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Effect of Di ethyl ether on the performance and emission characteristics of a diesel engine using biodiesel-eucalyptus oil blends

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ABSTRACT

The present work is to study the performance, emission and combustion characteristics of a single cylinder direct injection diesel engine using pongamia biodiesel (PB) and eucalyptus oil (Eu) along with addition of constant amount (10%) of Diethyl ether as a additive (DEE). They are blended with different proportion on constant volume basis such as B20E70, B30E60, B40E50 and B50E40 and tested at various loads (0, 3, 6, 9 and 12). The performance parameters such as Brake Specific Energy Consumption (BSEC), Brake Specific Fuel Consumption (BSFC), Brake Thermal Efficiency (BTE), Exhaust Gas Temperature (EGT) and exhaust emissions parameters such as Nitrogen Oxides (NOx), Carbon Monoxide (CO), Unburned Hydrocarbons (HC) and Smoke and combustion parameters like cylinder pressure and Heat Release Rate were measured. The brake thermal efficiency for B20Eu70DEE10 is found to be very closer to neat diesel and there is a significant reduction in BSEC, BSFC and EGT is observed at full load conditions. Further, the major emissions such as HC, CO and Smoke emission for B20Eu70DEE10 are 30%, 10% and 35.7% lower than that of diesel at full load condition respectively. Performance parameters also show satisfactory results. Thus it is to be said that B20Eu70DEE10 showed better results on the performance, emission and combustion characteristics without any modification on the engine.
**Keywords:** Eucalyptus oil, Pongamia biodiesel, Diethyl ether, Conventional diesel, Performance, Emission.

1. Introduction

The depletion of oil resources and the negative environmental impact associated with the use of fossil fuels, leads to go for an alternate energy sources. Biofuels are generally considered as offering many priorities, including sustainability, reduction of greenhouse gas emissions, regional development, social structure and agriculture, and security of supply [1]. The idea of fueling compression ignition engines on plant oil is as old as the diesel engine itself. In Rudolph Diesel’s preface to his 1912 patent he wrote that the “use of vegetable oil for engine fuel may seem insignificant today but in the course of times such oil may become as important as petroleum” [2]. It has been reported that high viscosity and low volatility of pure vegetable oil reduces fuel atomization and increases fuel spray penetration. Higher spray penetration and polymerization of unsaturated fatty acids at higher temperature are partly responsible for the difficulties experienced with engine deposits and thickening of the lubricating oil[4]. Although there are many ways and procedures to convert vegetable oil into a diesel like fuel(biodiesel), the transesterification process was found to be the most viable oil modification process[5]. Transesterification is the process of using an alcohol (e.g. methanol, ethanol or butanol), in the presence of a catalyst, such as sodium hydroxide or potassium hydroxide, to break the molecule of the raw renewable oil chemically into methyl or ethyl esters of the renewable oil, with glycerol as a byproduct. The main resources for biodiesel production can be non-edible oils obtained from plant species Jatrophacurcas(ratanjyot), Pongamiapinnata(karanja), Calophylluminophyllum(nagchampa), ossypiumhirsutumL(cotton), Heveabrasiliensis(rubber), etc. [6]. Many investigations have shown that using biodiesel in diesel engines can reduce HC, CO and PM emission but NOx emission may increase [7-9]. Oils that were used in blending with diesel and are reported to
have shown better performance, combustion and emission characteristics. In spite of improved performance, the essential oils suffers longer ignition delay due to their lower cetane number, resulting in more pronounced premixed combustion and higher NOX emission [15, 16]. Inspite of many positive aspects, certain disadvantages of biodiesel are higher viscosity, higher pour point, lower volatility, lower calorific value and poor oxidation stability [10]. In the aspects of utilizing biofuel resources widely, researchers have contemplated on blending alcohol based fuels (ethanol, methanol, butanol) with biodiesel. [11-14]. Yilmaz and Sanchez et.al [12] compared the performance and emission characteristics of a diesel engine fueled by biodiesel–ethanol and biodiesel–methanol blends, and they have found that biodiesel–ethanol blends are more effective than biodiesel–methanol blends in respect of engine performance and emission. Zhu et al. [13] have studied the emission and performance of a 4-cylinder naturally-aspirated DI diesel engine with diesel fuel, pure biodiesel, and biodiesel with additives (ethanol and methanol separately in 5%, 10% and 15% blends). They have observed that compared to diesel fuel, the blended fuels could lead to reduction of both NOX and PM of a diesel engine. Gokhan Tuçcar et.al [14] has observed that NOx decreases with butanol addition in diesel. Research studies also explicit the use of less cetane fuel of essential oils such as eucalyptus oil, orange oil, pine oil have also secured much attention in the recent past [15-17]. W.M. Yang et al. [18] investigated pine oil blended with kapok biodiesel and Results showed that HC (hydrocarbon), CO (carbon monoxide) and smoke for B50P50 were observed to be 8.1%, 18.9% and 12.5% lower than diesel at full load condition respectively and NOx emission is on par with diesel fuel. Devan and Mahalakshmi [19] blended methyl ester of paradise oil with eucalyptus oil and used them as alternate renewable fuel for diesel engine, eliminating the use of diesel completely, and reported better performance and lower emission than diesel. They indicated that NOX emission was slightly higher than that of diesel fuel. Though the lower cetane number of both alcohols and essential
oils affects the fuel ignition process, it can be successfully used in blends with biodiesel. Diethyl ether (DEE) can be produced from ethanol, which is produced itself from biomass [21], via a dehydrating process with strong dehydrating agents, thus being also a bio-fuel (bio-DEE). It can be used as a cetane improver. DEE has several favorable properties including very high cetane number, reasonable energy density for on-board storage, high oxygen content, low auto ignition temperature, broad flammability limits, and high miscibility. The DEE introduced directly into the intake pipe in the form of droplets (fumigation) which increases smoke, CO, HC emission and decrease of NOx [22]. The DEE is added with Karanja oil methyl ester (KOME) and its blends up to 20% by vol., at various loads and reported that slight decrease of smoke, monotonic decrease of NOx emissions with increasing percentage of DEE in the blend. There are only few studies available in the biodiesel essential oil blends on the aspects of complete replacement of conventional diesel. However there is no work done on the influence of high cetane fuel DEE with essential oil blends.

