	1442	4.226	1.68	1.782	0.372	24.57	389	36.25

Appendix A-9 Experimental results of the engine operating on K70EU30

Brake Load (%)	Engine Speed (rpm)	Brake Power (kW)	50ml fuel consumption time (sec)	Fuel Consumption (l/h)	BSFC (kg/Kw-h)	Brake Thermal Efficiency (%)	Exhaust Gas Temperature (°C)	Smoke Density (HSU)
No load	1491	0	6.63	0.452	1.800	0.00	190	2.15
25	1486	1.089	4.05	0.741	0.603	15.61	232	7.85
50	1480	2.169	2.80	1.071	0.438	21.50	270	8.56
75	1456	3.200	2.23	1.343	0.372	25.30	328	20.21
100	1438	4.214	1.63	1.837	0.386	24.37	396	38.21

Appendix A-10 Experimental results of the engine operating on K80EU20

Brake Load (%)	Engine Speed (rpm)	Brake Power (kW)	50ml fuel consumption time (sec)	Fuel Consumption (l/h)	BSFC (kg/Kw-h)	Brake Thermal Efficiency (%)	Exhaust Gas Temperature (°C)	Smoke Density (HSU)
No load	1502	0	6.92	0.434	1.800	0.00	201	2.14
25	1493	1.094	3.83	0.783	0.638	15.12	245	9.78
50	1478	2.151	2.75	1.091	0.449	21.48	278	10.78
75	1461	3.211	2.10	1.429	0.397	24.32	333	20.36
100	1439	4.217	1.58	1.895	0.401	24.08	402	42.64

Appendix A-11 Experimental results of the engine operating on K90EU10

Brake Load (%)	Engine Speed (rpm)	Brake Power (kW)	50ml fuel consumption time (sec)	Fuel Consumption (l/h)	BSFC (kg/Kw-h)	Brake Thermal Efficiency (%)	Exhaust Gas Temperature (°C)	Smoke Density (HSU)
No load	1500	0	7.00	0.429	1.900	0.00	206	2.11
25	1483	1.087	3.67	0.818	0.674	14.33	251	10.10
50	1475	2.142	2.65	1.132	0.469	20.60	289	11.35
75	1453	3.194	2.02	1.488	0.417	23.16	346	22.12
100	1435	4.206	1.52	1.978	0.421	22.94	411	44.90

The author, Harikrishna Nagwan was born on 5th February 1992 in Tehri Garhwal, district of Uttarakhand. He passed his High School in 2008 from S.V.M. New Tehri and Intermediate Examination in 2010 from G.I.C Narendra Nagar, Tehri (affiliated to Uttarakhand Board). He did B. Tech. degree in Mechanical Engineering from, THDC-Institute of Hydropower Engineering and Technology, B. Puram, Tehri (affiliated to Uttarakhand Technical University) in June, 2015. He took admission in the College of Post Graduate Studies at Govind Ballabh Pant University of Agriculture & Technology, Pantnagar in July 2016 for Master's degree in Mechanical Engineering with major in Thermal Engineering.

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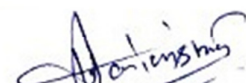
ABSTRACT

Name : Harikrishna Nagwan **Id. No.** : 51120
Semester & Year of admission : 1st, 2016-2017 **Degree** : Master of Technology
(Mechanical Engineering)
Major : Thermal Engineering **Department** : Mechanical Engineering
Thesis Title : **PERFORMANCE AND EMISSION CHARACTERISTICS OF DIESEL ENGINE USING KARANJA OIL METHYL ESTER AND EUCALYPTUS OIL BLENDS**
Advisor : Dr. Pramod Chandra Tewari

Demand of liquid fuel is very high in industrial and transportation sectors which results rise in price rapidly. In order to meet sustainable future demand of energy and reduce dependency on foreign oil, an environment friendly biofuels are gaining importance in recent years. So the biodiesel is seriously considered as an alternative fuel for diesel engine. In the present study, different blends of Karanja oil methyl ester and eucalyptus oil are used as an alternative fuel for diesel engine. Although, these fuels are used in diesel engine separately as well as blending with diesel in past studies but it is necessary to replace diesel completely from diesel engine by biodiesel because of increasing diesel fuel crises. Karanja oil and Eucalyptus oil are non-edible forest based oils, which is produced from karanja and eucalyptus seeds by mechanical expeller. The Karanja oil is converted into biodiesel by using esterification and transesterification reaction for enhancing its various properties. Methanol (13% by weight) is used as an alcohol in the presence of H_2SO_4 (0.1%) and NaOH (1% by weight) as a catalyst. 92% biodiesel yield is obtained by using esterification and transesterification reaction. Engine performance and emission characteristics of a 4.4 kW, single cylinder, four stroke diesel engine operating on dual fuel blends are investigated. Karanja oil percentage is varied from 10% to 90% (on volume basis). Eucalyptus oil is low cetane biofuel and combustion process in diesel engine depends upon cetane number and availability of oxygen. Karanja oil is added to increase cetane number of dual fuel blends and increasing the oxygen content. Experimental tests have been conducted at a fixed engine speed of 1500 rpm and at 0%, 25%, 50%, 75% and 100% load.

