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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 B50E40and tested at various loads (0, 3, 6, 9and 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 forB20Eu70DEE10 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 andSmokeemission for B20Eu70DEE10 are 30 %, 10% and 35.7% lower thanthat of diesel at full load condition respectively. Performance parameters also show satisfactory results. Thus it is to be said that B20Eu70DEE10showed better results on the performance, emission and combustion characteristics without any modification on the engine.

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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 timesuch 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

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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 NO_X emission [15, 16].Inspite of many positive aspects,certain disadvantages of biodiesel arehigher 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.GokhanTuccar 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. Yanget.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 ofdiesel fuel. Though the lower cetane number of both alcohols and essential

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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 NOxemissions 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.

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2.2. Test Fuels

2.2.1. Pongamia pinnata.

Pongamiapinnata is a species of family Leguminasae, 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, Strearicacid(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. Eucalyptusoil 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.

2.3. Transesterification

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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 100ºCto 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 (MakeSaj 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 stop watch .The exhaust emission HC(hydrocarbon), CO (carbon monoxide), CO_2 (carbon dioxide) and NO_X(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

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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 followingequation shows the total percentage uncertainty, W_R ofthese 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%.

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

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

$$\frac{dQ}{d\theta} = \frac{\gamma}{\gamma - 1} P \frac{dV}{d\theta} + \frac{1}{\gamma - 1} V \frac{dP}{d\theta}$$

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Where, $dQ/d\theta$ is the HRR per crank angle, θ 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 about10 min to get stable condition with the new fuel before measurements were taken. The engine was loaded from 0kg to15kg 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

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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 lowercetane 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 dieselis shown in Fig.2. The brake specific energy consumption of the B20Eu70DEE10blend 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, B40Eu50DEE10and 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.

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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 B20Eu70DEE10having 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 B20Eu70DEE10blend is higher than that of other blends due to less viscosity, improved atomization, fuel vaporization and combustion.The BTE of B20Eu70DEE10is 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 B50Eu40DEE10are29.34%, 28.75% and

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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 moreactive 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 366^0C 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, andreduced 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 CO_2. 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 CO_2, 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

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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 increasedas 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 COconcentration 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 is30% 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 (NO_X)

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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, andIn-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.TheNO_X emission of B20Eu70DEE10 is lower than that of other blends and neat diesel. The NO_X emission of B20Eu70DEE10is 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

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NO_Xemission 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 combustionchamber.

7.3.4. Smoke

One important parameter that represents the emission behavior of a diesel engine is smoke emission.Fig.9shows variation of smoke emission for variousloads 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 B20Eu70DEE10which 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 blendsB30Eu60DEE10, B40Eu50DEE10 and B50Eu40DEE10 are32.2%, 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:

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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 B20Eu70DEE10are 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 slightincrease 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.

References

RSC Advances Accepted Manuscript

1. Reijnders, L. 2006. Conditions for the sustainability of biomass based fuel use. Energy Policy, 34: 863–876.

2. Vasudevan P, Sharma S, Kumar A. Liquid fuel from biomass: an overview. J SciIndResh 2005; 64(11):822–31.

3. Yilmazn, Morton b. effects of preheating vegetable oils on performance and emissions characteristics of two diesel engines. Biomass bioenergy 2011; 35(5); 2028-33

4. GerhardVellguth, performance of vegetable oils and their monsters as fuels for diesel engines", SAE paper No-831358

5. Altin R, Cetinkaya S, Yucesu HS. The potential of using vegetable oil fuels as fuel for Diesel engines. Energy. Convers Manage 2001; 42:529–38.

6. Swarup, R. 2007 (April). Biofuels: Breathing new fire. Biotech News II (2): 14.

7. Velraj K, Sureshkumar R, Ganesan.Performance and exhaust emission characteristics of a CI engine fueled with Pongamiapinnata methyl ester (PPME)', and its blends with diesel Renewable Energy, vol33, pp. 2294–2302

8.Yadav VS, Khatri KK, Tanwar D, Sharma D, Soni S. Performance analysis and exhaust emissions of neem methyl ester operated compression ignition engine. J Renew Sustain Energy 2013; 5023-5033.

9. Schumacher LG, Borgelt SC, Fosseen D, Goeta W, Hires WG. Heavy-duty engine exhaust emissions tests using methyl ester soybean oil/diesel fuel blends. Bioresource Technolgy.1996; 57:31–6.

10. Demirbas a importance of biodiesel as transportation fuel energy policy, 35, 4661-4670(2007)

RSC Advances Accepted Manuscript

11. Yilmaz N, Vigil FM, Donaldson AB, Darabesh T. Investigation of CI engine emissions in biodiesel–ethanol–diesel blends as a function of ethanol concentration. Fuel 2014; 115:790–3.

