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PERFORMANCE EVALUATION, EMISSION CHARACTERISTICS AND ECONOMIC ANALYSIS OF FOUR NON-EDIBLE STRAIGHT VEGETABLE OILS ON A SINGLE CYLINDER CI ENGINE

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ABSTRACT

An experimental investigation has been carried out to analyze the performance and emission characteristics of a compression ignition engine fuelled with non-edible straight vegetable oils of Neem, Mahua, Linseed and Castor oil. Straight vegetable oils posed operational and durability problems when subjected to long term usage in CI engine. These problems are attributed to high viscosity, low volatility and polyunsaturated character of vegetable oils. Hence, process of transesterification is found to be effective method of reducing viscosity and eliminating operational and durability problems. Fuel preheating in the experiments for reducing viscosity of neat oils has also been done by a specially designed heat exchanger, which utilizes waste heat from exhaust gases. The test is conducted on single cylinder DI engine at constant speed of 1500 rpm. The performance parameters evaluated include thermal efficiency, brake specific fuel consumption (BSFC), brake specific energy consumption (BSEC), and exhaust gas temperature whereas exhaust emissions include mass emissions smoke. The results of the experiment in each case were compared with baseline data of diesel. Significant improvements have been observed in the performance parameters of the engine as well as exhaust emissions with use of neem, mahua and castor oil. Economic analysis was also done in the study and it is found that use of vegetable oil as diesel fuel substitutes has almost similar cost as that of mineral diesel.

Keywords: non-edible oils, CI engine, performance analysis, emission characteristics, transesterification, economic analysis.

1. INTRODUCTION

Using straight vegetable oils in diesel engines is not a new idea. Rudolf Diesel first used peanut oil as a fuel for demonstration of his newly developed compression ignition (CI) engine in year 1910. Later with the availability of cheap petroleum, crude oil fractions were refined to serve as 'diesel', a fuel for CI engines. During the period of World War-II, vegetable oils were again used as fuel in emergency situations when fuel availability became scarce. Nowadays, due to limited resources of fossil fuels, rising crude oil prices and the increasing concerns for environment, there has been renewed focus on vegetable oils and animal fats as an alternative to petroleum fuels.

Vegetable oil is easily available worldwide. It is a renewable fuel with short carbon cycle period (1-2 years compared to millions of year for petroleum fuels) and is environment friendly. These are the triggering factors for research all over the world to consider vegetable oils and their derivatives as alternative to petroleum diesel. However major disadvantage of vegetable oil is its viscosity, which is order of magnitude higher than that of mineral diesel. The fuel injection system of new technology engines is sensitive to fuel viscosity changes. High viscosity of the vegetable oil leads to poor fuel atomization, which in turn may lead to poor combustion, ring sticking, injector cocking, injector deposits, injector pump failure and lubricating oil dilution by crank-case polymerization [1, 2]. Viscosity of the vegetable oils must be reduced in order to improve its engine performance. Heating, blending with diesel and transesterification are some of the methods used to reduce viscosity of vegetable oils.

Many investigations have proved that vegetable oils are feasible substitutes for diesel fuel [1-19], although there is still a lot of work that needs to be done to apply vegetable oil in diesel engine.

As per the literature survey, many researchers have done work on non-edible vegetable oils such as linseed, Jatropha, Karanja (*Pongamia glabra*), kusum (*Schlerlchera trijuga*), Castor, Rice bran, etc. and edible vegetable oils separately to study the performance and emission characteristics of diesel engine. The present conventional fuel crisis inspired the authors to compare the performance and emission characteristics of compression ignition engine using oils of Neem, Mahua, Linseed and Castor oil and select the best one for the use in diesel engine.

