Experimental Investigation of CI Engine Fueled with Diesel Blended Mahua Oil with DEE and Kerosene as Additives

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Abstract. Biodiesel is a possible substitute to traditional diesel fuel produced from renewable resources, like non-edible vegetable oils. An increase in energy demand, stringent emission norms, and reduction of oil resources led to finding alternative fuels for internal combustion engines. In this paper, we study the performance and emission characteristics of CI engine fueled with Mahua oil Blended in the blending ratio B10, B20, B30, B10+5DEE, B20+5DEE, B30+5DEE, B10+5KER, B20+5KER, B30+5KER. The experiment was carried out in a four-stroke, single cylinder diesel engine by varying the load from 4 kg to 16 kg. The result shows that the addition of Mahua oil increases the Brake thermal efficiency with a reduction in specific fuel consumption and exhaust gas temperature.

1. Introduction
Energy is crucial to life. Billions of people would be left starving and cold without it. The significant source of energy is obtained from fossil fuels, out of which the primary fossil fuels utilized today by the majority of developing and industrialized countries are natural gas, oil, and coal. Among the above mentioned fossil fuels, nearly all of it is consumed by oil for energy conversion, followed by coal, then natural gas. The total generation of energy extracted from fossil fuels is expected to multiply even faster in the coming 20 years than it has in the previous 30 years. The consumption of energy leads to a surge in the supply, i.e., the production, and thus, the supply of such fossil fuels will start to decline. Since supply decreases and demand increases, prices will skyrocket substantially.

Biofuels have proved to have potential alternative energy and thus the use of these biofuels can significantly decrease the dependency on fossil fuels. Biodiesel, a key biofuel, can be used for diesel engines without any variation at low blend ratios [5]. Over time, mahua seed oil has emerged to be an important biofuel, with certain characteristics known to improve both the efficiency as well as the performance. mahua seed Oil can be procured using a process called Pyrolysis. The results of pyrolysis of mahua seeds can be used as a substitute fuel directly or mixed with other traditional fuels [8]. It can further be improved with processes like Catalytic pyrolysis which involves the presence of a catalyst such as CaO to increase the fuel quality [9]. Mahua Oil has been known to reduce smoke and CO in exhaust emissions [1]. The emission and performance parameters for various blends of it are also better when compared to traditional diesel [2]. With an increase in additive percentage in mahua biodiesel, the brake thermal efficiency also increases [6]. The same can be said about
the energy consumption, which is found to be akin to that of diesel, if not better [3]. This can be partly due to the fact that mahua seed oil is found to burn more efficiently than diesel [4]. Although fuel consumption is believed to be higher, studies show that the adding up of aluminium oxide nanoparticles results in a significant decrease in fuel consumption [7].

2. Methodology
The setup comprises a single-cylinder, four-stroke diesel engine producing 5.2 kilowatts at 1500rpm connected to a water-cooled dynamometer for loading purpose. It is imparted with the required apparatus for crank-angle measurements and combustion pressure. These signals are transferred to a computer with the use of an engine indicator.

![Figure 1 Engine Test Setup.](image)

In the beginning, the setup is run for ten to fifteen minutes with diesel initially and then with the various blends prepared (B10, B10 + 5 DEE, B20, B20 + 5 DEE, B30, B30 + 5 DEE, B10 + 5 KER, B20 + 5 KER and B30 + 5 KER) by providing the data of its calorific values and density values to the software. The speed of operation of the engine was maintained at 1600rpm under multiple load conditions (3 kg, 6 kg, 9 kg and 12 kg) to compute performance parameters like brake thermal efficiency, brake mean effective pressure, specific fuel consumption, indicated mean effective pressure, exhaust gas temperature and total fuel consumption. The exhaust of the engine is linked with the AVL analyser. This has an electrochemical oxygen gas sensor to measure how much engine emission values of hydrocarbons, carbon monoxide, nitrogen oxide and carbon dioxide are emitted.

