Performance Analysis of Multi-cylinder C.I. Engine by using Karanja Bio-diesel

Dipak Patil[1] , Dr. Rachayya.R. Arakerimath[2]
1 Dr. Babasaheb Ambedkar Technological University, Lonere, Maharashtra, India
2Department of Mechanical Engineering, G H Raisoni College of Engineering and Management, Wagholi, Pune, Maharashtra, India

A B S T R A CT

Bio-diesel (fatty acid methyl ester) which is derived from triglycerides by transesterification has attracted considerable attention during the past decade as a renewable, biodegradable and nontoxic fuel. Several process for biodiesel fuel production have been developed, among which transesterification using alkali as catalyst gives high level of conversion of triglycerides to their corresponding me using alkali as catalyst gives high level of conversion of triglycerides to their corresponding methyl ester in a short duration. A variety of edible and non-edible oils are considered for bio-diesel production. In the present work, Karanja (Pongamia pinnata) Biodiesel purchased from authorized agencies, and their important physical & chemical properties were tested & compared. It is found that these properties are approximately similar to diesel fuel and suitable to use in diesel engine. Also petro-diesel is purchased from local authorized agency and used before and after the biodiesels for verifying the engine condition due to biodiesels. The biodiesel from Karanja oil is used in a M&M Turbo Charged make four stroke, four cylinders, and water cooled diesel engine in pure and blended form without any modification in engine design or fuel system. The performance characteristics of an engine are studied with different proportions of biodiesel and petro-diesel .The power, torque, and brake thermal efficiency using biodiesel are found higher at various load conditions than the petro-diesel; however specific fuel consumption is found slightly more. The biodiesel blend KBD30 have shown better performance than the diesel and other blends.

Keywords: Karanja, transesterification,Bio-diesel blend, KbD20, KBD30,KBD40

I. Introduction

Energy Scenario in India

During last decade India has maintained a high growth rate in accepting the improved technological challenges in global scenario. India ranks sixth in the world in terms of energy demand accounting for 3.5% of world commercial energy demand in 2001. The energy demand is expected to grow at 4.8%. The demand of diesel is projected to grow from 39.81 million metric tons in 2001 – 02 to 52.32 million metric tons in 2006 – 07 @ 5.5% per annum. Also due to gradual depletion of the world petroleum reserve, rising petroleum prices, increasing threat to the environment from exhaust emission and global warming have generated an intense international interest in developing alternative non petroleum fuels. [11]

Why Bio fuels?

In recent years several researches have been made to use vegetable oil, animal fats as a source of renewable energy known as bio diesel that can be used as fuel in CI engines. Vegetable oils are the most promising alternative fuels for CI engines as they are renewable, biodegradable, non toxic, environmental friendly, a lower emission profile compared to diesel fuel and most of the situation where conventional petroleum diesel is used. Even though "diesel" is part of its name there is no petroleum or other fossil fuels in bio diesel. It is 100% vegetable oil based, that can be blended at any level with petroleum diesel to create a bio diesel blend or can be used in its pure form. Non edible vegetable oils are the most significant to use as a fuel compared to edible vegetable oils as it has a tremendous demand for using as a food and also the high expense for production. Therefore many researchers are experimenting on non edible vegetable oils. In India the feasibility of producing bio diesel as diesel substitute can be significantly thought as there is a large junk of degraded forest land, unutilized public land, and fallow lands of farmers, even rural areas that will be beneficial for overall economic growth.

There are many tree species that bear seeds rich in non edible vegetable oils. Some of the promising tree species are Pongamia pinnata (karanja), Melia 3 azadirachta (neem), Jatropha curcas (Ratanjyot) etc. But most surprisingly as per their potential only a maximum of 6% is used.

Problems with Biodiesel

Major problems encountered with vegetable oil as bio diesel used in CI engine are its low volatility and high viscosity due to long chain structure. The common problems faced are excessive pumping power, improper combustion and poor atomization of fuel particles. The conversion of the vegetable oil as a CI engine fuel can be done any of the four methods; pyrolysis, micro emulsification, dilution/blending and transesterification.

