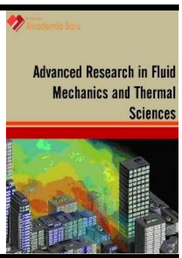
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Influence of Diethyl Ether on the Performance and Emissions of a Compression Ignition Engine Fuelled with Biodiesel

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N. Kapilan[1], Sadashiva Prabhu S.[2,*], Vasudeva M.[3]

[1] Department of Mechanical Engineering, Nagarjuna College of Engineering and Technology, Bangalore, Karnataka, 562164, India
[2] Department of Mechanical and Manufacturing Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, Karnataka, 576104, India
[3] Department of Mechanical Engineering, National Institute of Technology Karnataka, Surathkal, Mangalore, Karnataka, 575025, India

ARTICLE INFO

Article history:
Received 11 November 2019
Received in revised form 15 January 2020
Accepted 29 January 2020
Available online 15 August 2020

Keywords:
Additive; diethyl ether; engine tests; performance; emissions

ABSTRACT

India is one of the major importers of petroleum products and hence government of India has taken several steps to find suitable alternative fuels to the fossil fuels. The biodiesel derived from non-edible oils is considered as an immediate substitute for the fossil diesel. In this work, biodiesel was produced from non-edible honge oil and used as substitute for the diesel. The engine tests were carried out on a diesel engine which is most widely used for agricultural purpose. From the engine tests, we observed that the diesel engine performance with biodiesel is lower than the diesel due to lower volatility and slightly higher viscosity of the biodiesel. Hence, the objective of this work is to study the impact of diethyl ether (DEE) on the performance of the engine. The engine tests were conducted on a single cylinder, water cooled, compression ignition engine at steady state condition. The engine test results showed an increase in brake thermal efficiency and reduction in engine exhaust emissions such as CO, HC and smoke with the addition of DEE as an additive. From this work we conclude that the DEE can be used as an ignition improver for the honge oil biodiesel.

1. Introduction

The energy is the prime-mover of economic growth of any country. The long-term availability of energy from sources that are affordable, accessible and environmentally friendly improves the economic growth of any country. The energy demand of the world is increasing as the developed and developing countries continue to consume huge amounts of energy. Also, the demand for affordable and reliable energy will drive energy demand in near future.

It is reported that more than half of the projected increase in global energy consumption occurs in non-organization for economic cooperation and development (OECD) Asia, a region that includes

* *Corresponding author.*
E-mail address: ss.prabhu97@gmail.com

https://doi.org/10.37934/arfmts.74.1.4556

China and India. It is also suggested that the energy demand in non-OECD Asia is projected to increase by 51% during the period of 2015–40 [1]. The fossil fuels such as coal, petroleum products etc. supplies the most of the energy consumed worldwide. These fossil energy sources are the most of the energy consumed worldwide. However, these fossil energy sources are limited and will exhaust. An analysis done by few researchers indicates that the fossil fuel reserves depletion time for oil and coal are approximately 35 and 107 year respectively [2]. Hence researchers are finding suitable alternative renewable and sustainable energy technologies world-wide [3].

India is one of the largest energy consumers in the world after United States, China and Russia and it is reported that India’s primary energy consumption is approximately 4.52 percent of the global energy consumption. The crude oil is one of the eight core industries in India which has significant forward linkages with the economy and this sector accounts for 30 percent of the total consumption of energy in the country after coal [4]. India’s crude oil import during the year 2015-16 was 202.851 MMT as against import of 189.435 MMT in the year 2014-15 and the energy demand increasing every year [6]. India has to import most of its oil requirement to meet her energy demand which results in severe pressure on the economy when the oil prices rise [6].

Biofuels are derived from renewable bio-mass resources and promotes sustainable development and to supplement conventional energy sources in meeting the rapidly increasing requirements for transportation fuels associated with high economic growth. It is suggested that the biodiesel ease global energy concerns and mitigate climate change [7]. Also, it will stimulate rural development and create employment opportunities. According to India’s bio-fuel policy, ethanol and biodiesel derived from non-edible oils are considered as substitute for the gasoline and diesel respectively [8]. The objective of India’s Policy on Biofuels is to ensure that a minimum level of biofuels become readily available in the market to meet demand at any given time. The policy aims to push biofuels into the mainstream to supplement gasoline and diesel and an aspirational target of 20 percent blending of biofuels by 2017 was proposed, both for bio-diesel and bio-ethanol [9]. It will reduce the dependence on imported fossil fuels and meeting energy needs of India’s vast rural population by use of non-food feed stocks [10].

