Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
e-ISSN: 2395-3454

Vol. 18 | No. 1 | pp. 285-291 | 2019

Original Research Paper | Open Access

Exhaust Emission Reduction in a Single Cylinder Compression Ignition Engine Fuelled With Optimized Biodiesel Blends of *Eucalyptus tereticornis*

V. Hariram†, R. Prakash, S. Seralathan and T. Micha Premkumar
Department of Mechanical Engineering, Hindustan Institute of Technology & Science, Hindustan University, Chennai, India
†Corresponding author: V. Hariram

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 31-05-2018
Accepted: 02-08-2018

Key Words:
Eucalyptus tereticornis
Transesterification
Biodiesel
Compression Ignition engine
Exhaust emission

ABSTRACT

Inadequate resources, diminution in petroleum reserves, environmental pollution hazards and escalated crude oil pricing have become major points of concern for energy use. This urged the researchers to identify an alternative source of fuel energy similar to petroleum hydrocarbons to be used in internal combustion engine. In the present study, biodiesel from leaves of *Eucalyptus tereticornis* was used in the processed form in compression ignition engine. The steam distillation process yielded 4.8% of Eucalyptus bio-oil through a batch process. Single stage transesterification process using methanol and sodium hydroxide produced Eucalyptus biodiesel effectively at molar ratio of 8:1. The physico-chemical properties of Eucalyptus biodiesel were found to be comparable to commercial diesel and within ASTM limits. Eucalyptus biodiesel in straight and blended form at ratio of 50:50 with commercial diesel was used in a single cylinder compression ignition engine to understand its emission characteristics. Lower unburnt hydrocarbon and smoke emission was observed when D50EBD50 fuel blend was used at part and full load condition. EBD100 fuel emitted higher CO_2 across all loads. Oxides of nitrogen emission were found to be relatively higher at full load condition when compared with D100 and D50EBD50 fuel blends. The emission parameters of EBD100 and D50EBD50 were found to be comparable with mineral diesel.

INTRODUCTION

Fuel energy is a standout amongst other sources and has a huge contribution to the economic development of a nation. Exponential growth has been witnessed around the globe with respect to fuel energy requirements (Demirbas 2009). It is estimated that the energy requirement by the year 2022 will be around 192 metric tons, which is against the present requirement in which 78% of crude petroleum is imported from the other countries to encounter the current demand (Barnwal & Sharma 2005, Canakci & Sanli 2008). The significance of the biodiesel requirement increases day by day due to the rapid diminution of crude petroleum reserves and an increased environmental pollution hazard. Also, instability in petroleum pricing and global concerns like the greenhouse effect crafted an awareness and curiosity towards the development of non-edible vegetable based biodiesel to be used in compression ignition engines. Vegetable based bio-oils are long and short chain hydrocarbons, which are biodegradable, less toxic and principally renewable in nature. Operation of compression engine using vegetable oil was demonstrated by Rudolph's diesel in 1900 at the world exhibition in Paris. Use of biodiesel in compression ignition engine reduces dependency on non-renewable petroleum fuel along with improved efficiency and reduced emissions in the transportation sector (Guan et al. 2009, Ma et al. 1990).

Verma et al. (2016) elaborated the potentiality of eucalyptus biodiesel using compression ignition engine. The single stage transesterification process adopted to reduce the viscosity of eucalyptus oil in order to convert it into biodiesel. The results concluded that a lower blend of Eucalyptus biodiesel with mineral diesel reduced the smoke emission considerably. Devan & Mahalakshmi (2009) amalgamated the methyl ester of eucalyptus oil with paradise oil on a volume basis and analysed its effect in a single cylinder compression ignition engine. The pressure of paradise oil methyl ester acted as an ignition improver in the fuel blend, which significantly influenced the emission formation. A higher blend of eucalyptus oil-paradise oil methyl ester reduced the concentration of hydrocarbons, carbon monoxide and smoke considerably with a marginal increase in NO_x in the exhaust emission at higher load condition. Kommana et al. (2017) investigated the effect of eucalyptus methyl ester blend in palm kernel oil at a ratio of 5, 10 and 15 by volume. The experimental studies were conducted in the VCR engine at 19:1 compression ratio and 220 bar in-