Preparation of laboratory samples of esterified karanja oil (bio diesel):

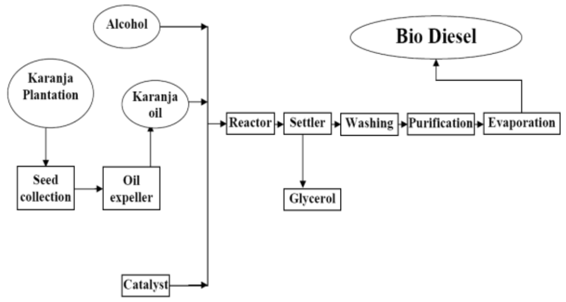


Fig.1.1 Preparation of laboratory samples of esterified karanja oil (bio diesel)

Relative Density: known as the specific gravity refers to the ratio of the density of a fuel to the density of water at same temperature. With it other properties could be judged. The density of the fuels was measured by means of a capillary stopper relative density bottle of 20ml capacity.

Flash and Fire point: Flash point is the lowest temperature corrected to a standard atmospheric condition at which application of a test flame causes the vapour of a specimen to ignite under specified conditions of test. Fire point is the lowest temperature at which a specimen will sustain burning for 5 seconds. These two parameters have great importance while determining the fire hazard (temperature at which fuel will give off inflammable vapour). Flash point and fire point of the samples were measured by Cleveland open Cup Tester (followed by the specifications IP 36, ASTM D92, IS: 1448).

Cloud and Pour point: Cloud point is that temperature, expressed as a multiple of 10C, at which a cloud or haze of wax crystals appears at the bottom of the test jar when the oil is cooled under the prescribed conditions. Pour point is the lowest temperature, expressed as multiple of 30C at which the oil is observed to flow when cooled and examined under prescribed conditions.
These two temperatures are of great importance in knowing the behaviour of fuels in a cold weather. These properties are determined by standard instrument for measuring cloud and pour point apparatus followed by IP15.

Calorific value: Calorific value of a fuel is the thermal energy released per unit quantity of fuel when the fuel is burned completely and the products of combustion are cooled back to the initial temperature of the combustible mixture. It measures the energy content in a fuel. This is an important property of the bio diesels that determines the suitability of the material as alternative to diesel fuels. The heating value of the prepared bio diesel was determined with the help of Bomb Calorimeter (followed by the specification IP 12 and ASTM D4809). A known amount of fuel was burnt in a bomb and the temperature difference was noted down. The effective heat capacity (water equivalent) of the system was also determined using the same procedure with dry and pure benzoic acid (6324calories/gm or 26460J/kg).

Viscosity measurements: The resistance to flow exhibited by fuel blends is expressed in various units of viscosity. It is a major factor of consequence in exhibiting their suitability for the mass transfer and metering requirements of engine operation. Higher the viscosity results low volatility and poor atomization of oil during injection in CI engine, that results in incomplete combustion and ultimately carbon deposits on injector nozzle as well as in the combustion chamber. The viscosities of Karanja oil as well as derived bio diesel are measured by Red Wood Viscometer (As per IP70) and a comparative study is made at different temperature. Different temperature dependent viscosities are shown in table 1.

	Karanja oil		Derived bio diesel	
Sl No.	Temp (^oC)	Viscosity (cSt)	Temp (^oC)	Viscosity (cSt)
01	30	29.65	30	8.73
02	45	17.34	45	7.44
03	60	14.62	60	5.97
04	75	11.74	75	5.34
05	90	10.63	90	4.62

Table 1 Temperature vs. Viscosity

Objectives of Project:
Keeping in mind the benefits of biodiesel and so the consequential importance renewable in the near future, the work was undertaken with following specific objectives:

1. To conduct short term field test on C.I. engine.

2. To study performance of C.I. engine with biodiesel produced from Karanja oil

In the present work, karanja biodiesel purchased from Mint-bio fuels ltd., Pirangut Pune. And their physio-chemical combustion properties were provided by same company. And then used for performance analysis in "4-stroke 4-cylinder water cooled diesel engine."

