Hariram et al. 2018. *Int. J. Vehicle Structures & Systems*, 10(6), 443-452
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.10.6.13

International Journal of Vehicle Structures & Systems
Available online at www.maftree.org/eja

Production of Biodiesel from Eucalyptus Tereticornis and its Effect on Combustion, Performance and Emission Characteristics of CI Engines

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ABSTRACT:

In the present investigation, bio-oil from Eucalyptus teriticornisis is extracted through steam distillation process. The effect of esterified bio-oil is analysed in a single cylinder compression ignition engine. For this purpose, Eucalyptus biodiesel is prepared by transesterification process with methanol and NaOH as catalyst under variable parameters. The performance, combustion and emission features of a four stroke diesel engine were investigated using methyl ester of eucalyptus biodiesel (EBD100) and its blend with 50% diesel (D50-EBD50). The test outcome reveals that there is marginal increase in brake thermal efficiency and slight drop in brake specific fuel consumption for biodiesel fuel when compared to that of mineral diesel fuel. The use of this biodiesel resulted in decreased emission of Hydrocarbons and Carbon monoxide and higher emission of Nitrogen oxide and Carbon dioxide at part loads. EBD100 exhibits similar heat release rate and lower in-cylinder pressure compared to that of the diesel fuel at same loads.

KEYWORDS:

Biodiesel; Transesterification; Combustion; Eucalyptus tereticornis; Emission

CITATION:

V. Hariram, S. Seralathan, V. Paulson, R. Prakash and T.M. Premkumar. 2018. Production of Biodiesel from Eucalyptus tereticornis and its Effect on Combustion, Performance and Emission Characteristics of CI Engines, *Int. J. Vehicle Structures & Systems*, 10(6), 443-452. doi:10.4273/ijvss.10.6.13.

1. Introduction

Vitality is a standout amongst the hugest contributions for development of all segments counting horticultural, modern administrations and transport segments. Vitality has been at the inside phase of national and worldwide monetary improvement since quite a few years. The interest for vitality, around the globe is expanding exponentially, particularly the interest for oil based vitality [1]. Oil inferred fills, really, surpasses the request of some other energizes or vitality assets. The world utilization for oil and other fluid fuel will develop from 85 million barrels/day in 2006 to 107 million barrels/day in 2030. Under these development presumptions, around half of the world's aggregate assets would be depleted by 2030. The majority of the power in enterprises and transportation is gotten from oil and coal. Exceptional specify is required for autos where all of the energies for ignition motor today are gotten from oil, a non in-exhaustible wellspring of vitality, which is nearing its end at a phenomenal pace.

The globe today utilizes around 147 trillion kWh of vitality which is relied upon to ascend in the coming future. The normal ascent in the planet utilization of vitality up to 2030 [2, 3]. A noteworthy piece of this ascent will be expected to the creating nations, which will undoubtedly develop significantly. The legislature of India has planned an eager National Biodiesel Mission to meet 20 for every penny of the nation's diesel necessities by 2016-2017 [4]. Rapid decrease in petroleum resources such as natural gas, crude oil and coal. Along with escalated demand and pricing of petroleum products urged the researches to identify alternative sources of energy. It is estimated that around 6.5 billion people across the globe use more than 500 million transportation vehicles raised the energy requirement to greater heights. At this juncture, Vegetable based biofuels gained a Promise able position as an alternate source of energy. The main reason is being the bio-degradability, Non-toxicity, Sustainability, Local availability and cost effectiveness. Due to their higher calorific value and Cetane number on par with diesel fuel, they can be used either directly or in trans-esterified form in a compression ignition engine.

Lower volatility and Higher viscosity of straight vegetable oil reduced the brake thermal efficiency (BTE) drastically which resulted in higher exhaust emission. This can be overcome by converting the tri-glycerides of the vegetable oil into methyl ester and glycerol there by reducing its viscosity and enhancing the combustible properties of the fuel [4-8]. Riva et al. [9] studied the possible ways for enhancing the biodiesel yield through transesterification process; enhancing the transesterification reaction by ultra sound based surface contact reactions produced better results. Hariram and Rajan [10] extracted oil from Nicotianatabacum seed through soxhlet apparatus using n-hexane solvent. Two state transesterification processes was adopted due to FFA content. 1:6 methanol to oil molar ratio, 60°C reaction temperatures and 100 minutes reaction duration

along with NaOH catalyst, yielded 92% of biodiesel. Zhang et al [11] developed an optimized extraction process method to convert waste tobacco leaves into bio-oil. They showed SE-SD combination method has higher yield of bio-oil of about 95% under an optimized process variables of temperature 41°C, liquid solid ratio 6.27ml/g and process time up to 5 hours. Devan and Mahalakshmi [12] studied the overall advantages of CI engine using various proportion of paradise oil and eucalyptus oil blend. At optimized proportion of Me50-Eu50 smoke and CO emissions have reduced to higher extent at full loads. Also validated the efficiency of comparing Me-Eu blends and diesel.

Srinivas et al [13] studied the performance and emission characteristics of VCR engine by following combination of palm kernel oil and eucalyptus oil. Study was carried out under the factors such as change in injection pressure and change in compression ratio at various compositions. And showed reduction in emission, with the increase of pressure and compression ratio. Takeda et al [14] experimented on the utilization of orange oil and eucalyptus oil in small passenger cars. They have reported that the oil obtained from leaves of eucalyptus tree by means of stream distillation, contained 1.8-cineole as the main ingredient. Tarabet et al [15] studied the combustion, performance, and exhaust emissions characteristics of spark-ignition SI engines at various compression ratio orange and eucalyptus oil as alternative fuels. Test was conducted using 20% volume of eucalyptus and orange oil which were blended separately with SI engine fuel. The results indicated that the performance of the fuel blends was much better than that of gasoline fuel at higher compression ratio. CO and HC emission levels in the exhaust gas were considerably lower with fuel blends at both the compression ratios. Senthil et al [16] conducted the experiment to study the performance, emission and combustion characteristics of a diesel engine using biodiesel-eucalyptus oil blends along with the additional 10% DEE. It is concluded that B20-Eu70-DEE10 showed better performance along with reduced exhaust emissions when compared to that of mineral diesel.