jection pressure. Senthil et al. (2016) studied the combined effect of eucalyptus biodiesel blended with Annona-oil at various ratios. The emission and performance evaluation on the test engine reveal higher NO_x when A50-Eu50 was used. Presence of oxygenate in blends of biodiesel and eucalyptus oil in a compression ignition engine show cast superior performance with reduced emission on comparison with mineral diesel. Methyl esters of eucalyptus oil and orange oil were also analysed at 20% volume ratio by Poola et al. (1994).

Lower blends of soyabean, cotton seed, rapeseed, sunflower, corn, palm and olive oil were tested in a 4S direct injection Ricardo test engine by Rakopoulos et al. (2006) and proved that exhaust emissions were greatly reduced inducing better performance. Riva et al. (2011) analysed the various possible ways for the production of biodiesel through ultrasound based transesterification. Zhang et al. (2012) developed SE-SD based oil extraction method to distillate vegetable oil from plant leaves. Higher yield of bio-oil under this optimized variable process of temperature 41°C, liquid solid ratio of 6.27 mL/s with a process time of 5 hours yielded 95% of bio-oil. Hariram et al. (2016) extracted bio-oil from seeds of *Nicotiana tabacum* using Soxhlet apparatus. Two stage transesterification process was adopted with molar ratio 1:6, reaction temperature of 60°C, and reaction time of 100 minutes yielded 92% of biodiesel when NaOH was used as catalyst.

In the present study, leaves of *Eucalyptus tereticornis* were selected as the source of bio-oil through the steam distillation process. The methyl esters of bio-oil are produced through single stage transesterification. The performance and emission characteristics of straight eucalyptus biodiesel and its blends was compared with mineral diesel in a single cylinder naturally operated compression ignition engine.

MATERIALS AND METHODS

Bio-oil extraction: In the present investigation, leaves of *Eucalyptus tereticornis* were used to extract bio-oil. The steam distillation process 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 was allowed to heat above 120°C, where 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 fluidizing the 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 in the Erlenmeyer flask

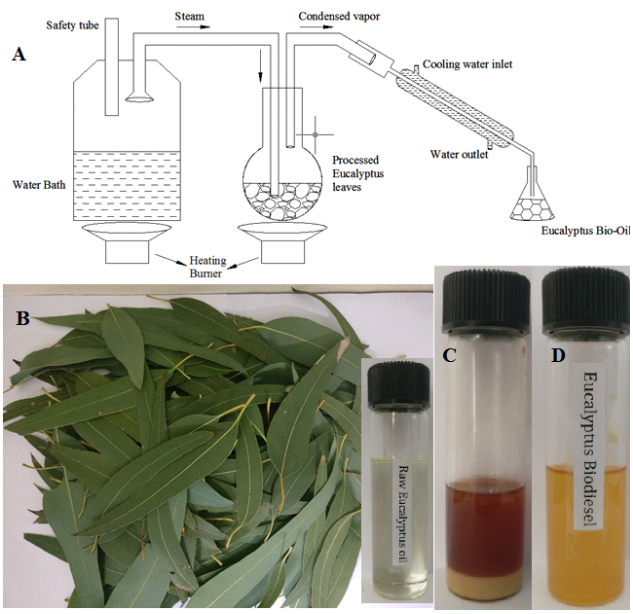

Fig. 1: Steam distillation process of Eucalyptus leaves (A), Eucalyptus leaves (B), Glycerol Separation (C) and Eucalyptus Biodiesel (D).

as shown in Fig. 1. Further, the left out eucalyptus leaves are allowed to react with *n*-hexane solvent in a closed chamber for 24 hours, which was followed by a mechanical expulsion for the removal of the remaining bio-oil. Batch process of 12 times yielded 453 mL of bio-oil from leaves of *Eucalyptus tereticornis* at an extracting efficiency of 4.8% oil (Zhang et al. 2012).