2. Karanja oil and its properties [13]

Karanja (Pongamia Pinnata) is one of the forest-based tree-borne non-edible oil with a production potential of 135,000 metric tons per year in India. It is one of the few nitrogen fixing trees (NFTs), which produce seeds containing 30–40% oil. The Karanja tree is cultivated for two purposes: (1) as an ornamental tree in gardens and along avenues and roadsides, for its fragrant Wisteria-like flowers and (2) as a host plant for lace insects. This species is commonly called pongam, Karanja, Pongamia, or a derivation of thesenames. Karanja is a medium sized fast-growing evergreen tree (Fig. 2), which reaches 40 feet in height and spread, forming a broad, spreading canopy casting moderate shade. Flowers are pink, light purple, or white. Pods are elliptical, 3– 6 cm long and 2–3 cm wide, thick walled, and usually contain a single seed (Fig. 3). Seeds are 10–20 mm long, fig oblong and light-brown in color. Native to humid and subtropical environments, Karanja thrives in areas having an annual rainfall ranging from500 to 2500 mm. In its natural habitat, the maximum temperature ranges of maximum from 27 to 38^0C and minimum 1–16^0 C. Mature trees can withstand water logging and slight frost. This species grows up to elevations of 1200 m. It can grow on most soil types ranging from stony to sandy to clayey, including Verticals. It does not do well on dry sands. It is highly tolerant of salinity. It is commonly found along waterways or seashores, with its roots in fresh or salt water. Highest growth rates are observed on well-drained soils with assured moisture. Air-dried Karanja kernels have typically 19.0% moisture, 27.5% fatty oil, 17.4% protein, 6.6% starch, 7.3% crude fiber, and 2.4% ash. Fatty acid composition and structure of Karanja oil is given in Table 2. A single tree is said to yield 9–90 kg seed per year, indicating a yield potential of 900–9000 kg seed/ha. A thick yellow–orange to brown, bitter, non-drying, non-edible oil is extracted from seeds. Yields of 25% (v/v) are possible using a mechanical expeller. It is typically used for tanning leather, soap, and as illuminating oil. The oil has a high content of triglycerides, and its disagreeable taste and odor are due to bitter falconoid constituents such as pongamiin and karanjin. The oil is also used as a lubricant, water-paint binder, and pesticide. The oil has also been tried as fuel in diesel engines, showing a good thermal efficiency. The objective of this paper is to investigate the performance and exhaust emission characteristics of a single cylinder diesel engine fuelled with Karanja oil (K100) and its blends K10, K20, K50 and K75 with and without preheating using a novel exhaust gas heat exchanger specially designed for this purpose.

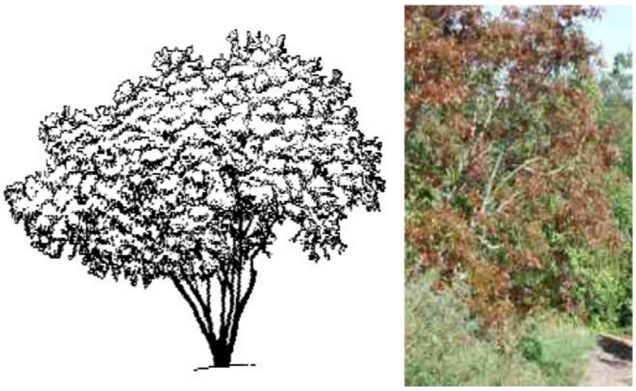


Fig. 2. Karanja tree.

Fig. 3. Karanja seed [26].

Table 2 Fatty acid composition of Karanja oil

Fatty acid	Structure	Formula	Percentage (%)
Palmitic acid	16:0	$C_{16}H_{32}O_2$	3.7–7.9
Stearic acid	18:0	$C_{18}H_{36}O_2$	2.4–8.9
Oleic acid	18:1	$C_{18}H_{34}O_2$	44.5–71.3
Linoleic acid	18:2	$C_{18}H_{32}O_2$	10.8–18.3
Lignoceric	24:0	$C_{24}H_{48}O_2$	1.1–3.5
Archidic	--	--	2.2–4.7
Behenic	--	--	4.2–5.3
Eicosenoic	--	--	9.5–12.4

3. Experimental setup

Introduction [14]