Datta et al [17] studied the CI engine performance and emission characteristics when fuelled with the mixture of jatropa biodiesel and pure diesel. He showed that when higher percentage of biodiesel is used in the blend the BTE decreases but increases the BSFC and also increases the emission rate. He found that the overall efficiency is slightly higher for pure diesel compared to the pure biodiesel. Ambarish and Bijan [18] used the numerical simulation software diesel RK to study the performance, combustion and emission characteristics of the diesel engine that fuelled with the blends of diesel and palm stearin biodiesel and alcohols. All the parameters of combustion, emission and performance expect BSFC has shown improvement when alcohol is added.

Atlin et al [19] used mustard oil biodiesel as an alternate fuel in the diesel engine and compared the performance, combustion and emission of biodiesel blends with diesel fuel under different loads. He proved that the less percentage of biodiesel in the blend show better efficiency at part loads and shows that emission of HC and CO are lower for biodiesel fuel where NO_x is poor for same biodiesel. The cylinder pressure for biodiesel fuel equal with the pure diesel. Silambarasan et al [20] studied the performance, emission and combustion characteristics of CI engine using Eucalyptus oil-annona biodiesel blend in various proportions and compared to the pure diesel. They found that the blend of 50% annona and 50% eucalyptus oil showed better performance than the diesel and he suggested the only drawback these blend is slight increase in the nitrous oxide emission compared to the pure diesel.

2. Materials and methods

2.1. Bio-oil extraction

In the present investigation leaves of eucalyptus tereticornis were used to extract bio-oil. Steam distillation was adopted for separation of bio-oil. This process contains a heating container filled with water bath, round bottomed flask, a coolant chamber and Erlenmeyer flask. Water in the bath allowed to heat above 120°C. It is converted into steam through an outlet tube the superheated steam reaches a container filled with processed leaves of eucalyptus tereticornis. Reaction takes place between water vapour and processed leaves extracting bio-oil. The condensation tube carries the complex form of bio-oil in vapour state and directed into the cooling chamber. Liquid eucalyptus bio-oil is collected at the end of the condensation chamber Erlenmeyer flask as shown in Fig. 1. Further the left out eucalyptus leaves is allowed to react with n-hexane solvent in a closed chamber for 24 hours which was followed by mechanical expulsion for the removal of remaining bio-oil. This process yielded 62% oil from the leaves of eucalyptus tereticornis [11].

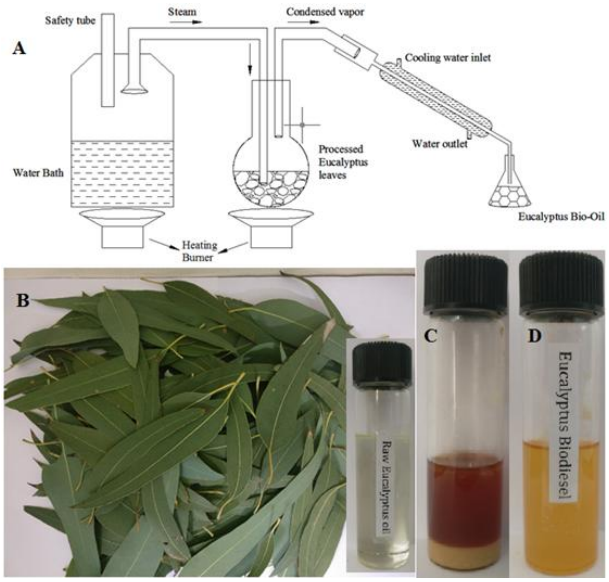

Fig. 1: (A) Steam distillation process of eucalyptus leaves, (B) Eucalyptus leaves, (C) Glycerol separation, (D) Eucalyptus biodiesel

2.2. Transesterification

The titration process with phenolphthalein solution showed the free fatty acid content as 1.52 in the extracted bio-oil. Literature suggested single stage

transesterification process is an efficient methodology to reduce the kinematic viscosity of any bio-oil with FFA content less than 2%. Likewise, in the present investigation base catalyst transesterification was adopted to esterify the derived bio-oil using sodium hydroxide and methanol solution. Transesterification process was carried out in a flat bottomed flask arranged with a magnetic stirrer and a thermocouple for varying the reaction temperature. 99% pure methanol was thoroughly mixed with 1.5% by weight of sodium hydroxide to form sodium methoxide solution. 500ml of eucalyptus tereticornis oil was heated up to 70°C in round bottom jar.

An RTD type thermometer with a cut out relay was positioned to maintain the reacting environment between 55°C and 75°C. A transesterification was initiated by mixing the bio-oil with Sodium-methoxide solution taken in a separate round bottom flask with continuous agitation at 400 to 450 rpm through a magnetic stirrer for 180 minutes. The products of the reaction was then transferred into a separating funnel and allowed to settle down for 24 hours. During this period a ring formation took placed characterizing eucalyptus tereticornis biodiesel as the upper layer and glycerol as the lower layer. The glycerol was very removed carefully from the bottom layer through the knob opening. Distilled warm water was mixed with methyl esters for the removal of impurities which included the catalyst, un-reacted oil and methanol in a separating funnel. Gravity separation process for 4 hours expelled the distilled water along with the impurities [10].

2.3. Physio-chemical properties

Biodiesel from eucalyptus tereticornis was subjected to various analyses under ASTM standards to identify its Physio-chemical properties. Mettler Toledo densitometer (ASTM-D792 and ASTM-D1963) was used to measure the density and specific gravity at 25°C and identified as 904kg/m^3 and 0.891gm/cm^3 respectively. Redwood viscometer under ASTM D445 measures the kinematic viscosity at 40°C as 2.7mm^2/sec. Hamco Bomb calorimeter (ASTM D5865) measured the calorific value as Eucalyptus tereticornis as 40.45MJ/kg. ASTM D3278 method was adopted to identify flash point using Abel flash point apparatus and found to be 101°C.

Table 1: Physio-chemical properties

Properties	Units	Diesel	Bio-oil	Biodiesel	D50-BD50
Density	kg/m^3	840	1048	905	1015
Viscosity	mm^2/s	2.6	3.8	2.8	2.54
Specific gravity	g/cm3		0.882	0.893	0.854
Flash point	°C	75	116	105	47
Fire point	°C	78	120	108	50
Calorific value	kJ/kg	42500	-	41930	-
FFA	%	--	1.5	1.2	--

Titration method was used along with phenolphthalein solution to measure the free fatty acid in the eucalyptus tereticornis biodiesel. The acid value was drastically reduced 2.02 mg KOH/gm. to 0.25mg KOH/gm. by ASTM D1980 method. The Cetane number was identified as 53 by ASTM D613. The physio-chemical properties of eucalyptus tereticornis oil and its biodiesel are given in the Table 1.