Thus the aim of the present work is to explore the effect of DEE in the performance, emission and combustion characteristics of eucalyptus oil and pongamia biodiesel blends in a single cylinder diesel engine.

2. Materials and Methods

2.1. Materials

The fundamental materials, pure pongamia and eucalyptus oil, DEE and other main ingredients for biodiesel production, including methanol, sodium hydroxide are utilized for the present study.
2.2. Test Fuels

2.2.1. Pongamia pinnata.

Pongamia pinnata is a species of family Leguminosae, native in tropical and temperate environment. The oil is extracted from the kernel by traditional expeller. The freshly extracted Pongamia oil is yellowish orange to brown and rapidly darkens on storage. The oil contains toxic flavonoids such as karanjin and di-ketone pongamol as major lipid associates, which make the oil non-edible. Pongamia oil contains significant amount of saturated fatty acids, Palmitic acid (3.7–14.1%) being the most common, Stearic acid (2.4–10.9 %) in smaller amount as well as traces of Capric Acid, Lauric acid, Arachidic Acid, Behenic Acid, greater amount of mono unsaturated Oleic acid (44.5–71.3%) being the most prominent fatty acid, and also it has diunsaturated Linoleic acid (10.8–27.1%), Linolenic acid (3.6–6.3%).[7,24]. The fuel properties reveal that the raw pongamia oil has higher viscosity and boiling point, which does not support its direct use in diesel engine. Therefore, it is essential to transesterify the extracted pongamia oil in order to reduce its viscosity, and bring it to the permissible biodiesel standard so as to make it feasible for using in diesel engine operation.

2.2.2 Eucalyptus oil

The eucalyptus tree grows in many parts of the world especially India. Eucalyptus oil can be extracted from eucalyptus leaves by steam distillation which is available abundantly throughout the year. The main chemical components of eucalyptus oil are a-pinene, b-pinene, a-phellandrene, 1,8-cineole, limonene, aromadendrene, epiglobulol, piperitone and globulol. A major constituent of eucalyptus oil is cineole. The empirical formula for cineole is C_{10}H_{18}O and its systematic name is 1, 3, 3-trimethyl-2-oxabicyclo octane.
Methyl alcohol (5:1 molar ratio to pongamia oil) and sodium hydroxide (1%w/w of oil) is taken in a flask with a narrow neck and shake well to dissolve the sodium hydroxide in methanol. Then one liter of pongamia oil is mixed with the mixture. Flask is heated on a hot plate having magnetic stirrer arrangement. The mixture is stirred at the same speed for the whole process. The temperature maintained for the whole process is between 60ºC and 65ºC and the reaction duration is fixed at 2 hour under reflux condition. After two hour, the reaction is stopped and the product is allowed to settle in two layers. The upper layer consisting of esters of methanol and the bottom layer having glycerin is separated. At the end of the process, methyl ester is heated at 100ºC to remove water and excess alcohol.