12. Yilmaz N, Sanchez TM. Analysis of operating a diesel engine on biodiesel–ethanol and biodiesel–methanol blends. Energy 2012; 46:126–9.

13. Zhu L, Cheung CS, Zhang WG, Huang Z. Emission's characteristics of a diesel engine operating on biodiesel and biodiesel blended with ethanol and methanol. Sci Total Environ 2010; 408(4):914–21.

.14.Gokhan Tuccar, TayfunOzgur, KadirAydın (2014) 'Effect of diesel–microalgae biodiesel–butanol blends on performance and emissions of diesel engine', Fuel vol132, pp47–52.

15. Vallinayagam R, Vedharaj S, Yang W, Lee P, Chua K, Chou S. Combustion performance and emission characteristics study of pine oil in a diesel engine.Energy 2013;57:344–51.

16. Purushothaman K, Nagarajan G. Performance, emission and combustioncharacteristics of a compression ignition engine operating on neat orange oil.Renewable Energy 2009;34:242

17.. Karthikeyan R, Nallusamy N, Alagumoorthi N, Ilangovan V. Optimisation of engine operating parameters for turpentine mixed diesel fueled DI diesel engine using Taguchi method. Mod ApplSci 2010; 4:182–92.

18.Vallinayagam, S. Vedharaj, W.M. Yang , P.S. Lee, K.J.E. Chua, S.K. Chou (2014) 'Pine oil–biodiesel blends: A double biofuel strategy to completely eliminate the use of diesel in a diesel engine', Applied Energy, vol.130, pp466–473.

19. Devan P, Mahalakshmi N. A study of the performance, emission and combustion characteristics of a compression ignition engine using methyl ester of paradise oil–eucalyptus oil blends. Appl Energy 2009; 86:675–80.

RSC Advances Accepted Manuscript

20. Bailey B, Eberhardt J, Goguen S, Erwin J. Diethyl ether (DEE) as a renewable diesel fuel. SAE paper no. 972978; 1997.

21. Rakopoulos DC, Rakopoulos CD, Giakoumis EG, Dimaratos AM. Characteristics of performance and emissions in high-speed direct injection diesel engine fueled with diethyl ether/diesel fuel blends. Energy 2012; 43:214–24.

22. Purushothaman K, Nagarajan G. Experimental investigation on a C.I. engine using orange oil and orange oil with DEE. Fuel 2009; 88:1732–40.

23. Iranmanesh M, Subrahmanyam JP, Babu MKG. Potential of diethyl ether as a blended supplementary oxygenated fuel with biodiesel to improvecombustion and emission characteristics of diesel engines.SAE paper no.2008-01-1805; 2008.

24.AgarwalAK, RajamanoharanK. Experimental investigations of performance and emissions of Pongamiaoil and its blends in a single cylinder agricultural diesel engine.ApplEnergy2009; 86:106–12.

25. RameshPoola B, Nagalingam B, Gopalakrishnan KV. Performance studies with biomass derived high octane fuel additives in a two stroke spark ignition engine. Int J Biomass Bioenergy 1994; 6:369–79.

26. Ferguson Colin R. Internal combustion engines, applied thermosciences. 1st edition. New York: John Wiley & Sons; 1985.

27. Holman JP. Experimental techniques for engineers. 7th ed. New Delhi: TataMcGraw Hill; 2004.

RSC Advances Accepted Manuscript

28. Barie NJ, Humke AL. Performance and emission characteristics of a naturally aspirated diesel engine with vegetable oil fuels. Society of Automotive Engineers Paper No: 810262, 1981.

29 Scholl KW, Sorenson SC. Combustion of soybean oil methyl ester in a direct injection diesel engine. Society of Automotive Engineers Paper No: 930934, 1993.

30. Canakci M. Performance and emissions characteristics of biodiesel from soybean oil. Proc. IMechE Part D Journal of Automobile Engineering 2005; 219:915–22.

31. Rakopoulos DC, Rakopoulos CD, Giakoumis EG, Dimaratos AM, Kyritsis DC. Effects of butanol–diesel fuel blends on the performance and emissions of a high-speed DI diesel engine. Energ Convers Manage 2010; 51:1989–97.

32. Hu Chen, Jianxin Wang, Wenmiao Chen, ShijinShuai. Effects of ethanol in ester ethanol–diesel blended fuels on fuel spray behavior and PM emission. SAE, Publication No. 2006-01 0236.