3. Experimental setup

Fig. 2 shows the illustrative outline of the experimental test bench of four stroke diesel engine. The engine used was Kirloskar (Model no: MMM1MET-201EL). It consists of fuel tanks with filter controlled by fuel switching system. Consumption of fuel and air flow rate is measured using optical sensor and differential pressure transducer respectively. Sensor whose probe is directly connected to Data Acquisition card which reads the output and get displayed in system connected with it. Engine gets coupled with eddy current dynamometer to vary the load using controller. A piezoelectric transducer is installed to measure the combustion pressure. AVL exhaust gas analyser and AVL smoke meter were used to determine the exhaust gas emission parameters and intensity of smoke opacity respectively whose value get displayed in the digital readings provided for that. Water is used as the coolant for this engine. The detailed engine specifications are displayed in Table 2.

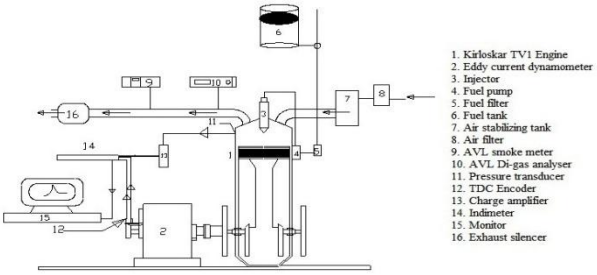

Fig. 2: Engine schematic diagram

Table 2: Test engine specification

Parameter	Description or value
Make	Kirloskar TV1
Type	4 stroke, single cylinder, CI engine
Cubic capacity (ltr)	0.661 ltr
Rated speed (rpm)	1500rpm
Stroke (mm)	110mm
Bore (mm)	87.5mm
Start of injection (BDTC)	23
Type of fuel injection	Direct
Cylinder pressure transducer	0-345.5 bar
Connecting rod length	234mm
Air flow transmitter	(-) 250-0 mm WC
Power rating (HP)	5hp (3.7 kw)
Compression ratio	17.5:1
Cooling	Water cooled
Sensor signal range (input for interface)	1-5 V

Initially the experimental trials were conducted on the engine with diesel to identify the optimum cooling rate which was followed by conducting the experiments with mineral diesel and other test fuel blends by maintaining this optimum rate of engine cooling. The performance tests on the engine was conducted one by one with diesel and biodiesel blends (D100, D50 EBD50 and EBD100) and compared. The experiments replicated for 5 times and average values of the readings are

recorded. Each and every time, when the biodiesel or blend proportion is changed the engine was run with diesel fuel for few minutes to wash the fuel lines. The performance of the engine was evaluated based on BSFC, BTE, Exhaust gas temperature along with HC, CO, NO_x and smoke emissions.

4. Result and discussions

4.1. Transesterification

The yield of biodiesel with sodium hydroxide as catalyst under different operational parameters like reaction duration, reaction temperature, catalyst concentration and molar ratio were carried out. Fig. 3 illustrates the effect of reaction duration on yield of biodiesel at 55°C, 65°C and 75°C reaction temperature. Few literatures evidenced that 75% of transesterification process was completed during the initial 8 minutes of reaction duration and triglyceride conversion to fatty acid methyl ester reached above 95% during 70-80 minutes of reaction period. In the present experimental study the reaction duration was varied between 15-100 minutes at various reacting temperatures. At 55°C reacting temperature maximum yield of biodiesel obtained was 86% at 90 minutes reaction duration. Increase in reaction temperature up to 65°C enhanced the conversion rate of triglyceride into FAMEs up to 92% at 82 minutes. Further increase in temperature up to 75°C showed a conversion efficiency of 82% at 70 minutes reaction duration which is much earlier, but prolonging the reaction duration had a negative impact on the conversion efficiency. This may be due to higher saponification rate of the triglycerides at elevated temperature and due to vaporization of methanol [4, 21].

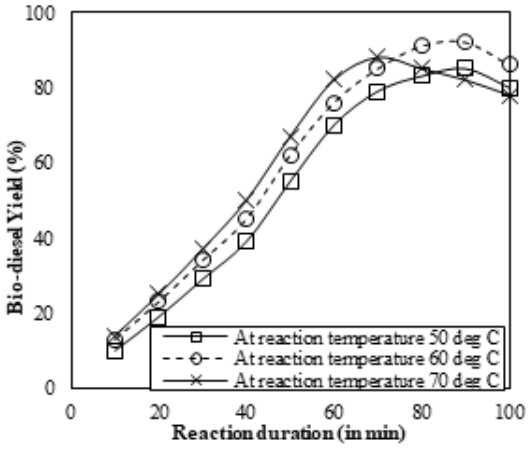

Fig. 3: Biodiesel yield vs. Reaction duration

Fig. 4 depicts the effect of NaOH concentration on biodiesel yield at various reacting temperature. It can be noticed that the catalyst concentration between 1.2% and 2.2% favoured the conversion of triglycerides into FAME's. During this experimental study reaction duration of 90 minutes and agitation speed of 400-450 rpm was maintained with variations in reaction temperature between 55°C and 75°C. It can be noticed that the reaction temperature had minimal effect on the transesterification efficiency with variable catalyst concentration. However, the catalyst concentration of 1.8% by weight at 65°C yielded 93% of biodiesel increase in concentration of NaOH beyond 1.8% showed negative improvement in the transesterification process due to soapy formation. A similar trend was observed at 75°C reaction temperature during which 90% of biodiesel was obtained at 1.76% by weight of NaOH. Sludge formation was seen during this process when NaOH concentration was increased beyond 2%. At lower reaction temperature (55°C) the conversion efficiency was very similar with biodiesel yield of 88%. Hence 1.8% of NaOH at 65°C and 450 rpm agitation speed was found to be optimum in the conversion of eucalyptus tereticornis into its biodiesel.

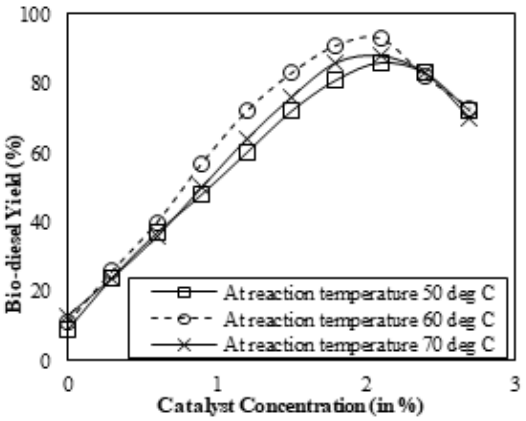

Fig. 4: Biodiesel yield vs. Catalyst concentration

Fig. 5 illustrates the effect of molar ratio on yield of biodiesel at reaction temperatures of 55°C, 65°C and 75°C. Molar ratio is considered to be the most influential parameter in converting the triglycerides into fatty acid methyl ester. Methanol to oil molar ratio between 2:1 and 10:1 at different reacting temperatures were investigated in the present study.