Study of Engine Performance has been an important process since the evolution of the engines. In the very early stages, only the external performance was studied with help of loading with a Dynamometer and measuring the parameters like Torque, Output power, Specific Fuel Consumption etc as the world progressed further, the necessity of refinement of engine design leaded to study the combustion events occurring inside the cylinder head. For this, in the earlier research, Mechanical Spring and piston type recorders were used. But, these had certain disadvantages like effects of spring stiffness etc. Further, with the advent of Piezo electric crystals, the Piezo Sensors have started been used with the amplification systems. Earlier the data was displayed on a Cathode Ray Oscilloscope, further recorded on Strip chart recorders and then analyzed separately. Now with help of Data Acquisition devices and using a PC, we can get this work done quite accurately. ATE has developed the Computerized IC engine Test Rigs with an intent not only to give the students how the testing is done and data is acquired, but to give them a more clear idea about the real time combustion by developing the combustion analysis system with Updates of the Pressure-Crank angle and Pressure Volume Curves every cycle. Along with that, one can get all other data like Heat Balance Sheet, Thermal efficiencies, BSFC, ISFC, Mech. Efficiency, Air-fuel ratio etc. Further the test rig is designed such that, if regular testing is to be carried out without using the Data Acquisition, it is possible to do that.

Components of the Computerized Test Rig

A Computerized Engine Test Rig consists of the following systems.
1) Dynamometer – Eddy Current type with computerized torque measuring
2) Engine fitted with a Piezo sensor for Pressure measurement
3) Connection between Dynamometer and Engine
4) Computerized Air Flow measurement system
5) Computerized Fuel Flow measurement system
6) Computerized Water Flow measurement system
7) Exhaust Gas Calorimeter with Computerized Temperature measurement system.

Dynamometer

A. Operating Principle

1. The operating principle of Eddy Current Dynamometer is that of Induced emf in a disc of conducting material rotating along its Axis between the poles of a fixed magnet.
2. The magnetic lines of force pass from one pole to the other through the disc and when the disc rotates, the lines of force is cut and an induced ELECTROMOTIVE FORCE (emf) is generated in the disc in radial direction.
3. The induced emf causes currents, known as Eddy Currents. These Eddy Currents interact with the original lines of force across the pole so as to oppose the motion of the disc as if a brake has been applied to it.

B. Construction

An Eddy Current Dynamometer consists of the following systems.
1) Basic power absorption system.
2) Torque weighing mechanism.

Engine Specification

Sr. No.	Particulars	Specification
1	Model	MDI 3200 TCA
2	Make	M&M
3	Power (kW)	27.6 KW
4	Speed (rpm)	5000 RPM
5	Cylinder Bore (mm)	88.9
6	Stroke Length (mm)	101.6
7	Connecting Rod Length (mm)	177.8
8	Cubic Capacity	2523 C.C.
9	Compression Ratio	18.1 : 1
10	No. of Strokes	4
11	No of Cylinders	4
12	Cooling	Water cooled
13	Fuel	Diesel

Table 3, Engine specifications

Piezo Pressure Transducer

It is Kistler Make – model 6613CQ09.

Connection between Dynamometer & Engine

1. The Dynamometer and Engine are connected by means of a Cardan Shaft having Universal Joints at both ends and Splined shaft for facilitating the movement along the axis of shaft.
2. A MS Fabricated Guard is provided to reduce the Impact in case of Failure of the shaft during the testing.

Computerized Air Flow Measurement system

1. For Air Flow measurement, the principle of Pressure Drop across a thin edged Orifice plate
2. It consists of a MS Fabricated Air box with an Orifice Plate Assembly at one end and a rubber diaphragm for compensating the effect the pressure drop inside the box.
3. The Air box is designed to damp the air pulsations due to cylinder suction etc
4. The output is tapped across the orifice and given to U Tube manometer. The Pressure drop in mm of Water Column can be measured and futher used in Air Flow calculations.

5. One Branch of this Air pressure tap is given to Low Pressure measurement side of a Differential pressure transmitter which can accurately amplify the signal.
6. The DP transmitter has 4 to 20 mA output corresponding to 0 – 250 mm of water column
7. The manometer pressure drop is read our at the Universal Input Scanner –channel number 7

Computerized Fuel Flow Measurement system

1. For Fuel Flow measurement, Time required for Fuel Consumption between two marking of a 25 CC pipette is measured.
2. It consists of a MS Fabricated box in which a pipette is fitted with Infra Red Sensor pair mounted on the tube.
3. A Signal Conditioner card conditions the Signal to produce a Digital Output when the
   Fuel Level crosses the sensor level.
4. The signal is interfaced with the Data Acquisition Card fitted in the PC to get the time between the events.