2. CHEMICAL COMPOSITION

Vegetable oils have comparable heat content, cetane number, heat of vaporization, and stoichiometric air/fuel ratio with mineral diesel. Heat values decreases with increasing un-saturation as a result of fewer hydrogen atoms in their molecular structure. The structure of typical vegetable oil molecule is given below:

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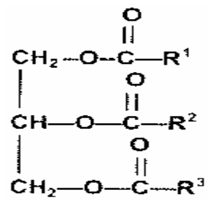
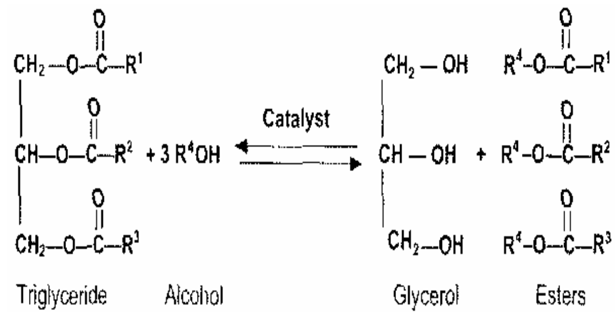


Here R^1, R^2 and R^3 represent straight chain alkyl groups. Free fatty acids are also found in vegetable oils. The large molecular sizes of the triglycerides results in the oils having higher viscosity and low volatility compared to mineral diesel. Proportion and location of double bonds affects cetane number of vegetable oils [20]. Problems associated with vegetable oils during engine tests can be classified into two broad groups, namely, operational and durability problems. Operational problems are related to starting ability, ignition, combustion and performance. Durability problems are related to deposit formation, carbonization of injector tip, ring sticking and lubricating oil dilution. The high viscosity, polyunsaturated character, and extremely low volatility of vegetable oils are responsible for the operational and durability problems associated with its utilization as fuels in diesel engines. High viscosity of vegetable oils causes poor fuel atomization, large droplet size and thus high spray jet penetration. The jet tends to be a solid stream instead of a spray of small droplets. As a result, the fuel is not distributed or mixed with the air required for burning in the combustion chamber. This results in poor combustion accompanied by loss of power and economy.

Blending, cracking/pyrolysis, emulsification or transesterification of vegetable oils may overcome these problems.

3. TRASESTERIFICATION

Transesterification is most commonly used and important method to reduce the viscosity of vegetable oils. In this process triglyceride reacts with three molecules of alcohol in the presence of a catalyst producing a mixture of fatty acids, alkyl ester and glycerol. The process of removal of all the glycerol and the fatty acids from the vegetable oil in the presence of a catalyst is called esterification. This esterified vegetable oil is called bio-diesel. Biodiesel properties are similar to diesel fuel. It is renewable, non-toxic, bio-degradable and environment friendly transportation fuel. After esterification of the vegetable oil its density, viscosity, cetane number, calorific value, atomization and vaporization rate, molecular weight, and fuel spray penetration distance are improved more. So these improved properties give good performance in CI engine. The chemical reaction of the transesterification process is shown below:



Physical and chemical properties are more improved in esterified vegetable oil because esterified vegetable oil contains more cetane number than diesel fuel. These parameters induce good combustion characteristics in vegetable oil esters. So unburnt hydrocarbon level is decreased in the exhaust. It results in lower generation of hydrocarbon and carbon monoxide in the exhaust than diesel fuel. The vegetable oil esters contain more oxygen and lower calorific value than diesel. So, it enhances the combustion process and generates lower nitric oxide formation in the exhaust than diesel fuel.

4. ECONOMIC ANALYSIS

The cost of making biodiesel from castor oil is shown in Table-1. However, cost of different vegetable oils keeps fluctuating since the markets are small.

Table-1. Cost of biodiesel produced from castor oil.

Biodiesel from castor oil	**Cost** (Rs/l)
Castor oil (98% yield of ester)	41.25
Methanol	4.15
Reagents	1.00
Electricity	1.25
Purification	0.55
Labor	1.65
Sub-total	1.65
Revenue from by-product (glycerol) sales	4.75
Total (cost less revenue)	45.10
Cost in USD/l	0.939

The costs of different fuels assumed in this study are given in Table-2. For diesel, cost was taken as the 2011 fuel price in India. The cost of vegetable oils is slightly higher than diesel because of the fragmented nature of vegetable oil market. There are several middle-men involved which increase the cost of vegetable oils. The cost of diesel is relatively lower because of the cross-subsidy offered by administered price mechanism of the government. If same subsidy is given to vegetable oils to be used as substitute fuel then it can be seen from Table-2 that its cost comes near to that of mineral diesel. Table-2 also shows that cost of vegetable oils per kilogram is lower than diesel but calorific value of vegetable oil is also lower than diesel, hence cost per unit of energy produced is almost same for the vegetable oils and diesel. Therefore, use of vegetable oil or biodiesel in diesel engine costs almost same as mineral diesel. If the vegetable oil crop cultivation program is implemented under a cooperative structure, the use of vegetable oils to partially substitute mineral diesel will also make economic sense. Various researchers have also shown that use of vegetable oils and their derivatives is economical and comparable to mineral diesel [21-24].