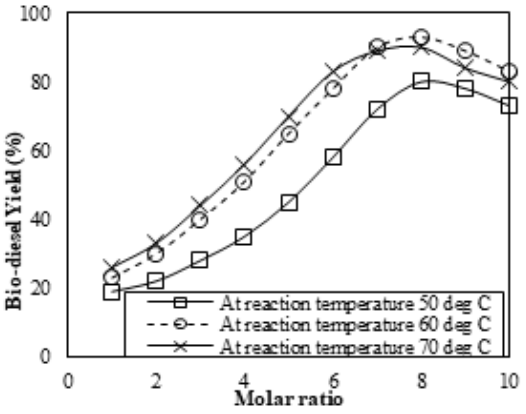

Fig.5: Biodiesel yield vs. Molar ratio

At 55°C methanol to oil molar ratio of 8:1 yielded 82% of biodiesel, increase in reaction temperature up to 65°C improved the biodiesel yield up to 94%. Further increase in reaction temperature up to 75°C exhibited a marginal decrease in the biodiesel yield, as seen in Fig. 5, which may be due to evaporation of methanol at incremented temperature. However, excess methanol favoured increase in yield of biodiesel; the catalyst concentration was very sensitive during the transesterification process. The kinematic viscosity of

derived biodiesel at various molar ratios were identified and found to be within ASTM standards.

4.2. Combustion characteristics

Fig. 6 shows the variation of in-cylinder pressure with different crank angle (CA) under various loads for mineral diesel (D100), D50 EBD50 and EBD100. It can be noticed that the start of ignition is delayed by 4-5 °CA for D50 EBD50 and EBD100 when compared with mineral diesel D100 up to 100% load. This ignition delay is due to the presence of carbon dioxide. The combustion rate is the reason for the peak pressure at no load and 25% which is forced by the fuel intake components. The peak pressure for D100, D50 EBD50 and EBD100 are 62.62 bar, 57.43 bar and 58.94 bar at 371°CA, 370°CA and 372°CA at 100% load respectively. The reason behind the lower in-cylinder pressure may be due to oxygen content in the biodiesel and its blends. Combustion is shorter for biodiesel than the mineral diesel due to consequences created by its properties like Cetane number and low air. The peak cylinder pressure for D100, D50 EBD50 and EBD100 at no load conditions are 46.23 bar, 37.78 bar and 35.90 bar at 368°CA, 371°CA and 371°CA respectively [22]. At initial stage of combustion the pressure for biodiesel is lower than the mineral diesel which may be due to more delay. The peak cylinder pressure for D100, D50 EBD50 and EBD100 at 25% load condition are 46.23 bar, 43.48 bar and 42.60 bar at 368°CA, 371°CA and 371°CA respectively.

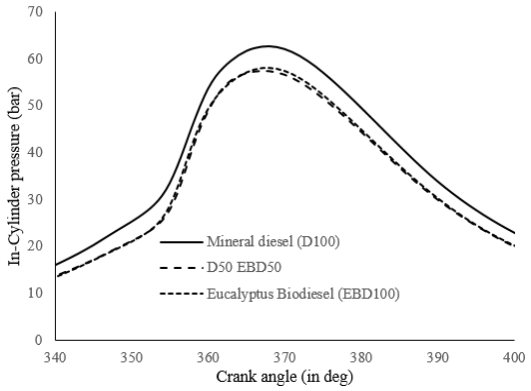

Fig. 6: In-cylinder pressure vs. Crank angle at full load

When the load increases combustion get improved which also increases the peak pressure for biodiesel, due to some major properties of biodiesel like oxygen content and Cetane number. The peak cylinder pressure for D100, D50 EBD50 and EBD100 at 50% load condition are 55.41 bar, 49 bar and 47.95 bar at 367°CA, 367°CA and 368°CA respectively. Every stage show low peak pressure for biodiesel which is even less than the biodiesel blended with diesel which may due to more oxygen content. The peak cylinder pressure for D100, D50 EBD50 and EBD100 at 75% load condition are 59.85 bar, 53.41 bar and 53.12 bar at 368°CA, 368°CA and 367°CA respectively. When the load keeps on added the level of peak pressure for biodiesel equalling with the other fuel mixture due to it work load. The peak cylinder pressure for D100, D50 EBD50 and EBD100 at full load condition are 62.62 bar, 57.43 bar and 58.14 bar at 368°CA, 367°CA and 368°CA respectively. At the final stage the biodiesel peak pressure records higher than its blended mixture which may be due to before combustion effect and temperature.

Fig. 7 shows the distinct of net heat release with different crank angle (CA) under various loads for mineral diesel (D100), D50 EBD50 and EBD100. The net heat release rate is directly depending on the rate of combustion, ignition delay period and formation of fuel mixture. At initial load conditions the ignition delay period is longer which forces the accumulation of fuel. Due to this the rate of heat release is higher for EBD100 compared to mineral diesel. The highest heat release rate for D100, D50 EBD50 and EBD100 occurs at 100% load condition are 41.06 kJ, 40.54 kJ and 43.85kJ respectively. At full load condition the heat release occur quickly for mineral diesel than the biodiesel because of oxygen content. The heat release rate for loads 25%, 50% and 75% are also observed and plotted with crank angle. The peak net heat release rates for D100, D50 EBD50 and EBD100 at no load conditions are 19.43 kJ, 17.58 kJ and 25.67 kJ at 360°CA, 362°CA and 360°CA respectively. At initial stage ignition delay is longer which forces accumulation of fuel. Hence the biodiesel fuel has more heat release than the mineral diesel [23].