Transesterification: 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 equipped with 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. 453 mL of *Eucalyptus tereticornis* oil was heated up to 70°C in a 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 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 were then transferred into a separating funnel and allowed to settle down for 24 hours. During this period a ring formation took place, characterizing *Eucalyptus tereticornis* biodiesel as the upper layer and glycerol as the lower layer. The glycerol was very carefully removed from the bottom layer through the knob opening.

Table 1: Physico-chemical properties of Eucalyptus oil, biodiesel and diesel.

S.No	Properties	Units	Diesel	Bio-oil	Biodiesel	D50-BD50
1	Density	kg/m^3	840	1048	905	1015
2	Viscosity	mm^2/s	2.6	3.8	2.8	2.54
3	Specific gravity	g/cm^3		0.882	0.893	0.854
4	Flash point	℃	75	116	105	47
5	Fire point	℃	78	120	108	50
6	Calorific value	kJ/kg	42500	-	41930	-
7	FFA	%	-	1.5	1.2	-

Distilled warm water was mixed with methyl esters for the removal of impurities which included the catalyst, unreacted oil and methanol in a separating funnel. Gravity separation process for 4 hours expelled the distilled water along with the impurities (Hariram & Gowtham 2016).

Physico-chemical properties: Biodiesel from *Eucalyptus tereticornis* was subjected to various analyses under ASTM standards to identify its physico-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 904 kg/m^3 and 0.891 g/cm^3 respectively. Redwood viscometer under ASTM D445 measured the kinematic viscosity at 40°C as 2.7 mm^2/sec. Hamco Bomb calorimeter (ASTM D5865) measured the calorific value of *Eucalyptus tereticornis* as 40.45 MJ/kg. ASTM D3278 method was adopted to identify flash point using Abel flash point apparatus and found to be 101°C. 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 from 2.02 mgKOH/g to 0.25 mgKOH/g by ASTM D1980 method. The Cetane number was identified as 53 by ASTM D613. The physico-chemical properties of *Eucalyptus tereticornis* oil and its biodiesel are given in Table 1.

Experimental Setup

Fig. 2 shows the schematic outline of the experimental setup. Kirloskar MMM1MET-201EL was used as the test engine. The setup consists of two fuel tanks, one for mineral diesel and the other for biodiesel blend with controller facility for fuel switching. The fuel and air consumption were measured by optical sensor and differential pressure transducer respectively, and fed into the data acquisition system. The loading of test engine is accomplished using an eddy current dynamometer as shown in the Fig. 2. AVL444 Di gas analyser measures the CO and UBHC using infrared method, and NO_x using the electro-chemical method. AVL437 smoke meter measures the smoke opacity using selenium photo cell detector. The detailed engine specifications are displayed in Table 2. Initially the experiments were conducted on the test engine with mineral diesel to identify the optimum cooling rate and further expanded with straight biodiesel and its blend by maintaining this optimum rate of engine cooling. The experiments were repeated for 3 times and mean values of the readings are recorded. The performance of the engine was evaluated in terms of brake thermal efficiency, brake specific fuel consumption, exhaust gas temperature, smoke density and the emissions of HC, CO and NO_x.

Table 2: Test engine specification.

Description	Specification
Make	Kirloskar TV1
Type	4 stroke, single cylinder, CI engine
No of Cylinders	One
Cubic Capacity (L)	0.661 L
Rated Speed (rpm)	1500 rpm
Bore (mm)	87.5 mm
Stroke (mm)	110 mm
Connecting rod length	234 mm
Air flow transmitter	(-) 250-0 mm WC
Power Rating (HP)	5hp (3.7 kw)
Compression Ratio	17.5:1
Start of Injection (BDTC)	23
Cooling	Water cooled
Cylinder pressureTransducer	0-345.5 bar
Sensor signal range (input for interface)	1-5 V
Dynamometer type	Eddy current

RESULTS AND DISCUSSION

Transesterification: The yield of biodiesel with sodium hydroxide as a 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. In the present experimental study the reaction duration was varied from 15-100 minutes at various reacting temperatures. At 55°C reacting temperature, maximum yield of biodiesel obtained