3. Experimental Setup:

Figure 1 shows the schematic diagram of the experimental set up. The test engine is a kirloskar tv1 model single cylinder four-stroke water-cooled diesel engine developing 5.2 kW at a speed of 1500 rpm. The specification of the engine are given in Table 1. This engine is directly coupled to an AG10 model water cooled eddy-current dynamometer (Make Saj Test Plant Pvt. Ltd.) with a control system. Lab view based Engine Performance Analysis software package “EnginesoftLV” is used for on line performance evaluation. The surge tank fixed on the inlet side of an engine maintains a constant airflow through the orifice meter. K type thermocouple in conjunction with a digital temperature indicator is used for measuring the exhaust temperature. The fuel flow rate is measured on volume basis using a burette and stopwatch. The exhaust emission HC (hydrocarbon), CO (carbon monoxide), CO₂ (carbon dioxide) and NOₓ (oxides of nitrogen) from the engine are measured with the help of the AVL 444 DI gas analyzer, These emission are measured using the emission analyzer based on NDIR (non-dispersive infrared) principle by selective absorption. The technical specifications of AVL 444 DI gas analyzer are shown in Table2. Further, the smoke level was measured in HSU (Hartridge Smoke Unit) using a standard AVL437C smoke meter. The
smoke emission is measured based on light extinction principle wherein, the amount of light blocked by the sample of exhaust gas from the engine.

4. Uncertainty Analysis

To specify the experimental accuracy, uncertainty analysis is required. In this experiment, uncertainties and errors can arise from experimental condition, environment, calibration, instrument selection, observation, and test preparation. The uncertainties for the engine performance parameters were determined using the propagation of errors methodology. The following equation shows the total percentage uncertainty, $W_R$ of these calculated experimental values: where $R$ is a given function of the independent variables $x_1$, $x_2$, ..., $x_n$ and $W_1$, $W_2$, ..., $W_n$ are the uncertainty of the independent variables [27]. The total uncertainty of the experiment was found to be ±2.21%.

$$W_R = \left[ (\frac{\partial R}{\partial x_1}W_1)^2 + (\frac{\partial R}{\partial x_2}W_2)^2 + \ldots + (\frac{\partial R}{\partial x_n}W_n)^2 \right]^{1/2}$$

5. HRR Analysis

HRR is the rate at which heat is generated by fire. It is the heat that is available in every square foot of surface absorbing heat within a particular surface. The HRR is calculated based on the cylinder pressure and volume measurements. The HRR formula, as given in the below equation, is derived from the first law of thermodynamics. For simplification purposes, leakage and heat transfer to the wall are assumed to be negligible and were excluded during the derivation of this equation.

$$\frac{dQ}{d\theta} = \frac{\gamma}{\gamma - 1}P \frac{dV}{d\theta} + \frac{1}{\gamma - 1}V \frac{dP}{d\theta}$$
Where, \( \frac{dQ}{d\theta} \) is the HRR per crank angle, \( \theta \) is the crank angle, \( P \) is the pressure, \( V \) is the cylinder volume.

6. Testing Procedure

The experiments were performed without any modification on the engine. The engine was started using diesel and then it was switched to biofuel blends after 20 minutes. Whenever, the fuel is changed the engine was run for about 10 min to get stable condition with the new fuel before measurements were taken. The engine was loaded from 0kg to 15kg progressively in steps of 3kg by controlling the current supplied to the eddy current dynamometer. When changing the engine load, the rack position of fuel pump is adjusted to regulate the supplied fuel so that a constant speed of 1500 rpm is maintained. All the readings, pertaining to the engine experiment and investigation, were noted down at ambient conditions, when the engine was stabilized and has attained steady state condition. The experiments are repeated for three times and average value of the readings were taken, and used for calculations to enhance the accuracy of the obtained results. At the end of the test, the fuel was switched back to standard diesel and the engine was kept running for a while before shut-down to flush out the test fuel from the fuel line and the injection system. The engine was run for 10 minutes and data were collected during last 4 minutes. The exhaust gas is sampled from exhaust pipe line and passed through an exhaust gas analyzer for measurement of carbon monoxide, carbon dioxide, unburnt hydrocarbon and oxides of nitrogen present in exhaust gases. A smoke meter is used for measurement of smoke capacity. The experimental uncertainties are given in Table 3.