33.Md. NurunNabi , Md. MustafizurRahman, Md. ShamimAkhter Biodiesel from cotton seed oil and its effect on engine performanceand exhaust emissions Applied Thermal Engineering 29 (2009) 2265–2270

34. Buyukkaya E. Effects of biodiesel on a DI diesel engine performance, emission and combustion characteristics. Fuel 2010; 89:3099–105.

35. Kannan D, Pachamuthu S, NurunNabi M, Hustad JE, Lovas T. Theoretical and experimental investigation of diesel engine performance, combustion and emissions analysis fuelled with the blends of ethanol, diesel and jatropha methyl ester. Energy Convers Manage 2012; 53:322–31

36. Lin CY, Lin HA. Engine performance and emission characteristics of a three phase emulsion of biodiesel produced by peroxidation. Fuel Process Technol 2007; 88:35–41.

RSC Advances Accepted Manuscript

37. Lujaji F, Kristof L, Bereczky A, Mbarawa M. Experimental investigation of fuel properties, engine performance, combustion and emissions of blends containing croton oil, butanol, and diesel on a CI engine. Fuel 2011; 90:505–10.

38. HoekmanSK,RobbinsC. Review of the effects of biodiesel on NOx emissions. Fuel ProcessTechnol2012; 96:237–49.

39. AjavE, SinghB, BhattacharyaT. Performance of as stationary diesel engine using vapourized ethanol as supplementary fuel. Biomass Bioenergy 1998; 15:493–502.

40. Yu MI, Hites RA, Identification of organic compounds on diesel engine soot, Analytical Chemistry 53/7 (1981) 951-954.

41. EvangelosG.Giakoumis, ConstantineD.Rakopoulos, DimitriosC.Rakopolos Exhaust emissions with ethanol or n-butanol diesel fuel blends during transient operation: A review Renewable and Sustainable Energy Reviews 17 (2013) 170–190.

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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

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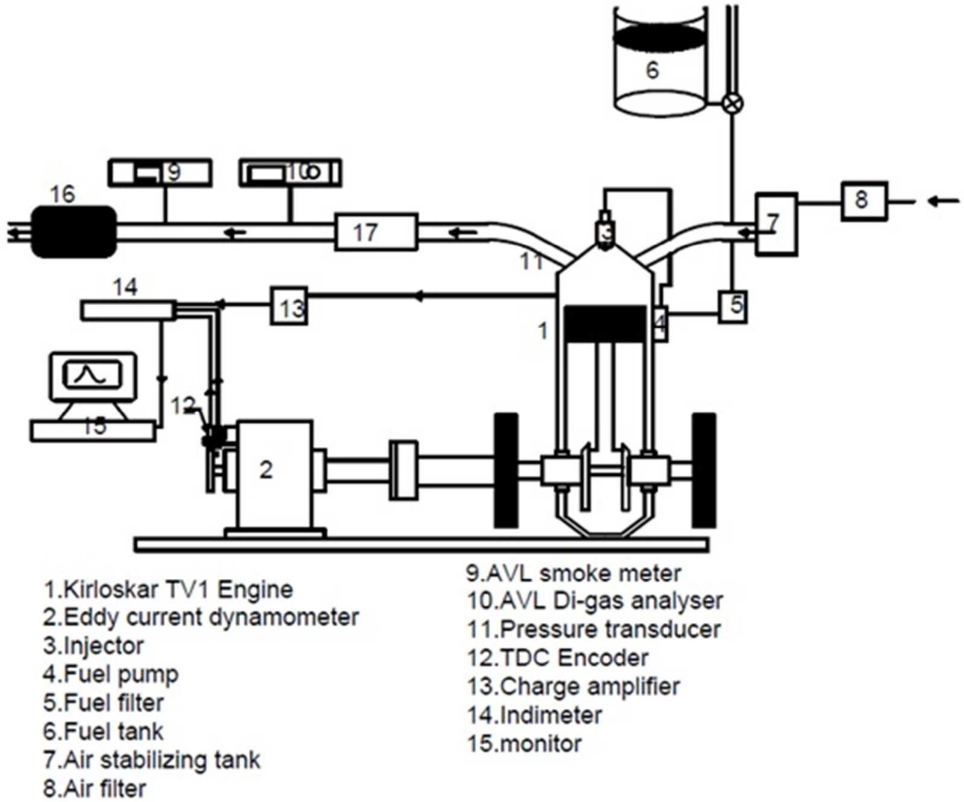