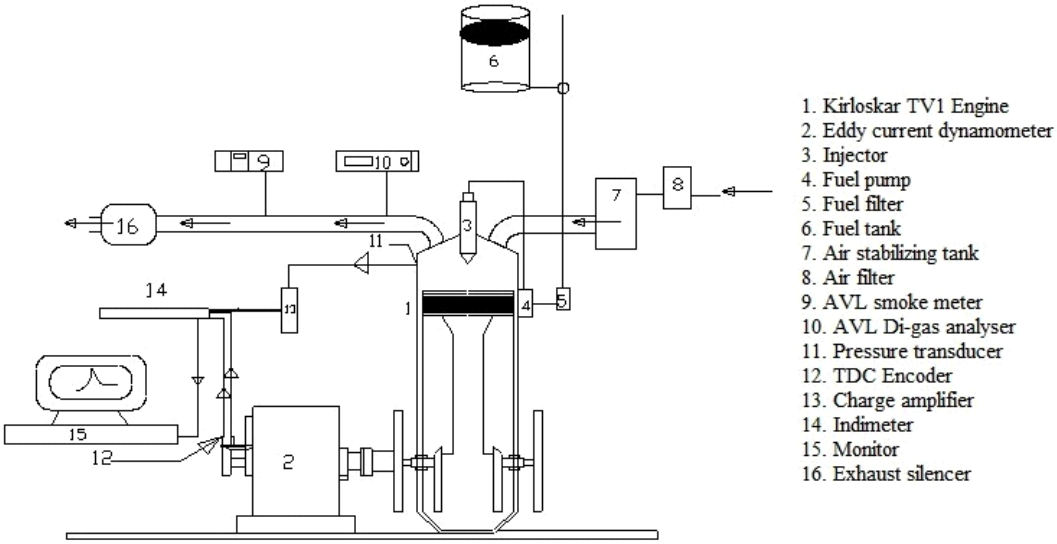

Fig. 2: Engine schematic diagram.

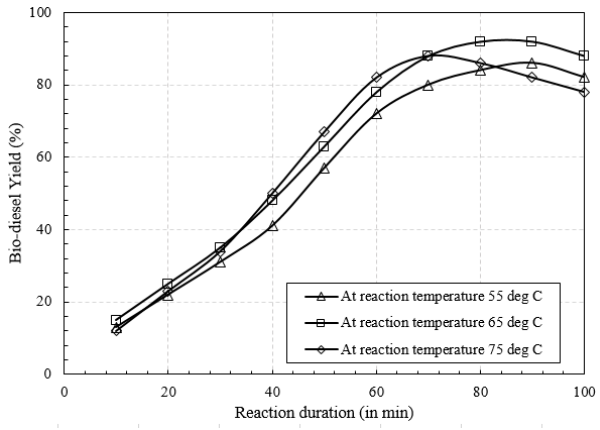

Fig. 3: Biodiesel yield versus reaction duration for different temperatures.

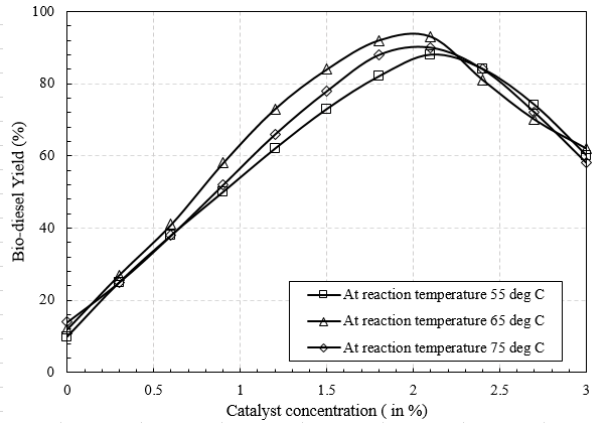

Fig. 4: Biodiesel yield versus catalyst concentration for different temperatures.

was 86% at 90 minutes reaction duration. Increase in reaction temperature up to 65°C enhanced the conversion rate of triglyceride into FAME's 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 also due to vaporization of methanol (Hariram & Gowtham 2016).