7. Results and Discussion

7.1. Fuel Properties
Properties of fuels are measured by using standard ASTM methods. The cetane index is an approximation to cetane number computed from the empirical correlation given in Colin R. Ferguson[26]. Table-4 shows the main properties of test fuels. It is evident that eucalyptus oil has lower viscosity, flash point and higher calorific value than its counterpart, Pongamia Methyl Ester (PME). The eucalyptus oil is deemed to have lower cetane number than PME, affecting the auto-ignition of it. Table 5 shows the properties of blended fuels. However, after blending eucalyptus oil with PME & DEE, properties of the blends are in comparable with diesel. For instance, the higher viscosity, and flash point of PME was balanced by the respective lower properties of eucalyptus oil, while, on the other hand, the lower cetane number of eucalyptus oil has been enhanced by the higher cetane number of PME & DEE.

7.2. Performance Characteristics

7.2.1. Brake Specific Energy Consumption (BSEC)

Brake specific energy consumption (BSEC) measures the amount of input energy required to develop one-kilowatt power [28]. The BSEC is an important parameter of an engine because it takes care of both mass flow rate and heating value of the fuel [29, 30]. The factors affecting the brake specific energy consumption are fuel density, viscosity, heating value, and volumetric fuel injection system. The variation of brake specific energy consumption with various load for different fuel blends and diesel is shown in Fig.2. The brake specific energy consumption of the B20Eu70DEE10 blend was 11.2 MJ/kW-h and lower than that of all other blends and neat diesel. The BSEC is reduced 12% for B20E70 DEE10 when compared to neat diesel. This may be due to better combustion, and an increase in the energy content of the blend. This value increases for other blends like B30Eu60DEE10, B40Eu50DEE10 and B50Eu40DEE10 of about 10.01%, 8.2% and 6.57% respectively. This is due to the fact that calorific value of Eucalyptus oil is higher than that of PME, hence reducing the amount of Eucalyptus oil in the blend increases the BSEC.
7.2.2. **Brake Specific Fuel Consumption**

BSFC is the amount of fuel consumed for generating 1 kW of power per hour in kg. It is measured by calculating the time taken for the engine to consume 10cc of fuel for the given fuel. Fig. 3 shows the variation of BSFC for each load. It can be seen that the BSFC of B20Eu70DEE10 is slightly higher than that of diesel fuel at low loads and it decreases with increase in load. 9.76% reduction is BSFC is seen for B20Eu70DEE10 when compared with diesel fuel at full load conditions. Likewise for B30Eu60DEE10, B40Eu50DEE10, and B50Eu40DEE10 exhibits reduction in BSFC than diesel of about 7.5%, 5.67% and 4.89% respectively when compared with neat diesel fuel. This is due to the B20Eu70DEE10 having higher density and lower heating value which cause poor atomization of the fuel resulting in higher SFC.

7.2.3. **Brake Thermal Efficiency (BTE)**

Thermal efficiency is the ratio of power output to the product of injected fuel mass flow rate and lower heating value. Brake Thermal Efficiency is simply the inverse of the brake specific energy consumption BSEC [31]. Fig. 4 shows the variation of BTE with load for all different fuel blends and neat diesel. The brake thermal efficiency of the B20Eu70DEE10 blend is higher than that of other blends due to less viscosity, improved atomization, fuel vaporization and combustion. The BTE of B20Eu70DEE10 is 30.2% and the diesel is 29% which is very close to the neat diesel. It may be due to better utilization of heat energy and better air entrainment. Adding diethyl ether to PME & eucalyptus oil will decrease viscosity of blends and it causes improvement in the shape of fuel spray and atomization. These finer fuel droplets tend to mix thoroughly with air and hence improving the combustion [32]. BTE is reduced with increasing the volume of PME due to the known fact that BTE is the reciprocal of BSEC, as BSEC increases it reduces the BTE for all the blends. The BTE for B30Eu60DEE10, B40Eu50DEE10 and B50Eu40DEE10 are 29.34%, 28.75% and
28.02%. Further, the inherent presence of oxygen in eucalyptus and PME, along with the superior evaporation and air/fuel mixing, have helped to attain a more reactive combustion, leads to increasing the BTE of the engine.