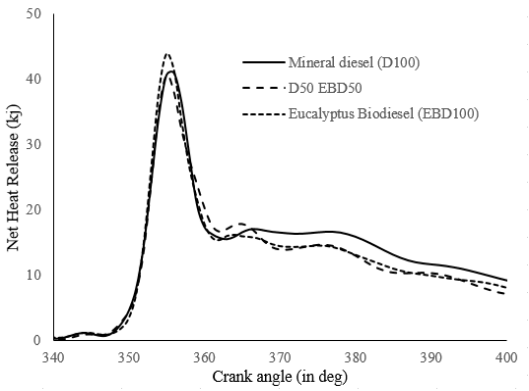

Fig. 7: Net heat release vs. Crank angle at full load

The peak net heat release rates for D100, D50 EBD50 and EBD100 at 25% load conditions are 25.30 kJ, 26.13 kJ and 25.31 kJ at 358°CA, 360°CA and 360°CA respectively. When the load increases accumulation gets cleared and biodiesel fuel gets heat release similar to the mineral diesel. The peak net heat release rates for D100, D50 EBD50 and EBD100 at 50% load condition are 35.03 kJ, 34.40 kJ and 30.55 kJ at 357°CA, 358°CA and 358°CA respectively. If further the load is increased the heat release rate is even better for biodiesel which is lower than the mineral diesel and the blended mixture. The peak net heat release rates for D100, D50 EBD50 and EBD100 at 75%load condition are 39.40 kJ, 41.26 kJ and 41.40 kJ at 356°CA, 356°CA and 356°CA respectively. At larger loads the heat release occurs little quickly for mineral diesel than the biodiesel. The peak net heat release rates for D100, D50 EBD50 and EBD100 at full load conditions are 41.06 kJ, 40.54 kJ and 43.85 kJ at 356°CA, 355°CA and 355°CA respectively. The slower attaining of heat release for biodiesel is due to the oxygen content in the biodiesel.

The peak cumulative heat release rates (Fig. 8) for D100, D50 EBD50 and EBD100 at no load conditions are 0.54 kJ, 0.52 kJ and 0.58 kJ at 421°CA, 429°CA and 412°CA respectively. At initial stage the cumulative heat release rate is higher for the biodiesel than the mineral diesel due to the oxygen content and less temperature. The peak Cumulative heat release rates for D100, D50 EBD50 and EBD100 at 25% load condition are 0.69 kJ, 0.64 kJ and 0.70 kJ at 421°CA, 427°CA and 439°CA respectively. When some part of load are added the cumulative heat release for biodiesel shows some improvement by equalling with mineral diesel as shown in Fig. 8. The peak cumulative heat release rates for D100, D50 EBD50 and EBD100 at 50% load condition are 0.73 kJ, 0.78 kJ and 0.83 kJ at 419°CA, 430°CA and 438°CA respectively. It gets added stage by stage and shows higher rate of heat release for each successive loads and the biodiesel fuel shows larger effect than the other fuel mixtures. The peak cumulative heat release rates for D100, D50 EBD50 and EBD100 at 75% load condition are 0.85 kJ, 0.94 kJ and 0.97 kJ at 421°CA, 432°CA and 437°CA respectively. Heat get added in the cumulative heat release rate from the continuation of the before stage and shows maximum rate of heat release. The peak cumulative heat release rates for D100, D50 EBD50 and EBD100 at full load conditions are 0.90 kJ, 1.08 kJ and 1.11 kJ at 422°CA, 438°CA and 442°CA respectively. When the loads keeps on increasing, the cumulative heat release rate also get increased and biodiesel being the large production of heat when compared to the mineral diesel.

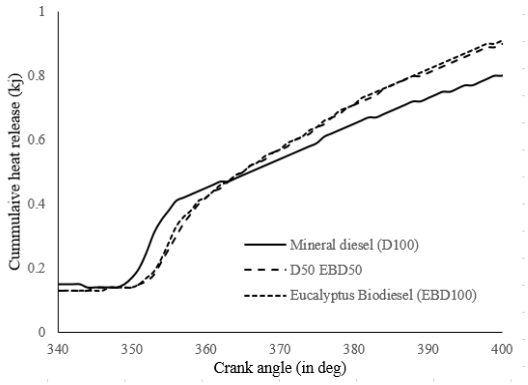

Fig. 8: Cumulative heat release vs. Crank angle at full load

4.3. Performance characteristics

Fig. 9 shows the BTE under various loads for mineral diesel (D100), D50 EBD50 and EBD100. The BTE of EBD100 and D50 EBD50 show slightly higher than the D100. At full load EBD100 show lower BTE 19.85% which is due to low calorific value of biodiesel. BTE increases with increase in load for all mixture fuels and biodiesel has higher BTE than Mineral diesel because of its nature containing of oxygen which provides efficient burning. Hence its blend D50 EBD50 shows slightly higher BTE of about 24.51% which is the maximum out of all. The BTE for D100, D50 EBD50 and EBD100 at no load conditions are 4.82 %, 5.54% and 5.05 % respectively. At initial stage of the combustion itself biodiesel records slightly higher BTE than the diesel and its blend mixture also records higher than it, which may be mainly due to calorific value of the biodiesel. The BTE for D100, D50 EBD50 and EBD100 at 25% load condition are 10.51 %, 11.79% and 10.59 % respectively.

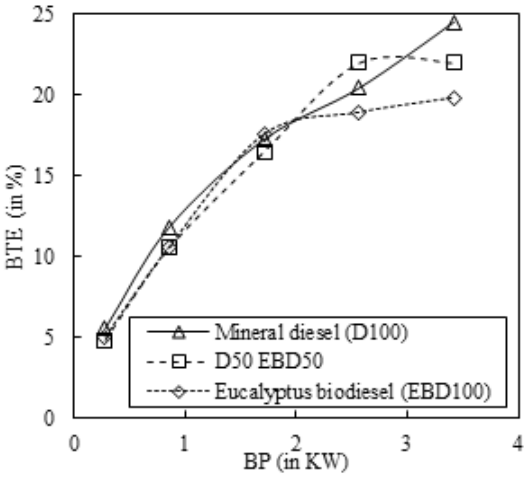

Fig. 9: BP vs. BTE

As the load increases, BTE also get increased and records equal ratio of reading as in the no load condition. The BTE for D100, D50 EBD50 and EBD100 at 50% load condition are 16.47 %, 17.24% and 17.58 % respectively. At half load blended mixture shows lower BTE than the biodiesel which is higher than all the mixture. The BTE for D100, D50 EBD50 and EBD100 at no load condition is 21.96%, 20.42% and 18.94 % respectively. When the loads go on increasing the efficiency get changes and BTE for biodiesel suddenly get decreased than the mineral diesel, due to the complete combustion with more loads. The BTE for D100, D50 EBD50 and EBD100 at no load condition are 21.96%, 24.51% and 19.84 % respectively. At final stage only a slight lower BTE for biodiesel then the mineral diesel whereas blended mixture shows good BTE which may be due to the effect both the mixture properties [24].