Fig. 4 depicts the effect of NaOH concentration on biodiesel yield at various reacting temperatures. 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, the reaction duration of 90 minutes and agitation speed of 400-450 rpm were maintained with variations in reaction temperature between 55°C and 75°C. It can be noticed that the reaction temperature has 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 impact 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

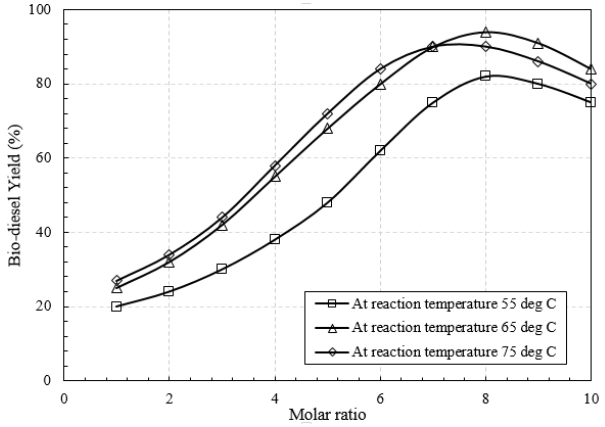

Fig. 5: Biodiesel yield versus molar ratio for different temperatures.

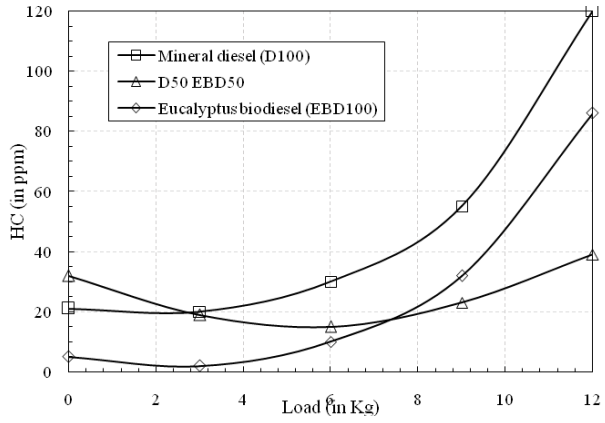

Fig. 6: Variations in hydro-carbon emission.

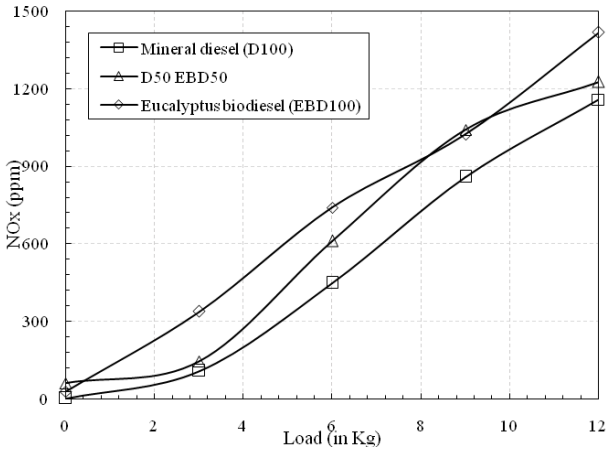

Fig. 7: Variations in NO_x emission.

biodiesel yield of 88%. Hence 1.8% of NaOH at 65°C and 450 rpm agitation speed were found to be optimum in the conversion of *Eucalyptus tereticornis* into biodiesel.

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 ratios between 2:1 and 10:1 at different reacting temperatures were investigated in the present study. 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 shown in Fig. 5, which may be due to evaporation of methanol at increased temperature. However, excess methanol favoured an increase in the yield of biodiesel, the catalyst concentration was very sensitive during the transesterification process. The kinematic viscosity of derived biodiesel at various molar ratios was identified and found to be within the ASTM standards.