Fig.1 Schematic Diagram of the Experimental Set Up

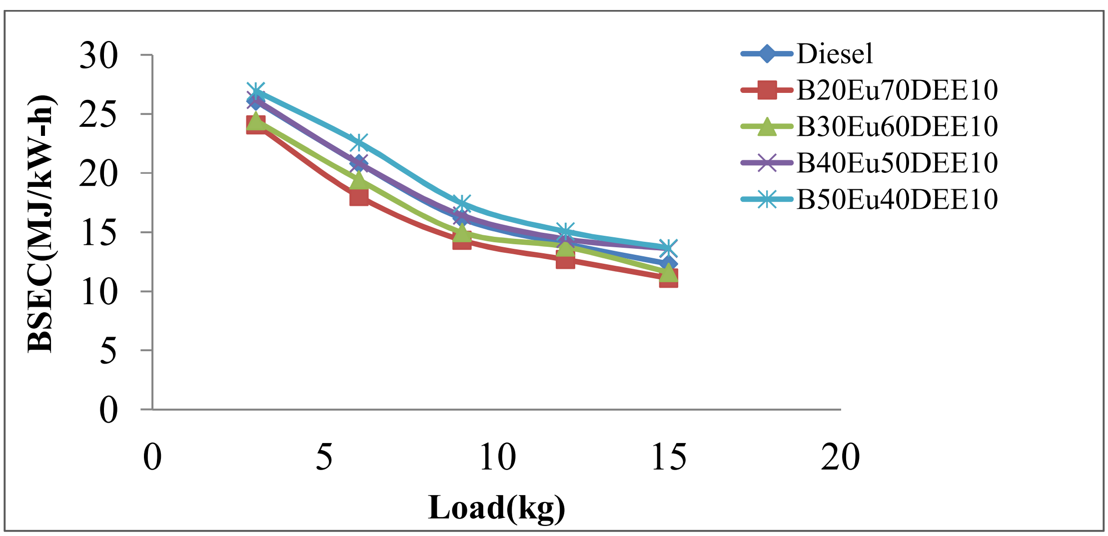

Fig.2. variation of Brake specific energy consumption versus load

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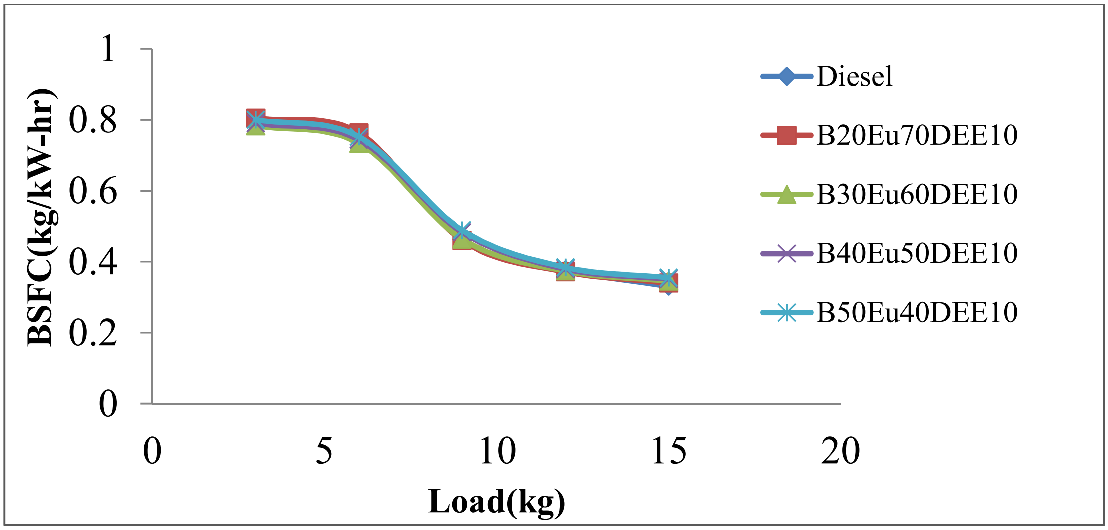