Fig. 10 shows the BSFC under various loads for mineral diesel (D100), D50 EBD50 and EBD100. BSFC is defined by the ratio of the total fuel consumption (TFC) to brake power (BP). From the graph, it is observed that all the fuel mixture shows higher BSFC up to moderate load which is due to poor conversion rate of fuel to work. Later, when the brake power increases the conversion rate is improved and shows lower BSFC of about 0.34 kg/kWhr for D50 EBD50 due to rich mixture. Comparison shows that at above 2 bar of BP the BSFC of EBD100 is higher than the mineral diesel (D100) of 0.453 and 0.385 kg/kWhr respectively which is mainly due to the lower calorific value of biodiesel. The BSFC for D100, D50 EBD50 and EBD100 at no load conditions are 1.75 kg/kWhr, 1.54 kg/kWhr and 1.69 kg/kWhr respectively. At initial stages the fuel consumption is always less due to no load condition because less power is required to work at this hence lower fuel is consumed.

The BSFC for D100, D50 EBD50 and EBD100 at 25% load condition is 0.80 kg/kWhr, 0.72 kg/kWhr and 0.81 kg/kWhr respectively. When the load is added the fuel consumption is higher for these small loads which are mainly due to poor conversion rate of fuel to work.

The BSFC for D100, D50 EBD50 and EBD100 at 50% load conditions is 0.51 kg/kWhr, 0.49 kg/kWhr and 0.48 kg/kWhr respectively. At the half stage it shows poor consumption due to same problem of poor conversion. The BSFC for D100, D50 EBD50 and EBD100 at 75% load conditions is 0.38 kg/kWhr, 0.41 kg/kWhr and 0.45 kg/kWhr respectively. There is slight improvement in the conversion rate of fuel to work. It shows slightly higher consumption for biodiesel compared to the mineral diesel. The BSFC for D100, D50 EBD50 and EBD100 at 100% load conditions are 0.38 kg/kWhr, 0.34 kg/kWhr and 0.43 kg/kWhr respectively. The improvement level in the conversion is increase due to complete combustion and useful amount of work is gained for little fuel consumption. Biodiesel shows slight improvement in the consumption.

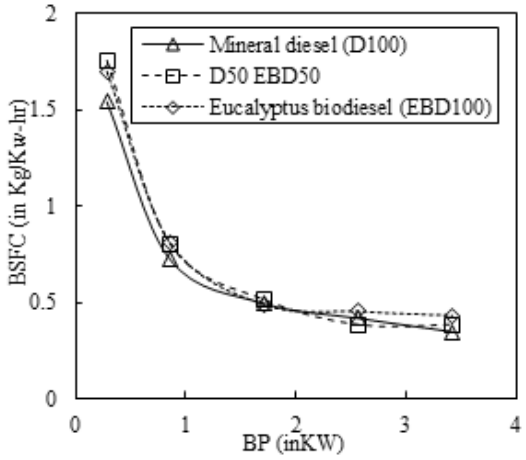

Fig. 10: BP vs. BSFC

Fig. 11 shows the exhaust gas temperature (EGT) under various loads for mineral diesel (D100), D50 EBD50 and EBD100. From the graph it is observed EGT increases with increase in the brake power. EGT for EBD100 records higher under all loads compared to D100 and D50 EBD50. D100 and D50 EBD50 show similar EGT with slight variation. The EGT values of D100, D50 EBD50 and EBD100 for full condition are 360°C, 369°C and 429°C respectively.

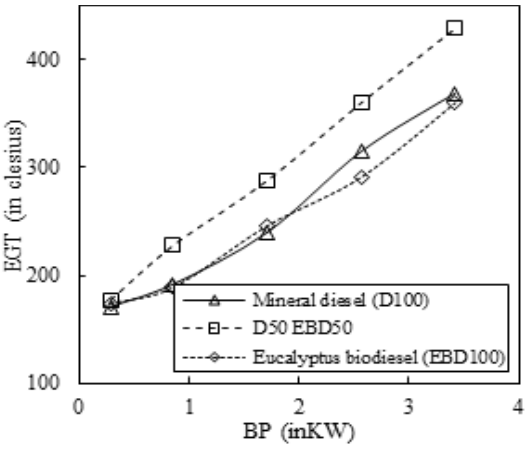

Fig. 11: BP vs. EGT

4.4. Emissions

Fig. 12 shows the emission of NO_x under various loads for mineral diesel (D100), D50 EBD50 and EBD100. The NO_x emissions are mainly influenced due to the higher contribution of the oxygen concentration and also with the combustion temperature, pressure and time. In every mixture blend the NO_x emission increases with increase in load above 60% compared to half loads which are due to the increased temperature of the combustion with end loads. Eucalyptus biodiesel EBD100 shows higher emission rate of about maximum of1400 ppm where as D100 and D50 EBD50 records maximum rate of 1100 ppm and 1220 ppm respectively. This is due to rapid combustion with higher Cetane number of the biodiesel. Eucalyptus biodiesel holds double bond which results a larger group of atoms that encourages causing NO_x emissions. The emission of nitrogen oxide for mineral diesel (D100), D50 EBD50 and EBD100 at load condition are 2 ppm, 60 ppm and 28 ppm respectively. The emission is very low for mineral diesel than other blends. This is because of starting stage and no load condition where the temperature is much low. The emission of nitrogen oxide for mineral diesel (D100), D50 EBD50 and EBD100 at 25% load condition are 108 ppm, 144 ppm and 337 ppm respectively.

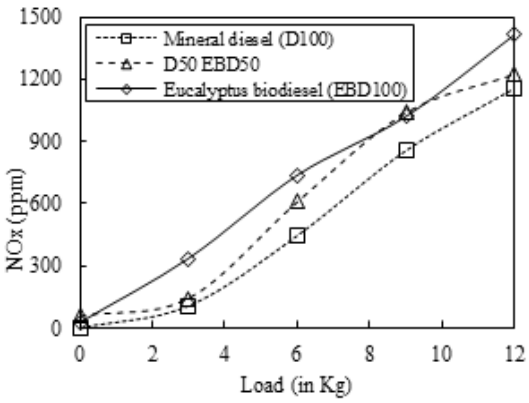

Fig. 12: Emissions of NOx vs. Load

The biodiesel shows higher emission and sudden increasing rate which may be due to its oxygen content. The emission of nitrogen oxide for mineral diesel (D100), D50 EBD50 and EBD100 at 50% load condition are 447 ppm, 608 ppm and 738 ppm respectively. When the load increases, the NO_x emission rate also increases due to its increase in temperature. The emission of nitrogen oxide for mineral diesel (D100), D50 EBD50 and EBD100 at 75% load condition are 108 ppm, 144 ppm and 337 ppm respectively. Bulk modulus is the important property for biodiesel which result in accumulation of fuel before rapid combustion which may increase the temperature up to peak level. The emission of nitrogen oxide for mineral diesel (D100), D50 EBD50 and EBD100 at 100% load condition are 1157 ppm, 1225 ppm and 1416 ppm respectively. The NOx emission found to be increased when the biodiesel percentage is high which means full biodiesel without diesel mix.