Exhaust emissions: Fig. 6 depicts the clear plot between unburnt hydrocarbons and various engine loads of D100, D50EBD50 and EBD100. Unburnt fuel composition from the combustion chamber is termed as UBHC emission. From the graph, it was noted that in part and full load condition, higher UBHC emission was showcased and also it is notable that D50EBD50 depicted the lowest UBHC emission, which may be due to the less viscous nature of the fuel leading to better fuel atomization, which enhanced the complete combustion. At low load condition, D100, D50EBD50 and EBD100 showed 20 ppm, 32 ppm and 5 ppm respectively, whereas at part load condition resulted with 30 ppm, 15 ppm and 10 ppm respectively of UBHC emission. During the full load condition, D50EBD50 emitted lowest UBHC as 39 ppm, which may be due to higher cetane number than mineral diesel leading to shorter ignition delay thereby enhancing complete combustion (Aydin & Bayindir 2010).

Fig. 7 depicts the variation in oxides of nitrogen of mineral diesel, straight biodiesel and diesel-biodiesel blends with respect to the engine loads. Oxides of nitrogen are formed by the disintegration of nitrogen molecules due to higher temperature which then clubs with oxygen delivering oxides of nitrogen. From the plot, it is clear that NO_x increased as the load increases, which may be due to the higher temperature during high loads. From the result, it is noted that straight biodiesel detailed higher value of NO_x than diesel fuel, which may be due to higher oxygen content in biodiesel. This allows the rise in temperature during the premixed combustion phase of fuel burning. At low load condition, NO_x values for mineral diesel, D50EBD50 and EBD100 were noted as 108 ppm, 144 ppm and 337 ppm respectively, whereas at part load condition, it is 447 ppm, 609 ppm and 738 ppm respectively. During the full load condition, highest NO_x was depicted by EBD100 as 1416 ppm and lowest was depicted by mineral diesel as 1157 ppm (Kannan et al. 2011).

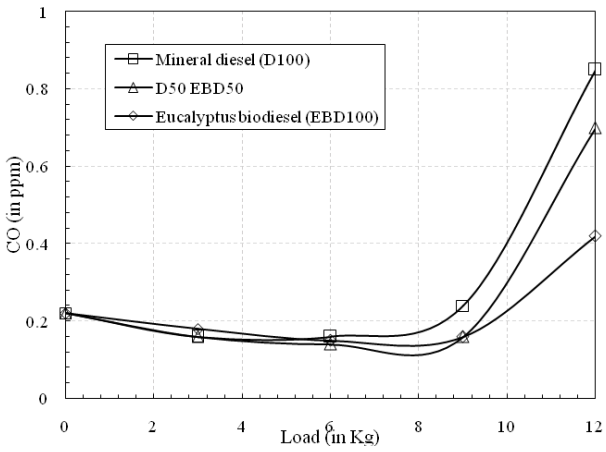

Fig. 8: Variation in CO emission.

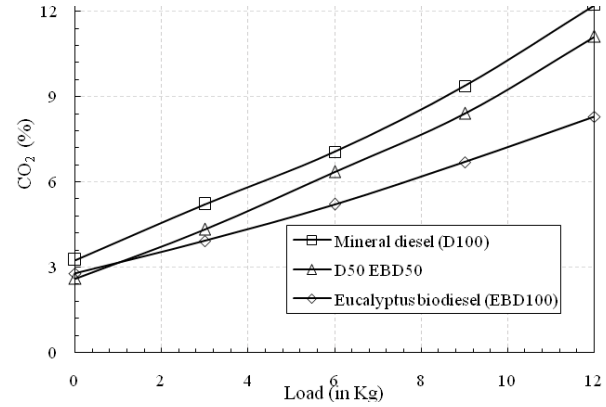

Fig. 9: Variations in carbon dioxide emission.

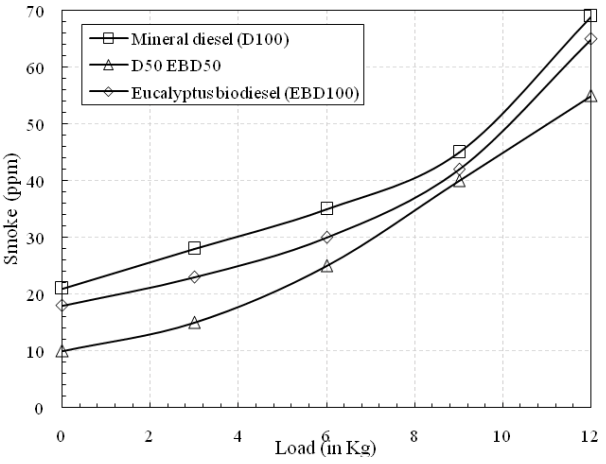

Fig. 10: Variations in smoke emission.