Fig.3. variation of Brake specific Fuel consumption versus load

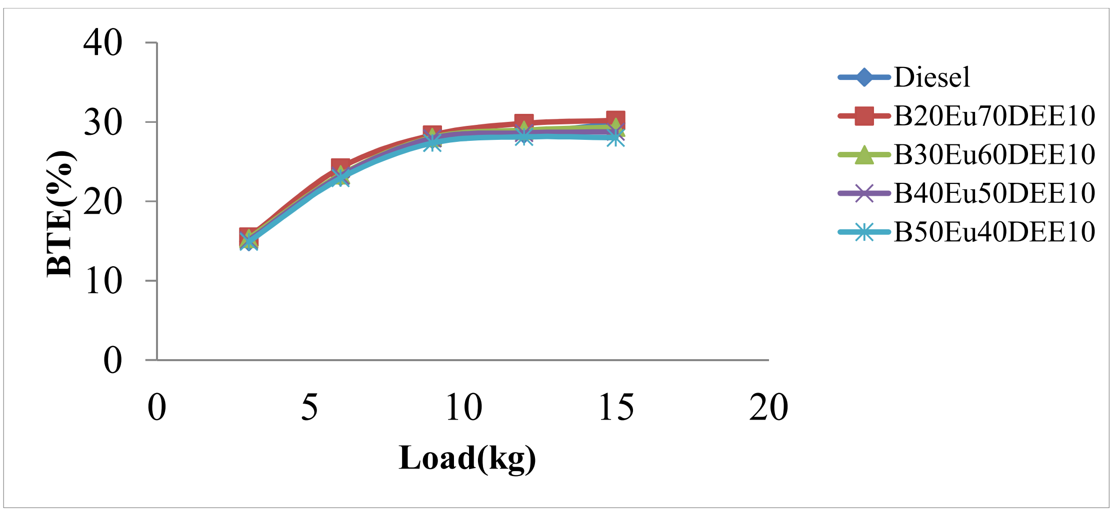

Fig.4. Variation of brake thermal efficiency versus load

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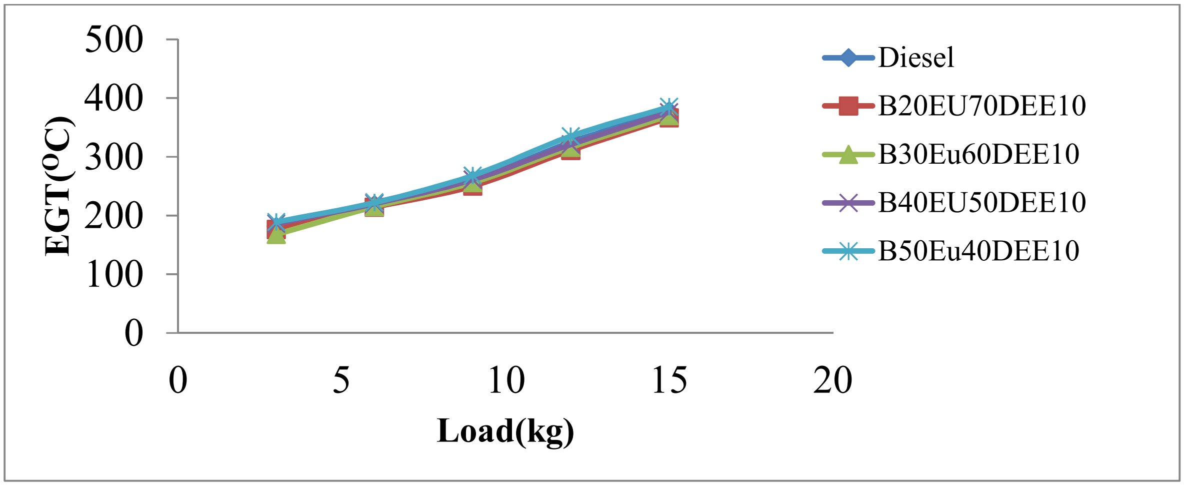