Few researchers suggested that the biodiesel is a renewable, biodegradable alternative fuel to the fossil diesel as the properties of biodiesel are comparable to the fossil diesel [11]. It is reported that the genetically modified biodiesel fuels can be used into the diesel engine for better environmental and economic results [12].

The biodiesel is produced from straight vegetable oil, animal fat and waste cooking oil. The properties of biodiesel are similar to fossil diesel. However, it is biodegradable, non-toxic, safe to handle and free of sulfur and aromatics components as compared to fossil diesel. The cost of the biodiesel is higher than the fossil diesel [13]. Hence newer technologies are being developed to reduce the production cost, to increase the biodiesel yield, to reduce the initial cost and to reduce the cost of raw materials [14]. The nano-catalyst technology has been widely used for biodiesel production due to large surface area, reusability and high activity of the nano-catalyst [15]. In India, non-edible oils are used for biodiesel production and among the non-edible oils, honge oil has most widely used for the biodiesel production [16]. Few researchers used blends of honge biodiesel and diesel as fuel in compression ignition engine without making any modifications in the fuel injection system [17]. The honge biodiesel is having lower oxidation stability and hence anti-oxidants are added with it to enhance the storage stability [18].

The oxygenated additives contain oxygen and are added with diesel to enhance its combustion and also to increase the efficiency of the engine. Few oxygenated additives have higher cetane number and it increases the cetane number of the fuel blends. The generally used oxygenated additives are alcohols, ether and ester [19]. The addition of oxygenated additive to the fuel minimizes the ignition temperature of biodiesel and reduces the smoke emission of the diesel engine [20]. The oxygenated additives directly affect the fuel properties of the blend such as flash point, viscosity, cetane number, volatility and calorific value [21]. Mohanan *et al.,* [22] used diethyl ether (DEE) as the ignition improver for the diesel in the compression ignition engine and they reported that the DEE can be used as an ignition improver for the diesel in the diesel engine.

Ali *et al.,* [23] studied the effect of adding small portions of a DEE additive to biodiesel–diesel blended fuel (B30). The experimental engine test was conducted at 2500 rpm which produce maximum torque. They reported a slight improvement in density and acid value with a significant decrease in the viscosity, pour point and cloud point of the blended fuel with an 8% additive ratio by 26.5%, 4°C and 3°C, respectively, compared with blended fuel without additive. They also reported that the coefficient of variation for B30 was the lowest and increased as the additive ratios increased and suggested that the additive has a noticeable effect on increasing the cycle-to-cycle variations [23]. The delay period of the biodiesel is higher than the diesel as the chemical and physical properties of the biodiesel is slightly varies from the diesel. The cetane number improvers can reduce the delay period and can enhance the combustion of the fuel as the shorter ignition delay period leads to more complete combustion of the fuel.

Roy *et al.,* [24] produced biodiesel from canola oil and mixed two additives (5% and 15% by volume), ethanol and DEE with biodiesel-diesel blends B20, B50 and B100. The engine tests were carried out on a modern 4-cylinder direct injection diesel engine at idling with no load conditions. Their results show that, CO and NOx emissions decrease, but HC emissions increase after warm-up than cold start. They reported that the diesel-biodiesel blends with additives produce lower CO emission level than neat diesel; ethanol and DEE additives can reduce NOx emission level in diesel-biodiesel blends, and increasing biodiesel content reduced HC emissions [24]. Ayhan and Tunca [25] reported that the optimum emulsified fuel can be formed as a blend of 20% biodiesel, 5% DEE, 10% tap water, 2% surfactant and 63% diesel, by mass. From the engine tests conducted at the maximum torque condition, they conclude that a small reduction in engine torque and power, and improvements up to 19% in brake efficiency, and a 12.5% reduction in NO emission, and a 29% reduction in smoke emission, and remarkable reductions in CO and increases in HC emissions [25].

The biodiesel has lower volatility and hence it is necessary to add volatile oxygenated fuel additive to it. However, it is desirable to add renewable oxygenated fuel additive to the biodiesel. Among the additives, DEE has higher cetane number, highly volatile and also produced from renewable energy sources. Hence it was used as an additive in this work to enhance the fuel properties of the honge biodiesel and also to improve its combustion in the diesel engine. The honge oil was used for the production of biodiesel as it has considerable potential for the production of biodiesel in India as compared to other non-edible oils. Figure 1 shows the honge tree.