Fig. 8 depicts the variation in carbon monoxide emissions of mineral diesel, straight biodiesel and diesel-biodiesel blends with respect to the engine loads. CO emission portrays the incomplete combustion of the fuel. During low load condition, D100, D50EBD50 and EBD100 showcased almost closer percentage values of carbon monoxide. Similar pattern was noted during the part load conditions. Also it was noted that for straight biodiesel, the CO formation was reduced due to its higher cetane number, which affected the fuel atomization leading to shortened ignition delay thereby causing better premixed combustion phase. During the full load condition, CO emission was increased, which may be due to the improper latent heat of vaporization because of the lesser time duration for fuel atomization thereby promoting incomplete combustion (Tamilselvan et al. 2016, Datta et al. 2014).

Fig. 9 shows the variation in carbon dioxide emission of D100, D50EBD50 and EBD100 with respect to engine load. CO_2 emission is the oxidation of CO to CO_2 portraying the complete combustion. It can be noted from the plot that the CO_2 emission increased as the load increases. During the full load condition, it was noted that D50EBD50 shows 10.07% lower CO_2 emission than mineral diesel which may be due to higher oxygen content than diesel leading to complete burning of fuel. Also its lower viscosity promotes better fuel atomization thereby enhancing complete combustion. At part load condition, it is to be noted that EBD100 on comparison with D100 expelled lower CO_2 which may be due to higher ignition delay, which eventually affected the oxidation process through poor atomization (Hariram et al. 2017).

Smoke emission variation of D100, D50EBD50 and EBD100 with respect to engine load is shown in Fig. 10. It was noted from the graph that smoke emission increased as the load increases. Smoke formation, in general, is due to factors of kinematic viscosity, volatility and air-fuel mixture. It is to be noted at all the load conditions that D50EBD50 evidenced lowest smoke opacity percentages, which may be due to the appropriate oxygen content present in the air-fuel mixture enhancing better combustion. At low load condition, mineral diesel showed a higher smoke emission as 21%, which may be due to rich air-fuel mixture delivered for the ignition process leading to incomplete combustion. During part and full load conditions, diesel and straight biodiesel resulted with higher smoke opacity as 70% and 68%, which may be due to higher density leading to poorer atomization thereby increase in smoke emission.

CONCLUSIONS

In this experimental study, optimized biodiesel production from *Eucalyptus tereticornis* and its effect on the emission characteristics of single cylinder compression ignition engine have been evaluated and compared with commercial diesel. From this study, the following conclusions are drawn,

- Bio-oil extraction through steam distillation technique

yielded 4.8% of *Eucalyptus tereticornis* oil.

- Base catalysed transesterification using sodium hydroxide and methanol yielded 94.5% of biodiesel at molar ratio of 8:1.
- Kinematic viscosity of Eucalyptus biodiesel and its blend was found to be comparable with mineral diesel. The calorific value of EBD was also noticed to be marginally lower than mineral diesel.
- As far as exhaust emissions are concerned, it is noted that UBHC, CO and smoke emissions were abridged significantly with a marginal increase in NO_x. D50EBD50 fuel blend showed 2.4% increase on NO_x with 23.6% reduction in UBHC emission.
- From the emission analysis, it can be concluded that Eucalyptus biodiesel is one of the suitable alternative fuel for compression ignition engine. Its blend with mineral diesel at the ratio of 50:50 significantly reduced the exhaust emissions.

REFERENCES

Aydin, H. and Bayindir, H. 2010. Performance and emission analysis of cottonseed oil methyl ester in a diesel engine. Renew. Energy, 35: 588-92.