Table-2. Cost of different CI engine fuels.

	Diesel	**Linseed oil**	**Mahua oil**	**Neem oil**	**Castor oil**
Cost (USD/l)	0.854	0.967	0.944	0.977	0.939
Cost after subsidy (USD/l)	0.854	0.823	0.803	0.830	0.798
Density (kg/l)	0.842	0.894	0.904	0.916	0.874
Cost (USD/kg)	1.014	0.916	0.888	0.906	0.913
Calorific value (MJ/kg)	45.343	39.75	38.86	39.50	40.37
Cost (USD/MJ)	0.022	0.023	0.023	0.023	0.023

5. EXPERIMENTAL SET UP AND PROCEDURES

5.1 Materials

All the non-edible oils used in the experiment are collected from local market. Necessary acids and chemical equipments required for transesterification is developed in I C Engines laboratory of PDA College of Engineering, Gulbarga. Double-distilled water is used for this whole experiment.

5.2 Experimental setup and plan

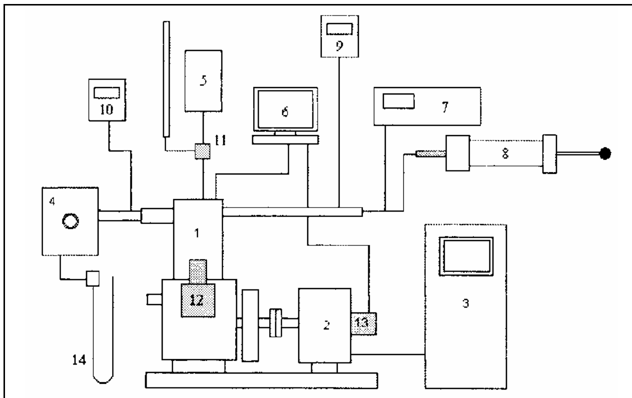


Figure-1. Experimental test rig.

Test rig description

1	Diesel engine	8	Exhaust gas calorimeter
2	Eddy current dynamometer	9	Exhaust temperature indicator
3	Dynamometer control	10	Air inlet temperature
4	Anti pulsating drum	11	Two way valve
5	Fuel tank	12	Fuel injection pump
6	Computer with DAQ	13	Crank angle encoder
7	Smoke meter	14	Manometer

The test bed consists of a diesel engine, an eddy current dynamometer; fuel tank with thermostat-controlled heater is inbuilt in control panel with fuel measuring unit, and a data acquisition system. Two filters are installed: one at exit of tank and other one at fuel pump. Fuel is fed to the injector pump under gravity. Lubricating oil temperature is measured by using a thermocouple. The cooling water temperature is maintained constant (65 to 70^{0}C) throughout the research work by controlling the flow rate of fuel. The exhaust gas composition was analyzed by using exhaust gas analyzer and smoke opacity with measurement range%: 0-100% with 0.01% resolution was measured using smoke opacity meter.

The physical and chemical properties of Mahua, Honne, Honge, Castor, Neem oil are measured as per Indian standards (IS) methods in fuel testing laboratory and tabulated in Table-1. Calorific value and viscosity are measured by Bomb calorimeter and Redwood viscometer (Petroleum Instruments India Pvt. Ltd.), respectively. The flash point and fire point are determined by Pensky-Martens apparatus closed-cup method.

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Table-3. Fuel properties of four non-edible oils and diesel.

Properties	Diesel	Neem	Linseed	Mahua	Castor
Viscosity, cSt (at 40°C)	5.032	29	16.23	34	78
Calorific Value, kJ/kg	42707	39400	40374	38000	36000
Sp. Gr. At 25°C	0.834	0.919	0.8645	0.917	0.956
Density, kg/m^3	834	919	874	917	956
Flash point, °C	78	178	108	277	320
Fire point, °C	85	195	---	298	345

The engine tests were conducted for entire load range (0 to 100%) at constant speed of 1500rpm. The engine parameters, such as fuel consumption air consumption, exhaust gas temperature and exhaust gas emissions were measured. In cylinder pressure and TDC signals were acquired and stored on a high speed computer based design data acquisition system.