Computerized Water Flow Measurement system

1. For Water Flow measurement, a Wheel Flow meter is used. The Flow meter produces a 4 to 20 mA Signal Corresponding to 0 – 1000 LHP water flow rate.
2. The water flow rate is read our at the Universal Input Scanner – Channel No. 8
3. The Flow rate is same for the Calorimeter as well as engine
4. The flow rate should be adjusted to approx 300 to 500 LPH so as to maintain Engine Water Outlet Temperature to 60 to 80 degree Centigrade

Exhaust Gas calorimeter system

1. This is used to deriving the Mg x CPgw value for Gases of Combustion which are delivered through the exhaust.
2. The calorimeter is a Cross Flow, Tube in Shell type Heat Exchanger.
3. The Exhaust Gases flow through the pipes and water flowing through the jacket cools the gases.
4. Knowing the Calorific value of water, flow rate of water and the Gas and water temperatures at inlet and outlet of calorimeter, the Mg x CPg value for Gases can be calculated.

Universal Input Scanner UniSCAN Nx

This is provided for measurement of the following parameters

Measured parameters	Channel no of scanner	Type of sensors
Water inlet to calorimeter	1	RTD
Water outlet from Calorimeter	2	RTD
Water inlet to engine	2	RTD
Water outlet from engine	3	RTD
Exhaust Gas inlet to calorimeter	4	Cr-Al Thermocouple
Exhaust Gas outlet from Engine	6	Cr-Al Thermocouple
Pressure Drop Across the Manometer	7	DP Transmitter
Water Flow Rate through Calorimeter	8	Wheel Flow Transmitter

Table 4 Universal Input Scanner UniSCAN Nx Parameters

Engine Combustion Analysis Software

The manual guides the user in Installing, operating and troubleshooting of EPA Software. The software works with NI 6221 Card provided with the System only. This software communicates with various systems of test rig and collects the data, displays and saves data, & generates reports as and when required.

Procedure

1. Before staring the test, prepare a loading cycle.
2. Start the Engine after completing primary checks mentioned in manual for test rig. Run it for approx. 8 to 10 minutes at idling speed for warming up the components of the engine.
3. Observe that various parameters like temperatures, water flow rate etc. are indicated in the Display tab.
4. Select Load1 in the combo box.
5. Apply desired load by using the Dynamometer Load Control. Also use the Throttle actuator to attain desired speed. Allow some time (typically 5 minutes) for the engine to achieve steady state condition on Load.

6. Then Press FC Meter Start button. When this is pressed shut the ball valve provided before the pipette to disconnect fuel flow from fuel tank. Now fuel will flow only from pipette to the engine fuel pump. The fuel level should drop gradually. When the level crosses top sensor, FCM Top indicator will glow. When the Fuel crosses middle sensor, the FCB Bottom Indicator will glow and time will be displayed in FC Time.
7. When the FC Meter is ON, the slow speed data acquisition temporarily freezes and resumes after FCM Bottom Level is crossed.
8. After the proper FC time is noted, the other displays will come out of frozen state. Wait for a minute and then press save button.
9. Now observe the Table. Observe the Torque Reading saved. If it is according to the actual reading on indicator, then proceed to next set of reading. If it is ZERO, then press save button again to over-write all the readings in Load1 Column.
10. If steps 5 to 11 are properly completed, then select Load2 in the combo box. Repeat Steps 5 to 11 for the next desired Load as per the load cycle decided.
11. If steps 5 to 11 are properly completed, then select Load3 in the combo box. Repeat Steps 5 to 11 for the next desired Load as per the load cycle decided.
12. If steps 5 to 11 are properly completed, then select Load4 in the combo box. Repeat Steps 5 to 11 for the next desired Load as per the load cycle decided.
13. If steps 5 to 11 are properly completed, then select Load5 in the combo box. Repeat Steps 5 to 11 for the next desired Load as per the load cycle decided.
14. After all readings are acquired, press Stop button to terminate the data Acquisition.
15. Press Back to Return to the main screen.