7.2.4. Exhaust Gas Temperature (EGT)

The variation EGT is an indicator of the heat of the fuels tested at combustion period. The exhaust gas temperature with various loads for a different fuel blends and neat diesel is shown in Fig 5. It is observed that the exhaust gas temperature of the B20Eu70DEE10 blend is higher than that of all other blends. The EGT for B20Eu70DEE10 is 366°C and a reduction of 3.5% is achieved when compared to neat diesel. This is due to decreased energy content of the fuel blends, better combustion, and reduced ignition delay due to increased percentage of biodiesel in the blends and addition of DEE. This is also due to reduction in energy losses to the exhaust signifies the conversion of available energy into useful work.

7.3. Emission Characteristics

7.3.1. Carbon Monoxide Emission (CO)

CO is an intermediate combustion product and is formed mainly due to incomplete combustion of fuel. If combustion is complete, CO is converted to CO₂. If the combustion is incomplete due to shortage of air or due to low gas temperature, CO will be formed [33]. Fig. 6 shows the variation of CO emission for with various loads and different fuel blends and neat diesel. The CO emission of B20Eu70DEE10 is lower than that of other blends and neat diesel. The CO emission of B20Eu70DEE10 is 0.18% and reduction of 10% is achieved when compared to neat diesel. This is due to the enrichment of oxygen owing to the eucalyptus oil and bio-diesel addition. This reduction in CO emission at higher loads is due to more complete combustion and better oxidation of CO to CO₂, governed by abundance of oxygen in the blended fuel. For B30Eu60DEE10, B40Eu50DEE10, B50Eu40DEE10 blends the CO emission value reduced about 6.7%, 8.01% and 5.54% than
diesel fuel, this is due to the viscosity changes and further atomization gets affected with the addition or increase of PME. It is to be noted that all blends shows reduced CO emission than diesel fuel at full load conditions. Further, the surface temperature of the combustion chamber happens to get increased as the load increases and this facilitates CO oxidation. Higher oxygen in fuel-rich combustion zone is believed to ensure more complete combustion which in turn reduces CO concentration in the exhaust emissions [34].

7.3.2. Hydrocarbon Emission (HC)

There are some regions within the combustion chamber of an engine fueled with diesel where the mixture is either too lean or too rich to ignite the partially decomposed and oxidized fuel in the exhaust. These unburnt species are collectively known as unburnt hydrocarbon emissions [34]. The variation of HC emission with load for different fuel blends and neat diesel shown in Fig 7. The HC emission of B20Eu70DEE10 is lower than that of other blends and neat diesel. The HC emission of B20Eu70DEE10 is 43 ppm and is 30% lesser when compared to neat diesel. This is due to lower viscosity of eucalyptus oil and DEE partially compensates the negative impact of higher viscosity of PME and therefore, HC emission is greatly reduced. HC emissions for reduces at about 20%, 18% and 16.44% B30Eu60DEE10, B40Eu50DEE10, B50Eu40DEE10 respectively when compared with neat diesel fuel. HC emission for all these blends is more than that of the lowest blend due to the reason that reducing Eucalyptus oil increases the viscosity and thereby complete burning is affected and results in more HC emissions[36, 37]. Lower distillation temperature of eucalyptus oil counteracts the poor volatility characteristics of PME. It improves the evaporation rate and allows better mixing of fuel with air leads to enhanced combustion. It also contributes to reducing the HC emission.