Nitrogen oxide, carbon dioxide, hydrocarbons and carbon monoxide were the gases obtained when the AVL DiGas analyser was used to check for emission values. A probe is inserted into the tailpipe to check for the readings present in the emission when the system is stabilized after a while. Line filter, paper filter and tube filter are the various types of filters used. The various blends were made by the cohesion of diesel with mahua oil and DEE/KER without any pre-heating or any other methods of mixing. Even after stagnation over extended periods of time, distinct layers weren't observed in the mixture case. Therefore, it is determined that the constituents have appreciable mixing properties.
### Table 1. Engine set-up Specifications

| ENGINE SET UP                     |
|----------------------------------|
| Engine output                   | 5.2 Kw                        |
| Maximum Engine speed             | 1500 rpm                      |
| Bore length                      | 88 mm                         |
| Stroke length                    | 112 mm                        |
| Connecting rod length            | 236 mm                        |
| Compression Ratio                | 17.0                          |
| Compression type                 | FCR                           |
| Number of Strokes                | 4                             |
| Number of cylinders              | One                           |
| Arm length of Dynamo             | 190 mm                        |
| Speed type                       | Constant speed                |
| Cooling type                     | Water-cooled                  |
| Dynamometer Current type         | Eddy current                  |
| Indicator type                   | USB-6210                      |
| Calorimeter type                 | Pipe in pipe                  |

#### SENSING RANGE

|                              |
|------------------------------|
| Exhaust gas temp.            | 0-1300 °C                     |
| Air flow transmitter         | (-) 260 – 0 mm WC             |
| Fuel flow DP transmitter     | 0-600 mm WC                   |
| Load cell                    | 0-60 kg                       |
| Sensor signal range          | 1-5 V                         |
| Cylinder pressure transducer | 0-355.5 bar                   |

### 2.1 Fuels Used

1. Diesel
2. Mahua oil
3. B10 - 90% diesel (900ml) + 10% mahua oil (100ml)
4. B20 - 80% diesel (800ml) + 20% mahua oil (200ml)
5. B30 - 70% diesel (700ml) + 30% mahua oil (300 ml)
6. 5DEE+B10 - (900ml diesel + 100ml mahua oil) - 50ml + 50ml DEE (1 liter)
7. 5DEE+B20 - (800ml diesel + 200ml mahua oil) - 50ml + 50ml DEE (1 liter)
8. 5DEE+B30 - (700ml diesel + 300ml mahua oil) - 50ml + 50ml DEE (1 liter)
9. 5KER+B10 - (900ml diesel + 100ml mahua oil) - 50ml + 50ml KER (1 liter)
10. 5KER+B20 - (800ml diesel + 200ml mahua oil) - 50ml + 50ml KER (1 liter)
11. 5KER+B30 - (700ml diesel + 300ml mahua oil) - 50ml + 50ml KER (1 liter)
2.2 Computerized digital data acquisition system

The values of top dead center (TDC) and cylinder pressure were collected and saved on a high-speed DAQ system. The stored signals were further computed with a bespoke testing operating program, in order to extract performance parameters (BTHE, IMEP, BMEP, SFC, EGT, peak pressure, heat balance, TFC, etc).

2.3 Load and speed measurement

A dynamometer is linked to the engine. The dynamometer system consists of a rotor set up on a shaft working on the bearings that rotate within the casing reinforced with the ball bearing trunnions that form the machine’s plate. The load calculation of a dynamometer is taken from the strain gauge’s load cell. The speed measurement is taken from a sixty-tooth wheel-mounted shaft with magnetic pulse pickup. The digital data rpm meter receives voltage pulses from the sensor for pulse conversion and the engine speed is displayed with 1 rev/min accuracy.

2.4 Emission Measurement

The hydrocarbons, carbon monoxide, nitrogen oxide and carbon dioxide exhaust emissions were measured. A full microprocessor-controlled system that uses non-destructive infrared techniques is employed by the AVL DiGas analyser.