Fig.4 M&M make multi-cylinder C.I. engine with computerised test Rig.

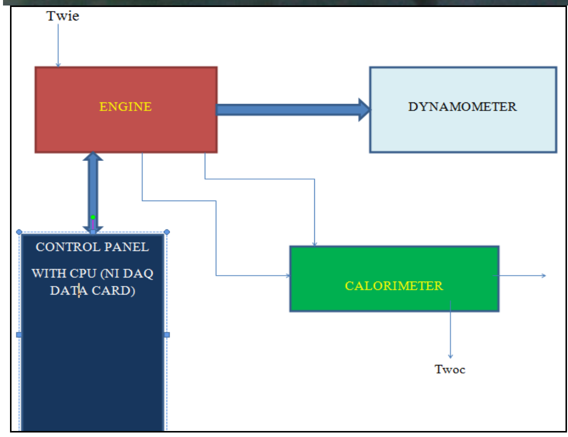


Fig. 5 Schematic diagram of engine setup

4. Performance analysis of Karanja Biodiesel

Performance tests were conducted on stationary cylinders, diesel engine, by using Karanja Biodiesel and its various blends with diesel from no load to full load condition. The tests were conducted also conducted with conventional diesel fuel for comparison; Biodiesel is blended with diesel in proportion like 20%, 30%, and 40%. These blends are termed as KBD20 (20% Karanja Biodiesel + 80% diesel), KBD40 (30% Karanja Biodiesel + 70% diesel), KBD60 (40%Karanja Biodiesel + 60% diesel). Petro diesel is used before and after the Karanja Biodiesel and their blends for verifying the engine performances because biodiesel and blends. The diesel used before the Karanja is denoted as Diesel2 and after the Karanja denoted as Diesel3 for convenience.

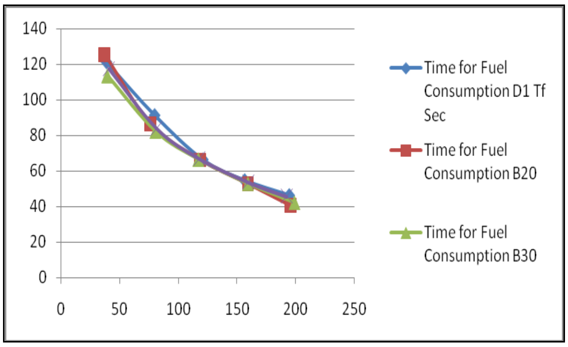
Engine performance, Heat balance, Exhaust gas emission analysis using these blends and pure biodiesel have been evaluated and presented in following articles. All the performance tests were conducted in the I.C. Engine laboratory, at Vidya Pratishthan's college of engineering, Baramati, Dist: Pune.india.

4.2 Engine Performance Analysis

The performance of an internal combustion engine is mainly studied with the help of combustion and operating characteristics. These characteristics obtained by using diesel and Karanja biodiesel in 4 cylinder, 4 stroke, M&M make,

4.2 Engine Performance graphs

a. Load Vs. Time for fuel consumption

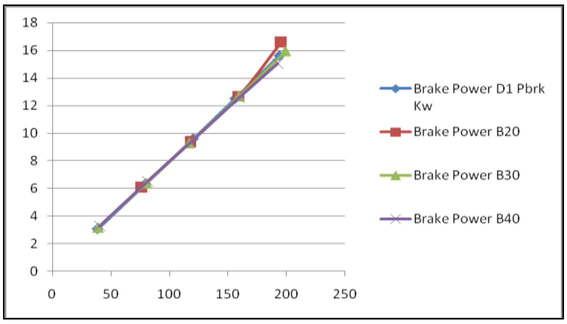


Load (N)

Fig.6 Load vs. Time for fuel consumption

The variation of Time for SFC with Load for Karanja biodiesel and its blends and diesel fuel are shown in figure. It is an important parameter that reflects how good the engine performance is. The Time for SFC is higher for KBD20 at low load while it is lower at high load. Fuel consumption decreases with increase in load.

b. Load Vs. B.P.