7.3.3. Oxides of Nitrogen Emission (NOx)
Combination of nitric oxide (NO) and nitrogen dioxide (NO$_2$) is known as Nitrogen oxides or NO$_X$. NO$_X$ formation depends upon: Temperature of the cylinder, Time needed for the reaction to take place, Coefficient of air surplus, and In-cylinder temperature. There are three mechanisms of NO$_X$ formation: (i) thermal, (ii) prompt and (iii) fuel. The first mechanism “thermal” is also known as Zeldovich Mechanism [38, 39]. This mechanism states that, “when Nitrogen molecule's triple bond is broken by high combustion temperature (1800K) then the nitrogen molecule dissociates into their atomic states and participates in series of reaction with oxygen and produces thermal NO$_X$”. Free radical development in the flame front of hydrocarbon flames leads to fast production of NO$_X$, recommended by prompt mechanism. In the time of combustion of fuel, NO$_X$ is shaped by the reaction of oxygen with nitrogen bound in the fuel. [38].the variation of NO$_X$ emission with variation to load for different fuel blends and neat diesel shown in Fig 8. Though the biofuel blends exhibits better emission characteristics and performance characteristics they tend to show more NOx emissions, though it is of a very slight increase. The NO$_X$ emission of B20Eu70DEE10 is lower than that of other blends and neat diesel. The NO$_X$ emission of B20Eu70DEE10 is 948 ppm and is 2.9% increasing when compared to neat diesel. This may be due to a higher combustion temperature inside the cylinder at a higher load, as a greater amount of fuel is burned at higher loads. It can be seen that EGT for B30Eu60DEE10, B40Eu50DEE10 and B50Eu40DEE10 blends is more which shows that the combustion chamber temperature is also more resulting in higher NOx emissions. Increase in NOx when compared with diesel for the blends B30Eu60DEE10, B40Eu50DEE10 and B50Eu40DEE10 are 2.43%, 1.98% and 1.501% respectively. Many studies show that increase in NO$_X$ emission, when lower cetane fuels such as ethanol, methanol and eucalyptus oil were being burnt in blends with either diesel or biodiesel in diesel engine[19, 35]. The main factor causing the increase in
NO\(_x\) emission are higher ignition delay due to lower cetane number leads to higher peak heat release rate and the ensuing prevalence of high temperature inside the combustion chamber.

### 7.3.4. Smoke

One important parameter that represents the emission behavior of a diesel engine is smoke emission. Fig. 9 shows variation of smoke emission for various loads for different fuel blends and neat diesel. Smoke which normally forms at fuel-rich zone at higher temperature and pressure [40] less viscous and high volatility fuels such as butanol has greater potential to reduce the smoke emission [41]. Like that, the reduced viscosity of B20Eu70DEE10 which improves in better atomization and mixing of the fuel and loads to reduction in, the smoke emission. Further the reduction may be attributed to the presence of extra fuel bound oxygen in the blends even at locally fuel rich zones. The smoke emission of B20Eu70DEE10 is lower than that of other blends and neat diesel. The smoke emission for B20Eu70DEE10 is lesser than diesel by about 35.7%. Further the percentage reduction of smoke when compared with neat diesel fuel for the blends B30Eu60DEE10, B40Eu50DEE10 and B50Eu40DEE10 are 32.2%, 21.01% and 14.86% respectively.

### 7.4. Combustion Analysis

#### 7.4.1. Heat Release Rate

Fig. 10 represents the heat release rate during the combustion process for the change in crank angle degree. It is evident that reduction in the heat release rate is observed at three fourth of load for all fuels. B20Eu70DEE10 blend, at three fourth of load the heat release rate is found to be 3.4% higher when compared to diesel at three fourth of load at standard engine specification. The heat release rate of other blends such as B30Eu60DEE10, B40Eu50DEE10 and B50Eu40DEE10 exhibits higher heat release rate of 3.86%, 4.45% and 4.86% than the best blend at all load conditions.

#### 7.4.2. Cylinder Pressure:
Changes of Cylinder Pressure values accordance to various Crank Angles, for all the blends at different loads, are presented in Figs. 11. It is seen that the Cylinder Pressure values of B20Eu70DEE10 are slightly higher than the values of B30Eu60DEE10, B40Eu50DEE10 and B50Eu40DEE10 for almost all the load conditions or various crank angles. But the cylinder pressure of all the biodiesel blends tends to be lower than that of the diesel fuel blend. The reason for this is considered to be the higher cylinder temperatures which result in higher Cylinder Pressures.

8. Conclusion

The present work has attempted to use biofuels (eucalyptus oil, PME, DEE) blends in a diesel engine and thereby, exclude the use of fossil diesel fuel completely. Based on the study the following conclusions are drawn.