Fig. 13 shows the emission of carbon monoxide (CO) under various loads for mineral diesel (D100), D50 EBD50 and EBD100. It is noticed at starting loads all the mixtures record slightly equal CO emission rate with little variations whereas at larger loads EBD100 shows maximum rate of CO emission of about 0.85 ppm where

D100 and D50 EBD50 records 0.25 ppm and 0.70 ppm respectively. The rate of unburned gaseous mixture fuel is the main cause for the formation of CO emission and in addition the mixture temperature, both has the role in control rate of fuel oxidation and decomposition. The CO emission of biodiesel and its blend has lower concentration up to half load which is due to good combustion process with oxygen contain, when the load increases the CO emission for biodiesel increases which is due to the result of poor combustion process. The emissions of CO for mineral diesel (D100), D50 EBD50 and EBD100 at no load condition are 0.22 ppm for all mixtures. Since it is the initial stage the combustion is not complete hence it will show higher emission of CO due to low temperature and longer delay in combustion. The emission of CO for mineral diesel (D100), D50 EBD50 and EBD100 at 25% load condition is 0.18 ppm, 0.16 ppm and 0.16 ppm respectively. At this stage the combustion has completed and decrease in emission value compared to no load. Biodiesel has much lesser than diesel which may be due to the oxygen content and Cetane number.

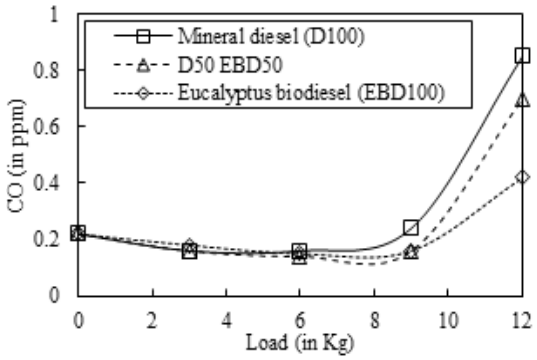

Fig. 13: CO emission vs. Load

The emission of CO for mineral diesel (D100), D50 EBD50 and EBD100 at 50% load condition is 0.15 ppm, 0.14 ppm and 0.16 ppm respectively. This stage has lesser emission when compared to no load and full load condition. Biodiesel shows higher CO emission than diesel which may be due to complete combustion [24, 25]. The emission of CO for mineral diesel (D100), D50 EBD50 and EBD100 at 75% load condition are 0.16 ppm, 0.16 ppm and 0.24 ppm respectively. Mineral diesel and blended fuel shows equal emission but whereas biodiesel shows better level of CO emission. The emissions of CO for mineral diesel (D100), D50 EBD50 and EBD100 at 100% load condition are 0.22 ppm, 0.70 ppm and 0.85 ppm respectively. At final stage of load the emission of CO for biodiesel and its blends show suddenly higher rate which may be due to unburned gaseous fuel in the mixture and also due to oxygen content, Cetane number and higher temperature level.

Fig. 14 shows the emission of carbon dioxide (CO_2) under various loads for mineral diesel (D100), D50 EBD50 and EBD10. It is observed CO_2 emission increases with increase in the load and under all loads EBD100 records larger CO_2 emission maximum up to 12.24%. Its shows combustion rate and temperature for EBD100 are high which proves by higher emission of CO_2. CO_2 emission is the product of the complete combustion. The CO_2 emission concentration for eucalyptus biodiesel and its blends are higher when compared with the mineral diesel (D100) [26, 28]. The emission of CO_2 for mineral diesel (D100), D50 EBD50 and EBD100 at no load condition are 2.79 ppm, 2.61 ppm and 3.25 ppm respectively. The combustion rate is much better for biodiesel than the diesel which is shown by the higher emission of CO_2 for biodiesel. The emissions of CO2 for mineral diesel (D100), D50 EBD50 and EBD100 at 25% load condition are 3.92 ppm, 4.33 ppm and 5.22 ppm respectively.

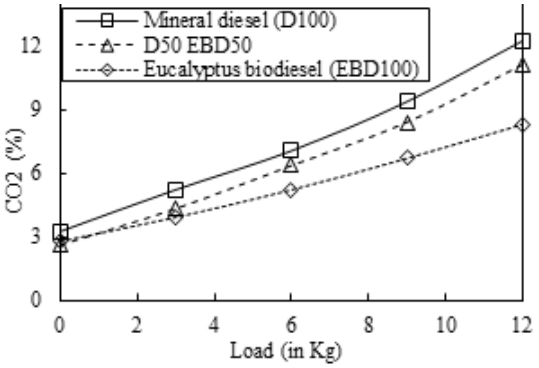

Fig. 14: Carbon dioxide emission vs. Load

The emissions of CO2 for mineral diesel (D100), D50 EBD50 and EBD100 at 50% load condition are 5.21 ppm, 6.36 ppm and 7.05 ppm respectively. the emission for biodiesel is higher when compared to the other fuel mixtures which may mainly due to the oxygen content and the biodiesel properties. The emissions of CO2 for mineral diesel (D100), D50 EBD50 and EBD100 at 75% load condition are 6.70 ppm, 8.40 ppm and 9.37 ppm. In this stage there is only slight increase in the emission range which is a good sign for the biodiesel and its blends. The emissions of CO2 for mineral diesel (D100), D50 EBD50 and EBD100 at 100% load condition are 8.30 ppm, 11.12 ppm and 12.24 ppm respectively. This is the main stage in the process for efficiency. Here 30% of more emission is recorded than the before stages which may be due to the complete combustion and releases the CO_2 emission.