Engine specifications

Manufacturer	Kirloskar Oil Engines Ltd., India
Model	TV-SR II, naturally aspirated
Engine	Single cylinder, DI
Bore / stroke	87.5mm/110mm
Compression ratio	16.5:1
Speed	1500 r/min, constant
Rated power	5.2kW
Working cycle	four stroke
Injection pressure	200bar/23° deg BTDC
Inlet valve opens/ inlet valve closes	4.5° BTDC/35.5° ABDC
Exhaust valve opens/ exhaust valve closes	4.5° BTDC/35.5° ABDC
Type of sensor	Piezo electric
Response time	4 micro seconds
Crank angle sensor	1-degree crank angle
Resolution of 1 degree	360 degree encoder with a resolution of 1^0

Technical features of smoke meter:

Make	Neptune India Ltd
Smoke sampling	Partial flow
Zeroing	Automatic
Temperature	Gas chamber temperature display
Measurement Range%	0-100% with 0.01 Resolutions.
Measurement Range k	0-9.99(0.00) with 0.01 Resolution.

6. RESULTS AND DISCUSSIONS

6.1 Kinematic viscosity

Figure-2 shows the variation in kinematic viscosity of diesel with different neat vegetable oils. It is observed that the viscosity is very high for castor oil among all other oils followed by that of Mahua oil. Kinematic viscosity of neat castor oil is 78 cst while that of diesel is 5.032 cst.

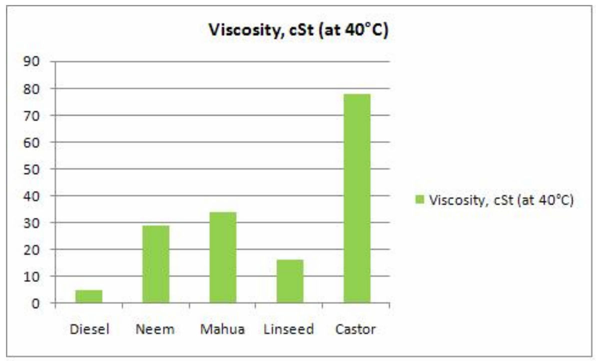

Figure-2. kinematic viscosity of diesel with different neat vegetable oils.

6.2 Density

Figure-3 shows the variation in density of diesel with different neat vegetable oils. Density is found to be more or less same for all neat oils.

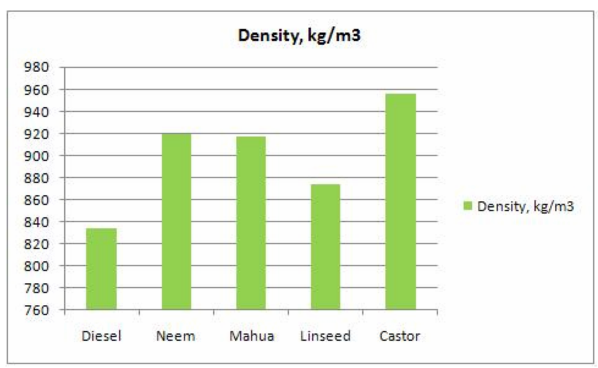

Figure-3. Density of diesel with different neat vegetable oils.

6.3 Calorific value

Figure-4 shows variation of calorific value of diesel with different neat vegetable oils. It is observed that calorific value of Castor oil is very low compared with diesel. The calorific value of neat Castor oil was found to be 36000kJ/kg, which is much lower than that of diesel. This may be due to the difference in the chemical composition or presence of oxygen molecule in the molecular structure of oil.

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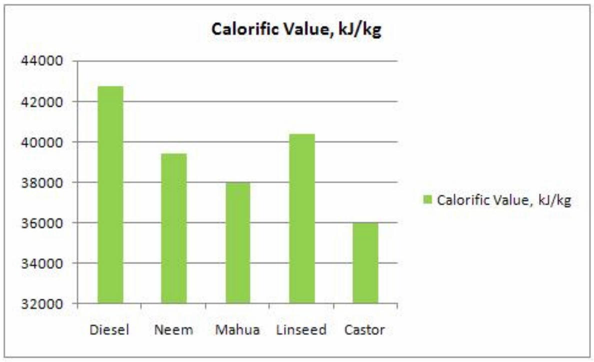

Figure-4. Calorific value of diesel with different neat vegetable oils.