Table 2. Characteristics of Diesel fuel, Mahua oil, DEE and KER and its blends.

| Fuel properties | Fire Point(°C) | Calorific value (KJ/Kg) | Kinematic Viscosity (CS) | Density (kg/cm³) |
|-----------------|---------------|-------------------------|--------------------------|-----------------|
| Diesel          | 48            | 42500                   | 4.1                      | 830             |
| Mahua Oil       | 230           | 0.03896                 | 38.4                     | 860             |
| DEE             | -             | 33892                   | 0.224(CP)                | 713.4           |
| Kerosene        | 50            | 35000                   | 2.5-3.5                  | 780-781         |
| B10             | 75            | 42000                   | 4.3                      | 840             |
| B20             | 84            | 39000                   | 4.78                     | 852             |
| B30             | 90            | 38000                   | 5.45                     | 858             |
| 5 DEE+B10       | 40            | 41701                   | 7.0                      | 827             |
| 5 DEE+B20       | 40            | 41337                   | 10.0                     | 830             |
| 5 DEE+B30       | 40            | 40973                   | 13.0                     | 833             |
| 5 KER+B10       | 40            | 42186                   | 7.0                      | 831             |
| 5 KER+B20       | 45            | 41810                   | 10.0                     | 833             |
| 5 KER+B30       | 46            | 41458                   | 13.0                     | 836             |
3. Results Obtained and Observations

3.1 Performance graphs

3.1.1 Brake thermal efficiency (BTE) v/s Load (kg)

Figure 2 depicts the curves of the BTE and load in kilogram at a constant speed. In accordance with the brake thermal efficiency formula, efficiency is known to be inversely proportional to coefficient of variation. The aforementioned figure shows that with an increase in load values, the BTE increases. So, this leads us to the observation that the BTE of B20 & B30 blends are closest to that of the diesel level and at 6kg load, both these blends are greater than diesel. Also notice that with the incorporation of Mahua oil, the brake thermal efficiency value increases, which means a blend with a greater content of Mahua oil has a much higher brake thermal efficiency. Although the same trend is not reciprocated with the inclusion of DEE/KER which decreases the brake thermal efficiency value of the blend.
3.1.2 Specific fuel consumption (SFC) v/s Load (kg)
An engine’s fuel consumption attributes are usually in terms of SFC in kg of fuel per kWh. It is an important parameter that shows how good the engine performs. The thermal efficiency of the engine is inversely proportional to the SFC.

![Specific Fuel Consumption (SFC) v/s Load (kg).](image1)

**Figure 4** Specific Fuel Consumption (SFC) v/s Load (kg).

![Percentage change in Specific Fuel Consumption (SFC) v/s Load (kg).](image2)

**Figure 5** Percentage change in Specific Fuel Consumption (SFC) v/s Load (kg).

The graph shows the relation of SFC with load. The fuel consumption was measured using the density and volume flow rate. Since the engine is operating at a constant speed and we have varying values of load, we can observe that with an increase in value of mahua oil, the value of SFC reduces which shows the opposite trend of above mentioned brake thermal efficiency v/s Load graph. We also notice that SFC increases with addition of DEE/KER, compared to diesel level in this case. In both the blends that is, B10 and B20 show the lowest SFC compared to diesel. In the corresponding BTE graph that displays an inverse relation to calorific value. The graph has peak specific fuel consumption values for the B30 blend that states that the fuel consumption is higher for the exact power output. The lowest value is with the B10 blend followed by B20 blend.
3.2 Emission graphs
3.2.1 Carbon Dioxide v/s Load

![Figure 6 Percentage volume of Carbon dioxide v/s Load.](image1)

![Figure 7 Percentage change in Carbon dioxide v/s Load.](image2)

The graph depicted in the figure 7 (above) has a distinctive curve that crests at 12 kilogram load and depicts that B30 always has been at the crest of the curve and B10+5% KER at the bottom end of the graph. The curve shows a decreased value of CO$_2$ at lesser loads, as the air-fuel ratio is more and fuel to burn in the air is less, another reason is the fact that combustion does not occur at lesser loads due to low cylinder temperatures leading to deficient atomization and so, at lesser loads the carbon residue present in the fuel becomes CO and not CO$_2$. The amount of CO$_2$ at lesser loads are lower as the A/F ratios are high and the fuel inlet is less which means less CO$_2$. At greater loads, the air-fuel ratio is lower and thus as the air-fuel ratio values are nearer to the stoichiometric ratio. There is higher soot formation which turns into spots where the fuel settles to cool. They remain unburnt and are released as HC during the exhaust stroke.