- The high cetane value of methyl ester and diethyl ether could compensate for the decreased cetane value caused by the eucalyptus oil in the blend. The lower heating value of all the blends was found to be par to that of diesel fuel.
- Smooth engine operation was observed for all the blends and BSEC were also envisaged to be improved at full load condition. BTE of the engine was increased slightly for all blends than diesel.
- HC, CO and Smoke emission for B20Eu70 was lower than diesel by 30%, 10% and 35.7%, respectively. There is a slight increase of NOx emissions (2.9%) for the B20Eu70DEE10 blend at full load.
- Heat Release Rate of B20Eu70 blend is higher than that of diesel by 3.4% but is lesser than the other blends.

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Fig. 1 Schematic Diagram of the Experimental Set Up
Fig. 2. Variation of Brake specific energy consumption versus load
Fig. 3. Variation of Brake specific Fuel consumption versus load
Fig. 4. Variation of brake thermal efficiency versus load
Fig. 5. Variation of exhaust gas temperature versus load
Fig. 6. Variation of carbon monoxide emission versus load
Fig. 7. Variation of hydrocarbon emission versus load
Fig. 8. Variation of oxides of nitrogen emission versus load
Fig. 9. Variation of smoke emission versus load
Fig 10: Variation of crank angle with heat release rate
Fig 11: Variation of crank angle with cylinder pressure
Fig. 1 Schematic Diagram of the Experimental Set Up

Fig. 2. variation of Brake specific energy consumption versus load

Legend:
- Blue: Diesel
- Red: B20Eu70DEE10
- Green: B30Eu60DEE10
- Purple: B40Eu50DEE10
- Cyan: B50Eu40DEE10
Fig. 3. Variation of brake specific fuel consumption versus load

Fig. 4. Variation of brake thermal efficiency versus load
Fig. 5. Variation of exhaust gas temperature versus load

Fig. 6. Variation of carbon monoxide emission versus load
Fig. 7. Variation of hydrocarbon emission versus load.

Fig. 8. Variation of oxides of nitrogen emission versus load.
Fig. 9: Variation of smoke emission versus load

Fig 10: Variation of crank angle with heat release rate
Fig 11: Variation of crank angle with cylinder pressure
Table 1 Specification of the engine.

<table>
<thead>
<tr>
<th>DETAILS</th>
<th>SPECIFICATION</th>
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<tbody>
<tr>
<td>Type</td>
<td>Four stroke, Kirloskar make, compression ignition, direct injection, and water Cooled.</td>
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<tr>
<td>Rated power &amp; speed</td>
<td>5.2kW &amp; 1500 rpm</td>
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<tr>
<td>Number of cylinder</td>
<td>Single cylinder</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>17.5:1</td>
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<tr>
<td>Bore &amp; stroke</td>
<td>87.5mm &amp; 110mm</td>
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<tr>
<td>Method of loading</td>
<td>Eddy current dynamometer</td>
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<tr>
<td>Dynamometer arm length</td>
<td>0.185m</td>
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<tr>
<td>Type of injection</td>
<td>Mechanical pump-nozzle injection</td>
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<td>Inlet valve opening</td>
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<tr>
<td>Inlet valve closing</td>
<td>35.55° after TDC</td>
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<tr>
<td>Exhaust valve opening</td>
<td>35.55° before BDC</td>
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<tr>
<td>Exhaust valve closing</td>
<td>4.5° after TDC</td>
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<tr>
<td>Injection timing</td>
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<tr>
<td>Injection pressure</td>
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<td>Lubrication oil</td>
<td>SAE 40</td>
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Table 2 Technical specification of exhaust gas analyzer.