6.4 Kinematic viscosity

Figure-5 shows the variation of kinematic viscosity of different neat vegetable oils with temperature. At high temperature of 80°C, the viscosity of each oil except castor oil becomes near about 10 cst, which is compatible of diesel engine. Hence all oils require preheating for easy flow through pump and nozzle.

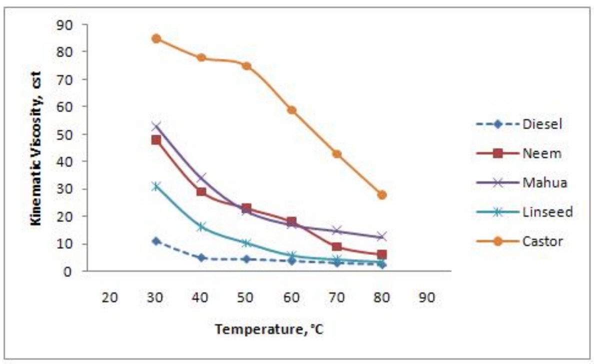

Figure-5. Variation of kinematic viscosity of different blends with temperature.

6.5 Brake thermal efficiency

Figure-6 shows variation of brake thermal efficiency with brake power for diesel and different vegetable oils. Brake thermal efficiency of Neem is very close to diesel for entire range of operation. Maximum brake thermal efficiency of Neem is 28.64% followed by 27.11% and 27.04% of Castor and Mahua, respectively against 33.13% of diesel oil, which are well comparable with diesel.

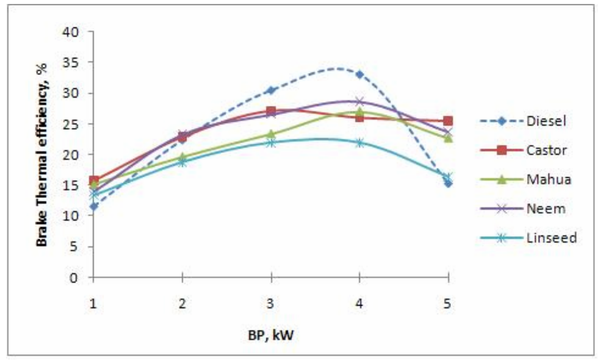

Figure-6. Variation of brake thermal efficiency with brake power.

6.6 Brake specifi fuel consumption

Figure-7 shows variation of BSFC with brake power for diesel and different vegetable oils in the test engine. BSFC of Neem closely matches with diesel, followed by Castor oil. Minimum BSFC of Neem and Castor oil are 0.298 and 0.336 kg/kW-hr against 0.251 kg/kW-hr diesel. BSFC of Neem oil is 0.047 kg/kW-hr higher than that of diesel.

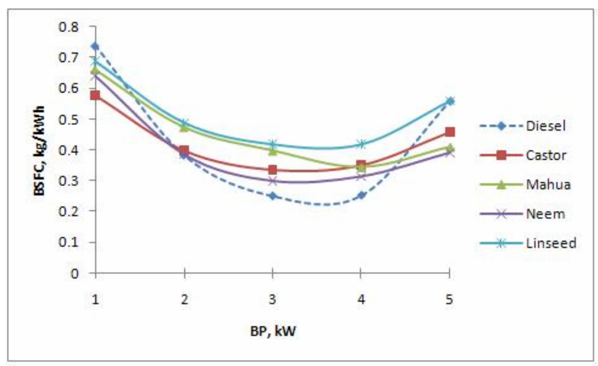

Figure-7. shows variation of BSFC with brake power.

6.7 Brake specifi energy consumption

The BSFC is not a reliable parameter to compare the different fuels as the calorific value and the density of the oils are different. Hence BSEC is a more reliable parameter for comparison. Figure-8 shows the variation of BSEC with brake power. BSEC of castor oil and Neem oil are in well comparable with diesel. BSEC of Linseed is much higher than diesel.

This drop in thermal efficiency and increase in BSFC and BSEC must be attributed to the poor combustion characteristic of vegetable oils due to poor volatility.