Barnwal, B.K. and Sharma, M.P. 2005. Prospects of biodiesel production from vegetable oils in India. Renewable Sustainable Energy Rev., 9(4): 363-78.

Canakci, M. and Sanli, H. 2008. Biodiesel production from various feedstocks and their effects on the fuel properties. J. Ind. Microbiol. Biotechnol., 35: 431-41.

Datta, Ambarish, Palit Samiddha and Mandal Bijan Kumar 2014. An experimental study on the performance and emission characteristics of a CI engine fuelled with Jatropha biodiesel and its blends with diesel. Journal of Mechanical Science and Technology, 28(5): 1961-1966.

Demirbas, Ayhan 2009. Progress and recent trends in biodiesel fules. Energy Conservation and Management, 50: 14-34.

Devan, P.K. and Mahalakshmi, N.V. 2009. A study of the performance, emission and combustion characteristics of a compression ignition engine using methyl ester of paradise oil-eucalyptus oil blends. Applied Energy, 86: 675-680.

Guan, Guoqing, Katsuki Kusakabe, Nozomi Sakurai and Kimiko Moriyama 2009. Transesterification of vegetable oil to biodiesel fuel using acid catalysts in the presence of dimethyl ether. Fuel, 88: 81-86.

Hariram, V. and Gowtham Rajan, A. 2016. Extraction of tobacco (*Nicotiana tabacum* L.) seed oil and biodiesel preparation through two stage transesterification. Research Journal of Pharmaceutical, Biological and Chemical Sciences, 7(2): 978-983.

Hariram, V., Sivamani, S., Premkumar T, M. and Tharun, P. 2017. Reduction of exhaust emissions using a nanometallic enriched lemongrass biodiesel blend. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 39(21): 2065-2071.

Kannan, G.R., Balasubramanian, K.R., Sivapirakasam, S.P. and Anand, R. 2011. Studies on biodiesel production and its effect on DI diesel engine performance, emission and combustion characteristics. International Journal of Ambient Energy, 32(4): 179-193.

Ma, F. and Hanna, M.A. 1990. Biodiesel production: A review. Biores. Technol., 70: 1-15.

Kommana, S., Balu Naik, B. and Kalyani Radha, K. 2017. Impact of fuel injection pressure and compression ratio on performance and emission characteristics of VCR CI engine fueled with palm kernel oil-Eucalyptus oil blends. Materials Today: Proceedings, 4: 2222-2230.

Poola, R.B., Nagalingam, B. and Gopalakrishnan, K.V. 1994. Performance studies with bio-mass derived high octane fuel additives in a two stroke spark ignition engine. Biomass Bioenergy, 6: 369-379.

Rakopoulos, C.D., Antonopoulos, K.A. and Rakopoulos, D.C. 2006. Comparative performance and emission study of a direct injection diesel engine using blends of diesel fuel with vegetable oil or bio-diesel of various origins. Energy Conservation Management, 47: 3272-87.

Riva, G., Toscano, G., Foppa Pedretti, E. and Duca, D. 2011. Refined soyabean oil transesterification enhanced by sonication. Energy and Bioenergy, 35: 2867-2873.

Senthil, R. and Silambarasan, R. 2015. Environmental effect of antioxidant additives on exhaust emission reduction in compression ignition engine fuelled with Annona methyl ester. Environmental Technology, 36(16): 2079-2085.

Tamilselvan, P., Vignesh, K. and Nallusamy, N. 2017. Experimental investigation of performance, combustion and emission characteristics of CI engine fuelled with chicha oil biodiesel. International Journal of Ambient Energy, 38(7): 752-758.

Verma, P., Sharma, M.P. and Dwivedi, G. 2016. Potential use of eucalyptus biodiesel in compressed ignition engine. Egyptian Journal of Petroleum, 25(1): 91-95.

Zhang, Xian Zhong, Hongjian Gao, Lifen Zhang, Donghong Liu and Xingqian Ye 2012. Extraction of essential oil from discarded tobacco leaves by solvent extraction and steam distillation, and identification of its chemical composition. Industrial Crops and Products, 39: 162-169.