<table>
<thead>
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<th>Gaseous components</th>
<th>Range</th>
<th>Accuracy</th>
<th>Resolution</th>
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<tr>
<td>CO</td>
<td>0-10%vol</td>
<td>0.06%vol</td>
<td>0.01%vol</td>
</tr>
<tr>
<td>CO₂</td>
<td>0-20%vol</td>
<td>0.30%vol</td>
<td>0.1%vol</td>
</tr>
<tr>
<td>HC</td>
<td>0-2000ppm</td>
<td>4ppm</td>
<td>1ppm</td>
</tr>
<tr>
<td>O₂</td>
<td>0-22%vol</td>
<td>0.10%vol</td>
<td>0.01%vol</td>
</tr>
<tr>
<td>NO</td>
<td>0-5000ppm</td>
<td>25ppm</td>
<td>1ppm</td>
</tr>
</tbody>
</table>
Table 3-List of instruments and their accuracy and percentage uncertainties.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Type &amp; Manufacturer</th>
<th>Measurement technique</th>
<th>Accuracy (%)</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load</td>
<td>Strain gauge, SensotronicsSanmar</td>
<td>Load cell</td>
<td>±10 N</td>
<td>±0.2</td>
</tr>
<tr>
<td>Speed</td>
<td>Kubler, Germany</td>
<td>Magnetic pickup principle</td>
<td>±10rpm</td>
<td>±0.1</td>
</tr>
<tr>
<td>Fuel flow measurement</td>
<td>Differential pressure transmitter</td>
<td>Volumetric measurement</td>
<td>±0.1cc</td>
<td>±1</td>
</tr>
<tr>
<td>CO</td>
<td>AVL exhaust gas analyser, Austria</td>
<td>NDIR technique</td>
<td>±0.02%</td>
<td>±0.2</td>
</tr>
<tr>
<td>HC</td>
<td>AVL exhaust gas analyser, Austria</td>
<td>NDIR technique</td>
<td>±0.03%</td>
<td>±0.1</td>
</tr>
<tr>
<td>NOx</td>
<td>AVL exhaust gas analyser, Austria</td>
<td>NDIR technique</td>
<td>±12ppm</td>
<td>±0.2</td>
</tr>
<tr>
<td>Smoke</td>
<td>AVL smoke meter</td>
<td>opacimeter</td>
<td>±1HSU</td>
<td>±1</td>
</tr>
<tr>
<td>EGT indicator</td>
<td>Make Wika, Thermocouple</td>
<td></td>
<td>±1°C</td>
<td>±0.15</td>
</tr>
<tr>
<td>Pressure Pick up</td>
<td>PCB, piezotronics</td>
<td>Magnetic pickup principle</td>
<td>±0.1 kg</td>
<td>±0.1</td>
</tr>
<tr>
<td>Crank angle encoder</td>
<td>Kubler, Germany</td>
<td>Magnetic pickup principle</td>
<td>±1 deg</td>
<td>±0.2</td>
</tr>
</tbody>
</table>
Table 4-Properties of test fuels.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Diesel</th>
<th>Eucalyptus oil</th>
<th>Pongamia oil</th>
<th>POME</th>
<th>DEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density $^0$C (g/m$^3$)</td>
<td>0.84</td>
<td>0.90</td>
<td>0.924</td>
<td>0.878</td>
<td>0.713</td>
</tr>
<tr>
<td>Heating Value (kJ/kg)</td>
<td>42700</td>
<td>43270</td>
<td>37.5</td>
<td>38500</td>
<td>33900</td>
</tr>
<tr>
<td>Kinematic Viscosity (Cst)</td>
<td>2.9</td>
<td>2.0</td>
<td>40.2</td>
<td>3.9</td>
<td>0.23</td>
</tr>
<tr>
<td>Flash Point $^0$C</td>
<td>54</td>
<td>58</td>
<td>225</td>
<td>172</td>
<td>-45</td>
</tr>
<tr>
<td>Cetane Number</td>
<td>49</td>
<td>18</td>
<td>42</td>
<td>50</td>
<td>&gt;125</td>
</tr>
</tbody>
</table>

Table 5-Properties of fuel blends.

<table>
<thead>
<tr>
<th>Properties</th>
<th>B20Eu70DEE10</th>
<th>B30Eu60DEE10</th>
<th>B40Eu50DEE10</th>
<th>B50Eu40DEE10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density $^0$C (g/m$^3$)</td>
<td>0.878</td>
<td>0.876</td>
<td>0.873</td>
<td>0.871</td>
</tr>
<tr>
<td>Heating Value (kJ/kg)</td>
<td>40920</td>
<td>40490</td>
<td>40060</td>
<td>39640</td>
</tr>
<tr>
<td>Kinematic Viscosity (Cst)</td>
<td>2.34</td>
<td>2.53</td>
<td>2.72</td>
<td>2.91</td>
</tr>
<tr>
<td>Flash Point $^0$C</td>
<td>73</td>
<td>84</td>
<td>92</td>
<td>98</td>
</tr>
<tr>
<td>Calculated cetane Index</td>
<td>35</td>
<td>39</td>
<td>42</td>
<td>44</td>
</tr>
</tbody>
</table>