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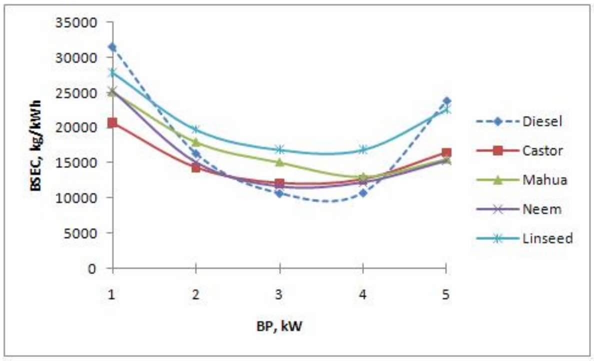

Figure-8. Variation of BSEC with brake power.

6.8 Exhaust gas temerature

Figure-9 shows variation of exhaust temperature with brake power for Diesel and other oils in the test engine. Exhaust temperature of Neem, Mahua and Castor are almost same as that of diesel in the mid range of load. This is an indication of lower exhaust loss and could be possible reason for higher performance. Exhaust temperature of Linseed is much higher than diesel.

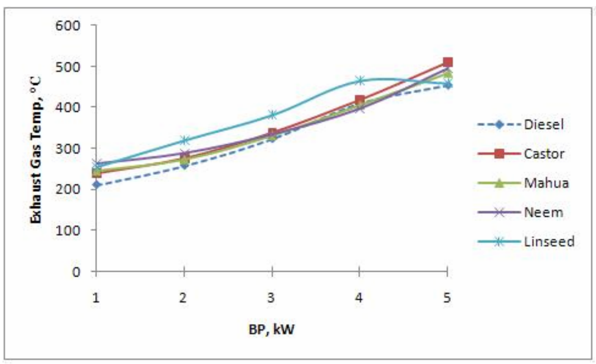

Figure-9. shows variation of exhaust temperature with brake power.

6.9 Smoke density

Figure-10 shows variation of smoke emission with brake power for Diesel and other oils in the test engine. Smoke emission of Castor is lower compared with other oils followed by Mahua. However smoke emission of Linseed is higher than that of diesel for entire range of operation and maximum emission of 74% occurs at maximum load for Linseed and minimum of 45% for Mahua followed by 54% of Neem.

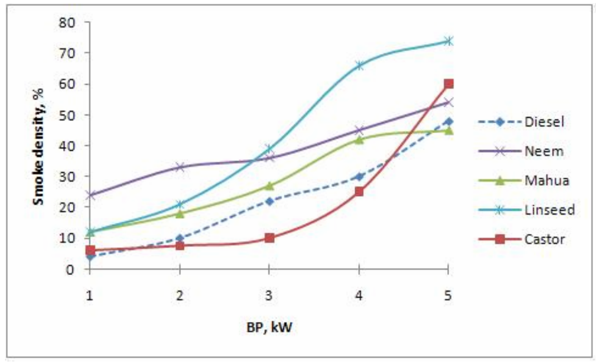

Figure-10. shows variation of smoke emission with brake power.

7. CONCLUSIONS

Experimental investigations are carried out in a single cylinder DI diesel engine to examine the suitability of different vegetable oils such as Neem, Mahua, Linseed and Castor as alternate fuels. Further the performance and emission characteristics of these oils are evaluated and compared with diesel and optimum fuel is determined.

From the above investigations, following conclusions are drawn.

- The properties viz: density, viscosity, flash point and fire point of above vegetable oils are higher and calorific value is lower than that of diesel.
- Viscosity at 300C of diesel is very close to the viscosity at 800C of neat Neem, Mahua and linseed oil, and that at @1200C for Castor. Hence preheating of oils is required to attain the smooth flow.
- Performance and emission characteristics of Neem, Castor and Mahua are better than other fuels. The maximum brake thermal efficiency and minimum BSFC of Neem, Mahua and Castor are well comparable with diesel.
- Smoke emission of Castor and Mahua followed by Neem are lower compared with other oils. For Linseed oil smoke emission is on higher side for entire range of operation.

Hence from above conclusions it may be stated that Neem, Mahua and Castor oils with preheating has acceptable performance with lower emissions. Hence these neat oils with preheating can be substituted as fuel for diesel engine without any modification in the diesel engine.

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