Figure 6 depicts the influence of mahua and DEE/KER addition leading to the generation of CO$_2$ at various loads. But just by observing the graph, it can be concluded that the effects on basis of average values denotes that the quantity of CO$_2$ is reduced when the amount of Mahua oil is increased in the blend. This can be observed when, with the inclusion of DEE/KER, the quantity of CO$_2$ in the exhaust is reduced. The carbon-hydrogen ratio of the
fuels lead to the formation of CO\textsubscript{2}. Higher contents of carbon in the blends cause more CO\textsubscript{2} emissions in the exhaust gases. Measured to diesel fuel as observed in Figure 7, carbon constituents of other blends are comparatively lesser in the identical volume of fuel consumed for the identical engine speed, which explains the reason for lesser CO\textsubscript{2} generation.

3.2.2 Nitrogen Oxide(ppm) v/s Load(kg)

![Figure 8 NO\textsubscript{X} v/s Load.](image)

Figure 8 NO\textsubscript{X} v/s Load.

![Figure 9 Percentage change in NO\textsubscript{X} v/s Load.](image)

Figure 9 Percentage change in NO\textsubscript{X} v/s Load.

Figure 8 portrays all the traits of a normal NO\textsubscript{X} curve which increases with load and hence the temperature in the cylinder rises. This increases the content of NO\textsubscript{X} produced. But it is also found that NO\textsubscript{X} value is reduced at greater loads. This setup produces 8 different oxides of N\textsubscript{2} via exhaust emissions. For burnt gases at regular flame temperatures at chemical equilibrium, nitrogen dioxide/nitric oxide ratios are quite negligible.

The rate of formation of thermal nitric oxide depends on numerous factors such as the content of oxygen in the reaction areas of the combustion chamber, peak flame and combustion temperature, and the residence time of nitrogen at that particular temperature. Though the greater cylinder temperature is a demonstrator of higher nitric oxide forming up, it is expressed that the temperature dissipation in the cylinder area is much more critical. This allows nitric oxide levels to rise in some cases and to fall in other scenarios. In the limits of
the cylinder of the engine, there are many elevated temperature regions corresponding to oxygen content. Hence, the large decrease in cetane number pushes the entire combustion process ahead to the expansion stroke which limits the stagnant period of the gases at peak temperature. This means that the thermal nitric oxide rate is now confined.

4. Conclusion
The different blends of KER/DEE and mahua oil mixed with diesel namely B10, 5 percent DEE+B10, B20, 5 percent DEE+B20, B30, 5 percent DEE+B30, 5 percent KER+B10, 5 percent KER+B20 and 5 percent KER+B30 were used to conduct tests at a speed of 1500 rpm under different loading conditions. The graphs between the mixture of mahua oil in diesel and the mixture of DEE/KER in diesel with mahua oil were marked at various loads and the subsequent results were shown.

The density, oxygen content and viscosity of the fuel increases but there is a reduction in calorific value due to the addition of mahua oil to diesel. There is also a rise in brake thermal efficiency on addition of mahua oil but this decreases the value of specific fuel consumption. The emission values of hydrocarbons, carbon monoxide, nitrogen oxide and carbon dioxide have reduced in this blend and there is an uprise in HC emissions which is undesirable and is caused mainly because of its high viscosity.

The viscosity, density and calorific value of diesel-blended mahua oil decreases with addition of DEE/KER but increases the oxygen content. Gratifiable effects were observed on the fuel's performance characteristics with addition of DEE/KER. Brake thermal efficiency is directly proportional to the increase in amount of DEE/KER added but not upto conventional diesel. Similar effects were observed in the emission curves. The amount of HC increases with addition of mahua oil and also causes a reduction in hydrocarbons, carbon monoxide, nitrogen oxide and carbon dioxide emissions. The final result concluded that mahua oil and DEE/KER can be utilised as fuel additives, and can replace diesel with the blend of the same without changing the engine configuration.

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