Fig. 1. Honge tree

2. Materials and Methodology

In this work, biodiesel was produced from non-edible honge oil using a two-step transesterification process as the acid value of the honge oil was high. The biodiesel yield obtained was 94 %. The DEE was added to the biodiesel in various volume proportions and various fuel blends such as B95D05, B90D10 and B85D15 were prepared. The B95D05 represent 95% biodiesel and 5% DEE. Similarly, B90D10 and B85D15 represent 90% biodiesel with 10% DEE and 85% biodiesel with 15% DEE respectively. The pure biodiesel without DEE is represented as B100. The properties of the diesel, biodiesel and biodiesel blends were determined as per the ASTM procedures.

The engine tests were carried out on a diesel engine which is most widely used in agricultural purpose. The diesel engine used in this work is a single-cylinder; water-cooled, naturally aspirated direct injection diesel engine. Figure 2 shows the engine experimental setup. The engine details are given in the Table 1. An eddy current dynamometer was used to load the engine. The engine test setup is provided with necessary instruments for recording the observations such as fuel flow rate, airflow rate, exhaust gas temperature and engine load. The engine test set up provided with air box, fuel tank, manometer, fuel measuring unit, transmitters for fuel flow measurement and process indicator. The engine cooling water flow rate was measured using a rotameter.

The engine tests were initially carried out with diesel to obtain baseline date. The engine tests were carried out at steady state for different engine loads and at a constant speed of 1500 rpm. The schematic view of engine setup is shown in Figure 3. An AVL exhaust gas analyser was used to measure the engine exhaust emission such as carbon monoxide, un-burnt hydrocarbon and nitrogen oxide emissions. The details of the exhaust gas analyser are shown in Table 2. A smoke meter was used to measure the engine exhaust smoke. The engine tests were carried out with B100 and various fuel blends such as B95D05, B90D10 and B85D15.

Table 1
Engine specifications

Item	Specification
Engine type	Direct injection compression ignition engine
No of cylinder	One
Make	Kirloskar
Engine Displacement (cc)	661
Maximum Brake Power (kW)	5.2
Rated Speed (rpm)	1500
Engine Compression Ratio	17.5 : 1
Engine Bore (mm)	87.5
Engine Stroke (mm)	110
Injection Time	23 degree bTDC

Table 2
Details of exhaust gas analyser and smoke meter

Item	Specification
Gas Analyser Make and Model	AVL India Pvt Ltd AVL Digas 444 N
Smoke meter Make and Model Make	Smoke meter AVL 437C
Quality	Range
CO (% vol)	0 to 15
HC (ppm)	0 to 30000
NOx (ppm)	0 to 5000
	Smoke meter
Measurement Range (%)	0 to 100
Resolution of the measurement (%)	0.1


Fig. 2. Engine experimental setup

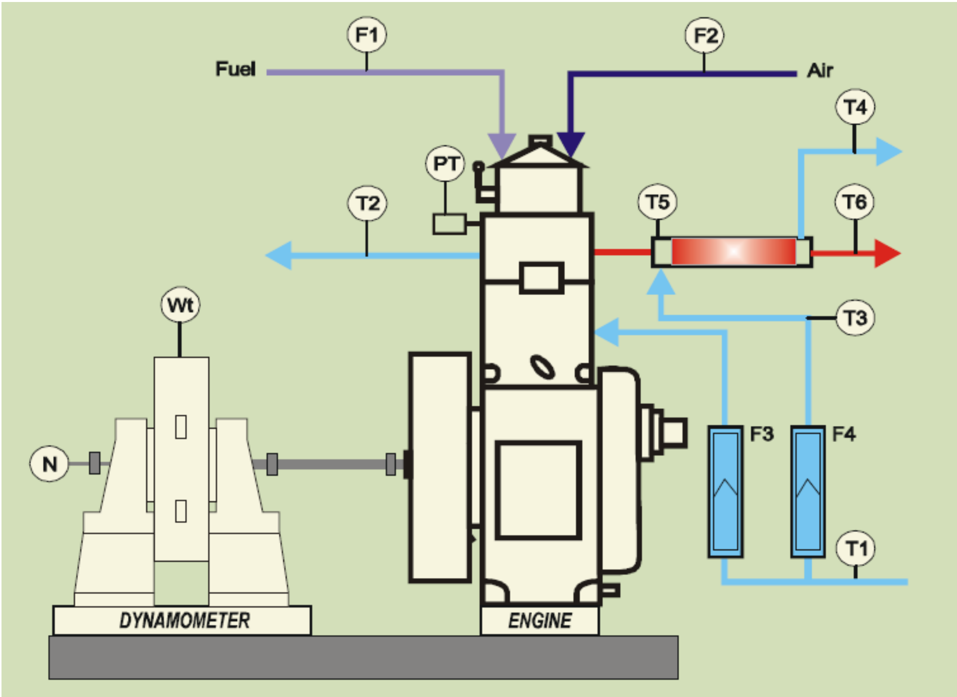

Fig. 3. Layout of the engine experimental setup

3. Results

The biodiesel was produced from honge oil and DEE was added with the biodiesel to prepare different fuel blends. The DEE dissolves in the biodiesel and the blend was mixed vigorously before the commencement of the engine tests.