Fig.5. Variation of exhaust gas temperature versus load

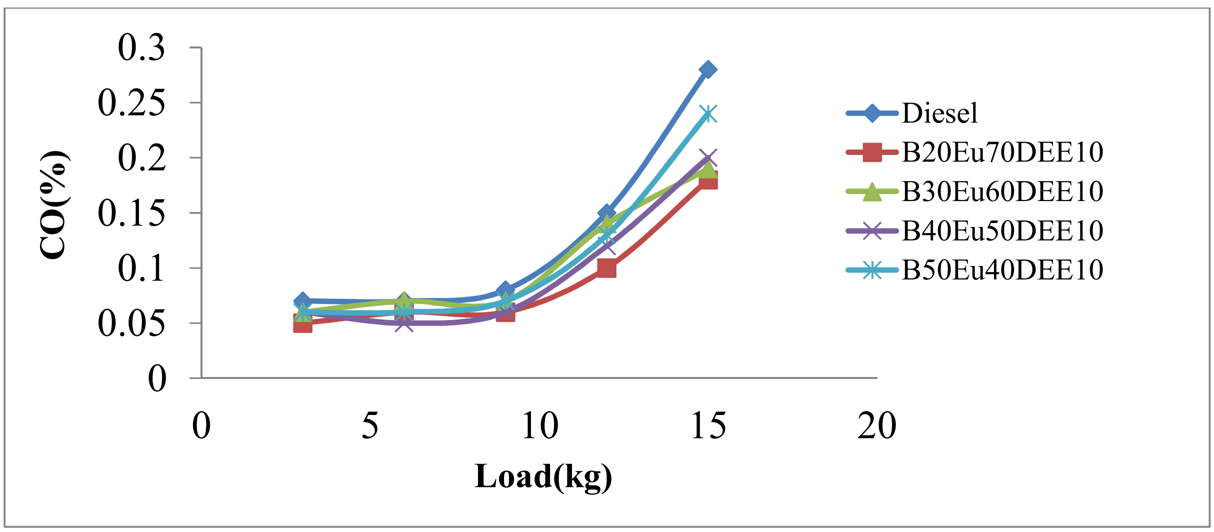

Fig.6. Variation of carbon monoxide emission versus load

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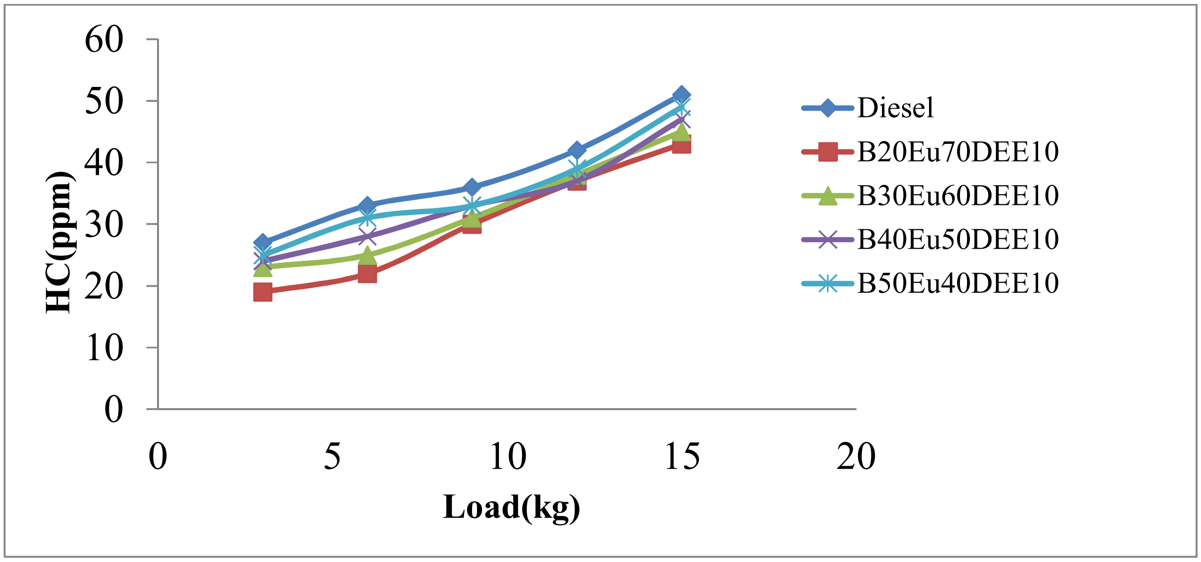