Fig. 15 shows the emission of hydrocarbons (HC) under various loads for Mineral diesel (D100), D50 EBD50 and EBD100. The HC emission of all fuels has sudden variation under each load and D50 EBD50 being the higher emission of HC under larger loads maximum of about 120 ppm. This is mainly due to the lower viscosity of biodiesel. At initial loads, HC emission increases since the mass participants of gaseous fuel. At high loads the HC emission decreases due to improved combustion caused due to higher gas temperature and rich gaseous fuel. The main reason for lower HC emission at high loads of biodiesel is oxygen content of about 10% with weight of the biodiesel. HC for mineral diesel (D100), D50 EBD50 and EBD100 at no load conditions is 32 ppm, 21 ppm and 5 ppm respectively. HC is a dangerous emission. Biodiesel has 50% reduction in the HC emission than the mineral diesel. The emissions of HC for mineral diesel (D100), D50 EBD50 and EBD100 at 25% load condition are 19 ppm, 20 ppm and 2 ppm respectively.

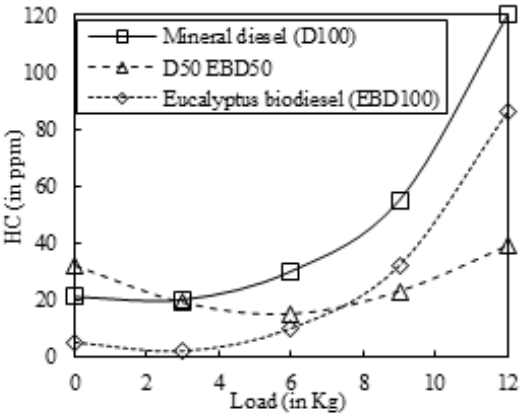

Fig. 15: HC emission vs. Load

The HC emission is much low for biodiesel due to higher Cetane number of biodiesel but here biodiesel blend recorded higher when compared to mineral diesel. The emission of HC for mineral diesel (D100), D50 EBD50 and EBD100 at 50% load condition is 15 ppm, 30 ppm and 10 ppm respectively. When the loads increase the HC emissions for diesel decrease and increase for the biodiesel and its blend. The emission of HC for mineral diesel (D100), D50 EBD50 and EBD100 at 75% load condition is 23 ppm, 55 ppm and 32 ppm respectively. HC emission for biodiesel blend has higher value than the other two fuel. The lower for biodiesel may be due to the oxygen content and higher Cetane number of biodiesel. The emission of HC for mineral diesel (D100), D50 EBD50 and EBD100 at 100% load condition is 39 ppm, 120 ppm and 86 ppm respectively. HC emission for biodiesel in final load has increased but it is lower than the blended biodiesel. The reason behind the lower emission is rapid combustion of biodiesel [27].

Fig. 16 shows the emission of smoke under various loads for mineral diesel (D100), D50 EBD50 and EBD100. The main product of smoke emission is the diffusive combustion stage. The biodiesel and its blends has higher smoke rate compared to mineral diesel. But the biodiesel fuel shows lower concentration of smoke by larger with increase in loads which is due to the oxygen content and oxygenated blends. Hence the diffusive combustion stage gets improved with presence of oxygenated blend in biodiesel which results in the smoke emission about 40% at larger loads. The emission of smoke for mineral diesel (D100), D50 EBD50 and EBD100 at no load condition are 2 ppm, 18 ppm and 21 ppm respectively. At initial stage the smoke emission low for diesel and also lower biodiesel compared large load stages this may be due to incomplete combustion. The emission of smoke for mineral diesel (D100), D50 EBD50 and EBD100 at 25% load condition are 5 ppm, 45 ppm and 38 ppm respectively.

Biodiesel shows lower smoke emission which is the good sign for a fuel. Lower concentration due to oxygen content in the biodiesel. The emission of smoke for mineral diesel (D100), D50 EBD50 and EBD100 at 50% load condition are 7 ppm, 57 ppm and 46 ppm respectively. The emission of smoke for mineral diesel (D100), D50 EBD50 and EBD100 at 75% load condition are 15 ppm, 51 ppm and 37 ppm respectively. When load increases smoke also get increased. Biodiesel blend with mineral diesel shows sudden decrease which is also due to diffusive combustion with oxygenated fuel mixture. The emission of smoke for mineral diesel (D100), D50 EBD50 and EBD100 at 100% load condition are 36 ppm, 70 ppm and 69 ppm respectively. At final load biodiesel blend proves to be equal with the biodiesel by recording same smoke level [29].

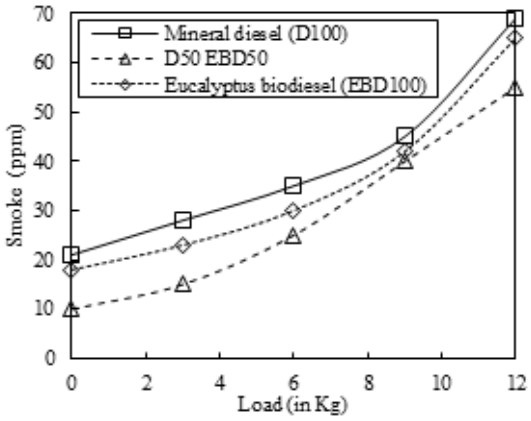

Fig. 16: Smoke emission vs. Load

5. Conclusion

In this study, the Eucalyptus oil biodiesel was used as alternative fuel for compression ignition engine. Methyl ester of Eucalyptus oil is obtained by transesterification process with NaOH as catalyst. The calorific value and Cetane number of the biodiesel are found to be lower than that of the diesel fuel. The performance, emission and combustion features for biodiesel and its blends are evaluated and compared with diesel. Based on the results obtained the conclusion are arrived. For biodiesel and its blend there is marginal increase in BTE. The BTE of EBD100 is higher than the diesel fuel at part load conditions. For biodiesel blend D50 EBD50 the BSFC value is lower than that of the diesel fuel at same loads. The exhaust temperature of the biodiesel increases with increase in the concentration of the biodiesel. EBD100 registers higher exhaust temperature compared to diesel fuel at all load conditions.

From the combustion study, the net heat release rate for biodiesel is comparable to that of diesel fuel at maximum load conditions and the cylinder pressure for biodiesel and its blends is slightly lower to that of diesel fuel at all load of the engine. CO and HC emissions have reduced for biodiesel fuel when compared to that of diesel fuel at same loads. CO_2 and NO_x emissions shows increased rate with increase in the concentration of biodiesel compare to that of the diesel fuels at full load. From the overall study, it is concluded that the Eucalyptus biodiesel and its blend with diesel could replace the diesel fuel for CI engine.

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