3.1 Fuel Properties

Table 3 shows the properties of the diesel, biodiesel and blends. From the table it is observed that the addition of DEE to the biodiesel improves the properties of the biodiesel. The addition of DEE to the honge oil biodiesel reduces the flash point of the biodiesel which increases the combustion properties of the biodiesel. The densities of blends of honge oil biodiesel and DEE is lower than the honge oil biodiesel. The density value of the blends reduces as the blend concentration value increases. The addition of DEE to the biodiesel reduces the calorific value of the biodiesel has the calorific value of the DEE is lower than the biodiesel. The honge oil biodiesel has higher pour point and addition of DEE improves the pour point significantly. The viscosity value of the honge oil biodiesel reduces as the blend concentration increases. The addition of DEE to honge oil biodiesel reduces the acid value significantly due to the dilution of the free fatty acids present in biodiesel by the DEE. The ash content value of the biodiesel and blends is almost same.

Table 3
Comparison of fuel properties

Property	Diesel	B100	B95D05	B90D10	B85D15
Flash Point (°C)	68	142	131	119	100
Density (kg/m^3)	841	872	865	860	856
Viscosity at 40°C (mm^2/s)	2.7	4.8	4.5	4.3	4.0
Calorific Value (MJ/kg)	42.9	37.1	36.8	36.7	36.5
Pour Point (°C)	-14	13	10	6	2
Copper Corrosion	1	1	1	1	1
Acid Value (mg KOH/g)	-	0.42	0.39	0.35	0.31
Ash Content (%)	0.01	0.01	0.01	0.01	0.01

3.2 Engine Performance

The engine tests were carried out without making any modifications in the fuel injection system. The engine performance parameters were determined and are discussed in the following paragraphs.

The brake thermal efficiency (BTE) is defined as the ratio of brake power developed by the engine to the heat supplied to the engine as a function of the thermal input from the fuel. It indicates how effectively engine converts the heat from a fuel into mechanical energy. Figure 4 shows the effect of fuels on engine BTE at different loads. From the figure, we observe that as the load increases the BTE also increases and this is due to lower frictional losses at the higher loads. The BTE of biodiesel added with DEE is higher than biodiesel (B100). There is a slight difference in BTE of B95D05 and B90D10. However, the biodiesel blend of B95D05 gives higher BTE as compared to other blends. This is due to improvement in fuel properties of biodiesel by the addition of DEE. The DEE has higher volatility and hence the addition of DEE to biodiesel improves the atomization and spray formation of the biodiesel. This results in better combustion and higher heat release. The B90D10 results in higher BTE as compared to B85D15. The B85D15 results in lower BTE as compared to other blends due to separation of DEE from biodiesel which affects the spray formation and combustion.