Fig.7. Variation of hydrocarbon emission versus load

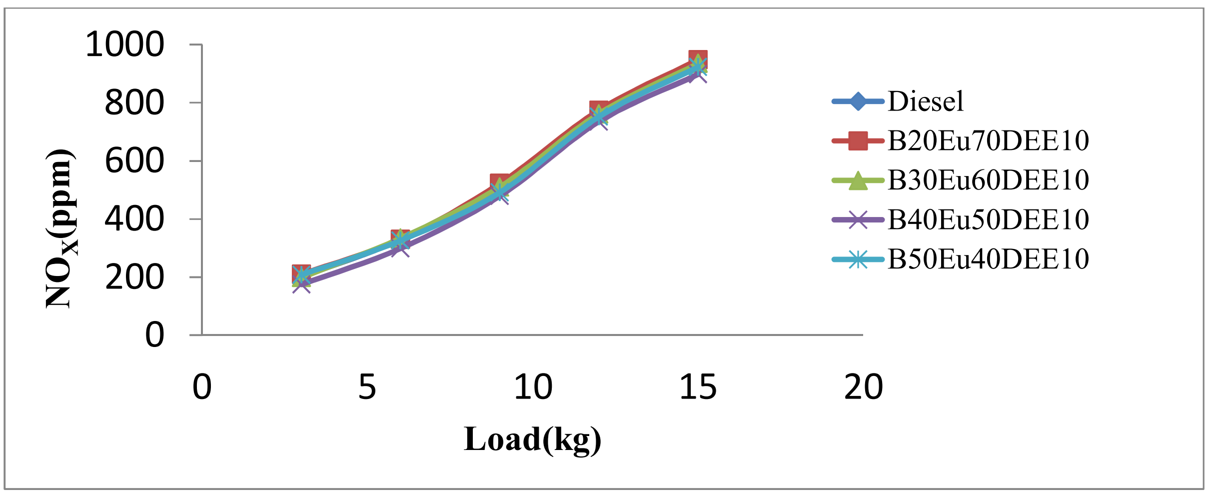

Fig.8. Variation of oxides of nitrogen emission versus load

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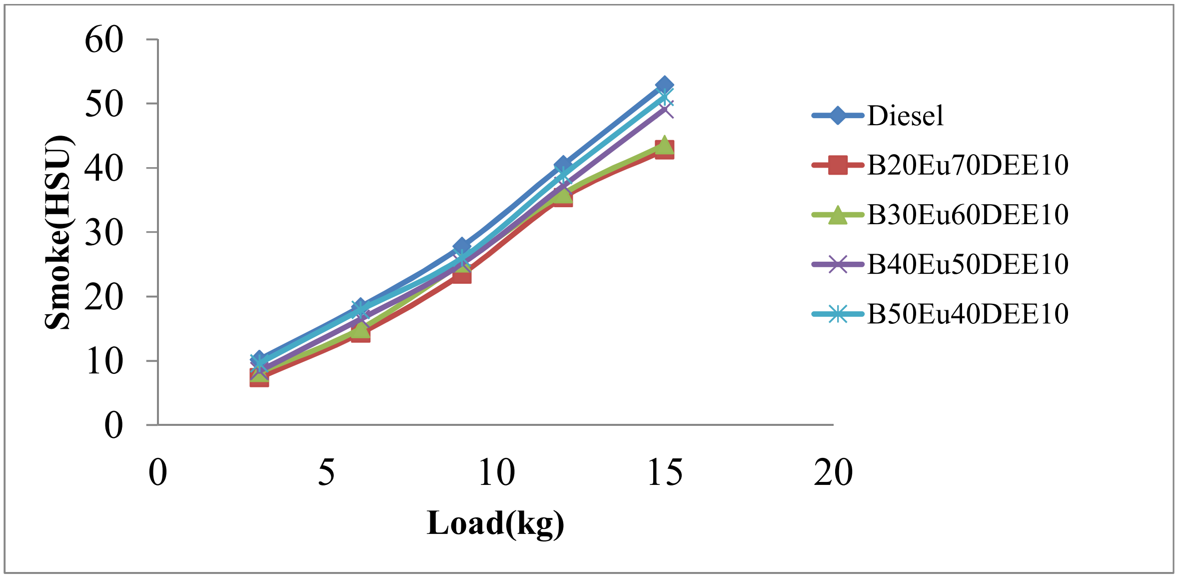