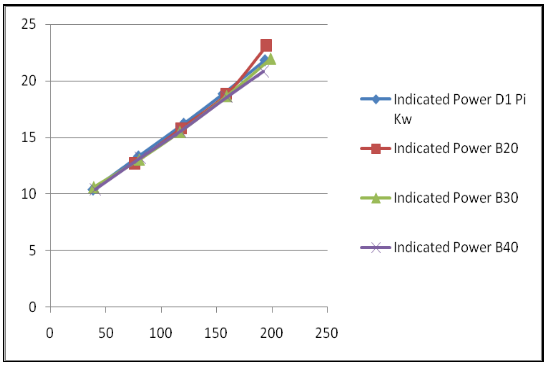
Load (N)

Fig. 7 Load Vs.B.P.

The variation of Brake power with Load for Karanja biodiesel and its blends and diesel fuel are shown in figure. It is observed that the B.P. is increasing with load and is higher than diesel for all blends. The biodiesel contains 10% (in weight) oxygen that can be used in combustion thereby increasing the torque and power. Here, maximum B.P. is obtained for KBD20 at higher load.

c. Load Vs.I.P.

The IP is the avg. Rate of work transfer from the gases in the engine cylinder to the piston during the compression and expansion strokes of the engine cycle. At low load maximum I.P. is obtained for KBD40 while it is maximum for KBD20 at higher load. The I.P. increases with increase in load



Load (N)

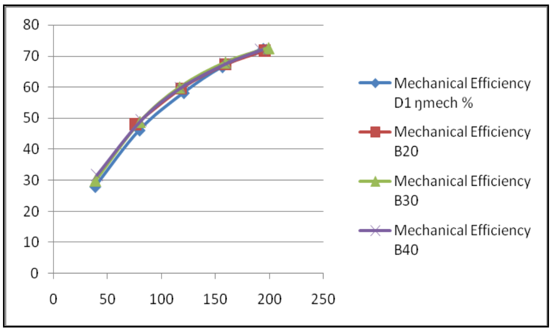
Fig.8 Load vs. I.P

d. Load Vs.Mechanical Efficiency

The variation of mechanical efficiency with Load for Karanja biodiesel and its blends and diesel fuel

Mechanical Efficiency (%)

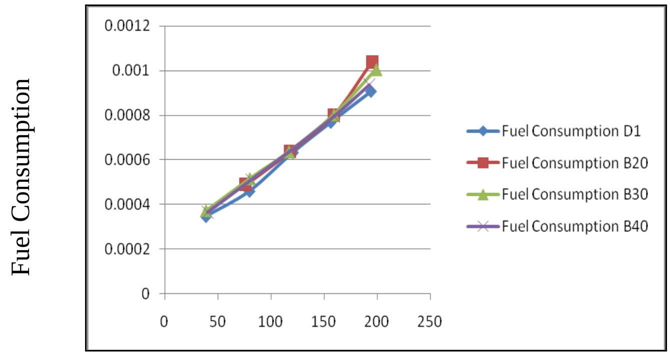
are shown in figure. It is seen from the figure that mechanical efficiency for the blends KBD20, KBD30 and KBD40 is higher than diesel fuel at low loads while it is higher for diesel at higher loads.



Load (N)

Fig.9 Load vs. Mechanical Efficiency

e. Load Vs.Fuel Consumption



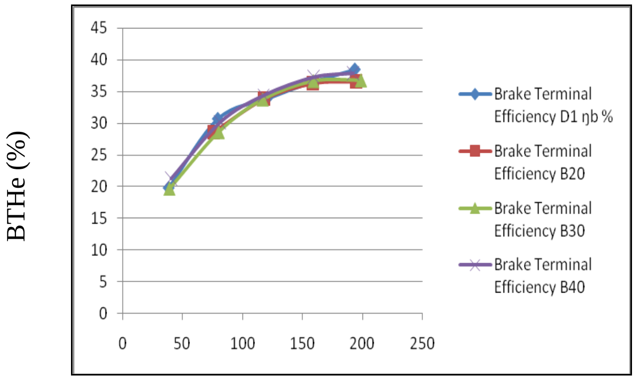
Load (N)

Fig.12 Load vs. Fuel Consumption

The variation of fuel consumption with Load for Karanja biodiesel and its blends and diesel fuel are shown in figure. It is inversely proportional to thermal efficiency.

f. Load Vs.BTHe

The variation of friction power with Load for Karanja biodiesel and its blends and diesel fuel are shown in figure. It is observed that brake thermal efficiency of diesel is higher for all the loads than the blends KBD20, KBd30, KBD40.