The engine performance parameters such as brake power, brake specific fuel consumption, brake thermal efficiency, smoke density, absorption coefficient and exhaust temperature have been measured and the optimum blends which gave the best results of these parameters are investigated. K30EU70 and K40EU60 blends are obtained as best fuel blends for diesel engine. The results of the experiment have been analyzed and compared with standard diesel. It is observed that there is slight improvement in the performance and emission characteristics of engine by using some blends. It is also concluded that biodiesel and its all blends show approximately similar properties to that of diesel fuel, thus they provided satisfactory results on the engine. The exhaust gas emissions of fuel blends are also found better than that of diesel fuel. Therefore, all these blends can be effectively and efficiently used as an engine fuel without any modifications in engine.


(Pramod Chandra Tewari)
Advisor



(Harikrishna Nagwan)
Author

सारांश

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शोध प्रबंध शीर्षक	: करांजा तेल मिथाइल ईस्टर एवं यूकेलिप्टस तेल के मिश्रणों के प्रयोग से डीजल इंजन की प्रदर्शन व उत्सर्जन विशेषताएँ		
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औद्योगिक और परिवहन क्षेत्रों में तरल ईंधन की मांग बहुत अधिक है जिसके परिणाम स्वरूप इनकी कीमतें बहुत तेजी से बढ़ रही है। उर्जा की सतत भविष्य की मांग को पूरा करने और विदेशी तेल पर निर्भरता को कम करने के लिए हाल के वर्षों में पर्यावरण अनुकूल जैव ईंधन महत्व प्राप्त कर रहे हैं। वर्तमान अध्ययन में करांजा तेल के मिथाइल एस्टर और यूकेलिप्टस के तेल के विभिन्न मिश्रण डीजल इंजन के लिए वैकल्पिक ईंधन के रूप में उपयोग किए गये हैं। यद्यपि पिछले कुछ अध्ययनों में इन तेलों का प्रयोग डीजल इंजन में अलग अलग और डीजल के साथ मिश्रित करके किया गया है। परंतु डीजल इंजन से डीजल को बायोडीजल द्वारा पूर्णरूप से बदलने की अति-आवश्यकता है क्योंकि डीजल का मूल्य निरंतर बढ़ रहा है। करांजा तेल एवं यूकेलिप्टस तेल गैर- खाद्य वन आधारित तेल है जो यांत्रिक ऐक्सपेलेटर द्वारा करांजा ओर यूकेलिप्टस के बीजों से शोधित किये जाते हैं। करांजा तेल की विभिन्न विशेषताओं को डीजल इंजन के अनुरूप करने के लिये एस्ट्रिफिकेशन और ट्रांसएस्ट्रिफिकेशन प्रतिक्रिया का उपयोग करके बायोडीजल में परिवर्तित किया गया। अल्कोहल के रूप में मेथनॉल (वजन से 13%) एवं उत्प्रेरक के रूप में H_2SO_4 (वजन से 0.1%) और NaOH (वजन से 1%) प्रयोग किया गया। एस्ट्रिफिकेशन और ट्रांसएस्ट्रिफिकेशन प्रतिक्रिया का उपयोग करके 92% बायोडीजल उपज प्राप्त की गयी। 4.4 किलोवाट, सिंगल सिलेंडर एवं चार स्ट्रोक डीजल इंजन के प्रदर्शन और उत्सर्जन विशेषताओं की जाँच की गयी जो कि दो ईंधनों के मिश्रणों पर चलाया गया। करांजा तेल का प्रतिशत 10% से 90% (आयतन के आधार पर) तक लिया गया। यूकेलिप्टस का तेल कम सिटैन जैव ईंधन है और डीजल इंजन में दहन प्रक्रिया सिटैन संख्या और ऑक्सीजन की उपलब्धता पर निर्भर करती है। करांजा तेल को ईंधन मिश्रणों के सिटैन संख्या और ऑक्सीजन सामग्री में वृद्धि करने के लिए मिलाया गया। 1500 आरपीएम की निश्चित गति तथा 0%, 25%, 50%, 75% और 100% भार पर प्रायोगिक परीक्षण किए गये।

ब्रेक पावर, ब्रेक विशिष्ट ईंधन खपत, ब्रेक थर्मल दक्षता, धुआँ घनत्व और निकास तापमान जैसे इंजन प्रदर्शन व उत्सर्जन मानकों को मापा गया और इष्टतम मिश्रण जो इन मानकों के सर्वोत्तम परिणाम प्रदान करते हैं, की जांच की गयी। K30EU70 और K40EU60 मिश्रण डीजल इंजन के लिए सबसे अच्छे ईंधन मिश्रण के रूप में प्राप्त किए गये। प्रयोग के परिणामों का विश्लेषण किया गया और इसकी तुलना मानक डीजल के साथ की गयी। यह देखा गया है कि कुछ मिश्रणों का उपयोग करके इंजन के प्रदर्शन और उत्सर्जन विशेषताओं में मामूली सुधार हुआ। यह भी निष्कर्ष निकाला गया कि बायोडीजल और इसके सभी मिश्रण डीजल ईंधन के लगभग समान गुण दिखाते हैं। इस प्रकार उन्होंने इंजन पर संतोषजनक परिणाम प्रदान किए। ईंधन मिश्रणों के निकास गैस उत्सर्जन डीजल ईंधन की तुलना में बेहतर पाए गये, इसलिए इन सभी मिश्रणों को इंजन में किसी भी संशोधन के बिना प्रभावी रूप से और कुशलता से इंजन ईंधन के रूप में उपयोग किया जा सकता है।


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