Fig.9. Variation of smoke emission versus load

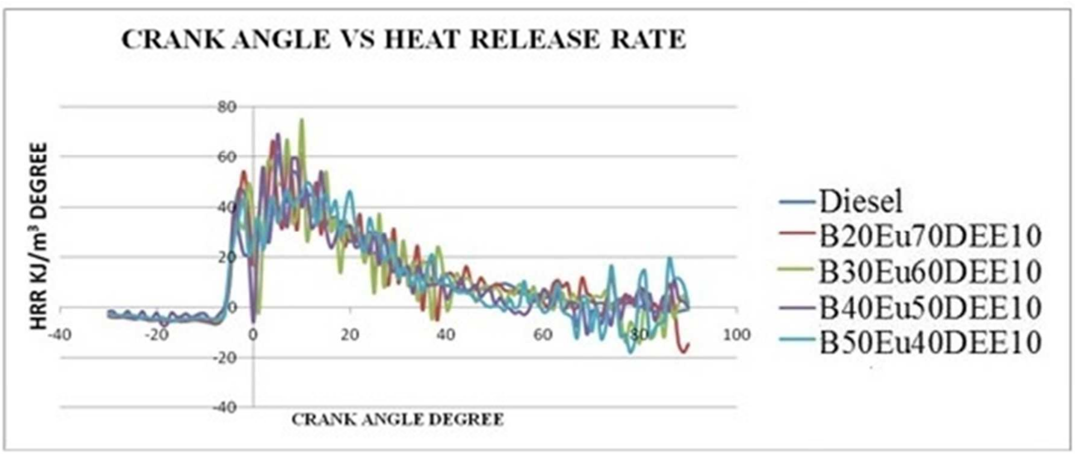

Fig 10: Variation of crank angle with heat release rate

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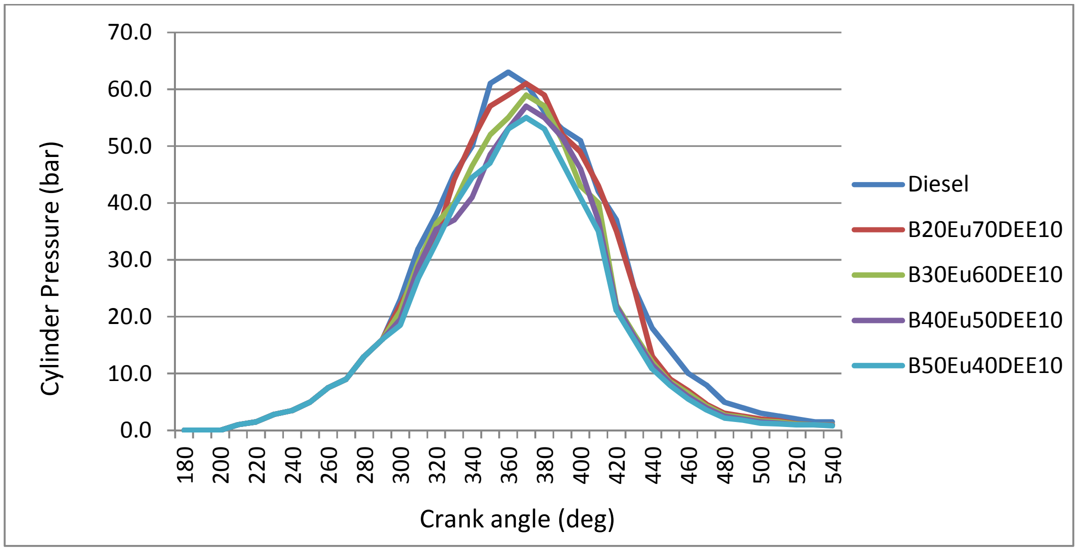

Fig 11: Variation of crank angle with cylinder pressure

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Table 1 Specification of the engine.

DETAILS	SPECIFICATION
Type	Four stroke, Kirloskar make, compression ignition, direct injection, and water Cooled.
Rated power& speed	5.2kW& 1500 rpm
Number of cylinder	Single cylinder
Compression ratio	17.5:1
Bore& stroke	87.5mm & 110mm
Method of loading	Eddy current dynamometer
Dynamometer arm length	0.185m
Type of injection	Mechanical pump-nozzle injection
Inlet valve opening	4.5°before TDC
Inlet valve closing	35.55°after TDC
Exhaust valve opening	35.55°before BDC
Exhaust valve closing	4.5°after TDC
Injection timing	23°before TDC
Injection pressure	220 bar
Lubrication oil	SAE 40

Table 2Technical specification of exhaust gas analyzer.

Gaseous components	Range	Accuracy	Resolution
CO	0-10%vol	0.06%vol	0.01%vol
CO_2	0-20%vol	0.30%vol	0.1%vol
HC	0-2000ppm	4ppm	1ppm
O_2	0-22%vol	0.10%vol	0.01%vol
NO	0-5000ppm	25ppm	1ppm

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Table 3-List of instruments and their accuracy and percentage uncertainties.

Measurement	Type &Manufacturer	Measurement technique	Accuracy (%)	uncertainty
Load	Strain gauge, SensotronicsSanmar	Load cell	±10 N	±0.2
Speed	Kubler,Germany	Magneticpickup principle	±10rpm	±0.1
Fuel flow measurement	Differential pressure transmitter	Volumetric measurement	±0.1cc	±1
CO	AVL exhaust gas analyser, Austria	NDIR technique	±0.02%	±0.2
HC	AVL exhaust gas analyser, Austria	NDIR technique	±0.03%	±0.1
NO_X	AVL exhaust gas analyser, Austria	NDIR technique	±12ppm	±0.2
Smoke	AVL smoke meter	opacimeter	±1HSU	±1
EGT indicator	Make Wika,	Thermocouple	$\pm 1^{O}C$	±0.15
Pressure Pick up	PCB, piezotronics	Magnetic pickup principle	±0.1 kg	±0.1
Crank angle encoder	Kubler,Germany	Magnetic pickup principle	±1 deg	±0.2

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Table 4-Properties of test fuels.

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

Table 5-Properties of fuel blends.

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

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