Load (N)

Fig.13 Load vs. BTHe

Conclusions

Biodiesel production is a modern and technological area for researchers due to constant increase in the prices of petroleum diesel and environmental advantages. Biodiesel from Karanja oil was produced by alkali catalysed transesterification process [4]. The engine performance studies were conducted with a computerized M&M make multi-cylinder diesel engine setup with eddy current dynamometer and a processor with NI DAQ data card.

It is observed that the biodiesel has good lubricity when used in diesel engines. The biodiesel with 20%, 30% and 40% blends are used in the conventional diesel engine without any modification in engine design or fuel system the biodiesel performance evaluation is done. No other trouble was found during entire running period of the engine.

It was observed that the Brake power (B.P), Brake thermal efficiency, Mechanical efficiency, and time for fuel consumption is higher at constant speed and also at variable speed and load condition for 20% and 40% biodiesel blends with diesel fuel.

Presently, the cost of biodiesel is more than the petroleum diesel due to non-availability of raw oil in abundance. General awareness of biodiesel and increased plantation of Karanja and other oil yielding crops will be the solution for non-availability. It has been predicted by IOC and HPCL that by increased production of biodiesel price will be half of the diesel.

References:

[1] H.Raheman and A.G.Phadatare, “Emissions and performance of diesel engine from Blends of Karanja Methyl Ester (Bio-diesel) and Diesel”.

[2] Magin Lapuerta, Octavio Armas, Jose Rodriguez-Fernandez.”Effect of biodiesel fuels on diesel engine emissions”. Progress in energy and combustion science 34(2008) 198-223.

[3] Y. C. Bhatt and M.K. Verma, “Effect of fuel temperature and injection Pressure on engine performance with Karanja (Pongamia glabra) Methyl Ester oil and blends with Diesel” November 2007.

[4] N. Stain, H.J. Prabhu, “Performance test of IC engine using Karanja Bio-diesel blending with diesel”. APRN journal of engg. And applied sciences, vol.2, No.5, October 2007.

[5] Avinash Kumar Agarwal, K. Rajamanoharan, “Experimental investigations of performance and emissions of karanja oil and its blends in a single cylinder agricultural diesel engine”. Applied Energy 86 (2009) 106-112.

[6] R.K. Singh, A. Kiran Kumar and S. Sethi, “Preparation of Karanja oil Methyl Ester”. Offshore World, April-May 2006.

[7] R. Anand, G.R. Kannan, K. Rajasekhar Reddy and S.Velmathi, “Performance and emissions of a variable compression ratio diesel engine fuelled with bio-diesel from cotton seed oil”. APRN journal of engineering and Applied sciences vol.4, No.9, November 2009.

[8] Dilip Kumar Bora, Dr.Rajkumar Singh (Dost), Dr. Ravi Jangir, “Performance of single cylinder diesel engine with Karabi seed bio-diesel”. Journal of Scientific & Industrial Research. Vol.68, November 2009, pp.960-963.

[9] Abdul Monyem, Jon H. Van Gerpen, “The effect of biodiesel oxidation on engine performance and emissions”. Biomass and Bio-energy 20 (2001) 317-325.

[10] S.R. Kalbande, S.N. Pawar, S.B. Jadhav, “Production of Karanja Bio-diesel and its utilization in Diesel Engine generator set for power generation”. Karnataka J. Agric. Sci., 20(3) :(680-683) 2007.

[13] Avinash Kumar Agarwal *, K. Rajamanoharan, “Experimental investigations of performance and emissions of Karanja oil and its blends in a single cylinder agricultural diesel engine”, Applied Energy 86 (2009) 106–112

[14] Ic Engineinstruction Manual, Four Cylinder Four Stroke Computerized Diesel Engine Test Rig, Manufacturer: - Accurate Test Equipments & Engineers