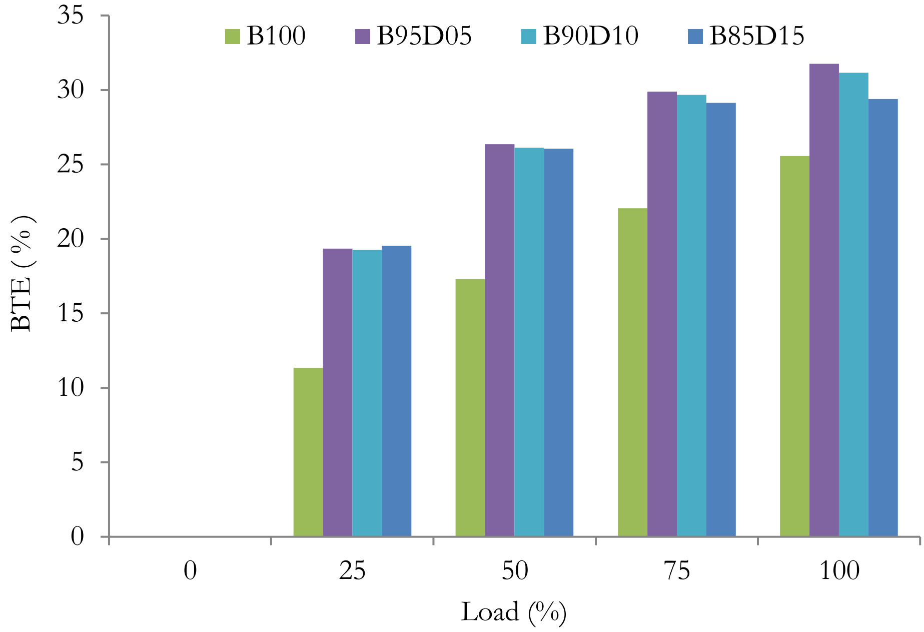

Fig. 4. Brake thermal efficiency versus load

Figure 5 shows the variation in engine exhaust gas temperature (EGT) of the engine at different loads with various fuels. From the figure we observe that the EGT value increases with increase in load. The biodiesel added with DEE results in higher EGT as compared to biodiesel. The biodiesel has higher viscosity and lower volatility which causes a higher ignition delay. This affects the combustion and combustion temperature. The addition of highly volatile DEE to the biodiesel reduces the ignition delay and enhances the premixed combustion phase. This results in better combustion and higher temperature. The higher combustion temperature results in higher EGT. At part loads, B95D05 results in higher EGT. However, the fuel blend B90D10 causes higher EGT as compared to other blends at 100% load.

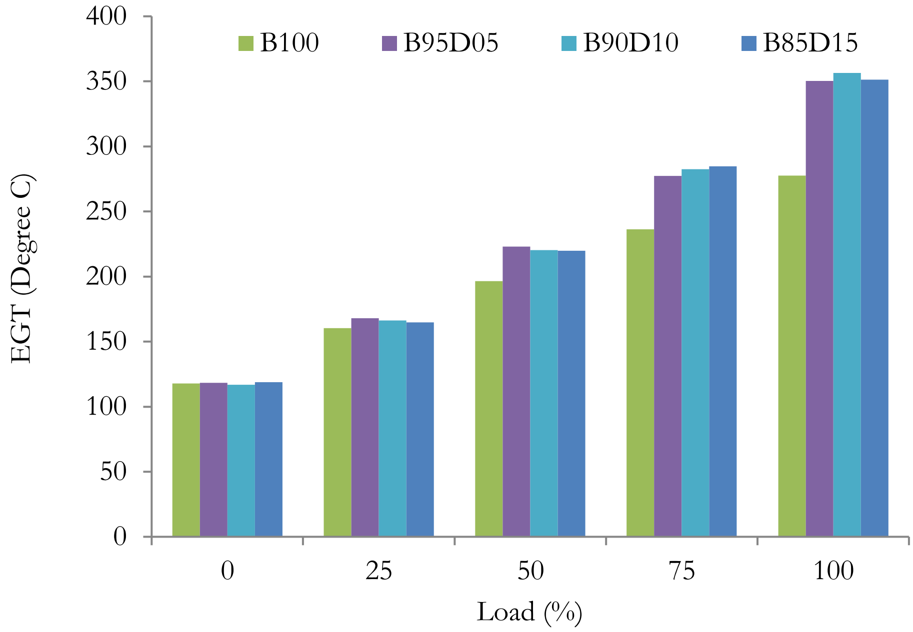

Fig. 5. EGT versus load

3.3 Engine Emissions

The CO emission is formed in the diesel engine is due to poor mixing of fuel and air, locally rich zone and incomplete combustion of fuel. The variation in CO emission of the engine with different fuels and at different loads is shown in the Figure 6. From the figure, it is observed that the CO emission of the engine increase from part load to full load as the air–fuel ratio decreases with increase in load. The CO emission of the diesel engine is high at full load due to consumption of higher amount of fuel. The higher fuel consumption and lower air-fuel ratio causes the formation of products of incomplete combustion. Hence higher CO emission level at 100 % load.

The addition of DEE to the biodiesel significantly affects the CO emission of biodiesel fuelled diesel engine. The biodiesel DEE blend, B95D05, results in lower CO emission as compared to other blends. At lower concentration of the DEE in the blend, the inbuilt oxygen helps in complete combustion of the fuel. But the higher concentration of DEE increases the volatility of the fuel and there is a slight change in phase separation of DEE during injection of the biodiesel into the combustion chamber. This causes poor atomization of biodiesel which results in poor combustion of fuel. This suppresses the complete combustion process and as a result the emission of CO increases. Among the fuel blends, the fuel B95D05 results in lower CO emission. The addition of higher concentration of DEE results in higher CO emission as compared to the biodiesel.

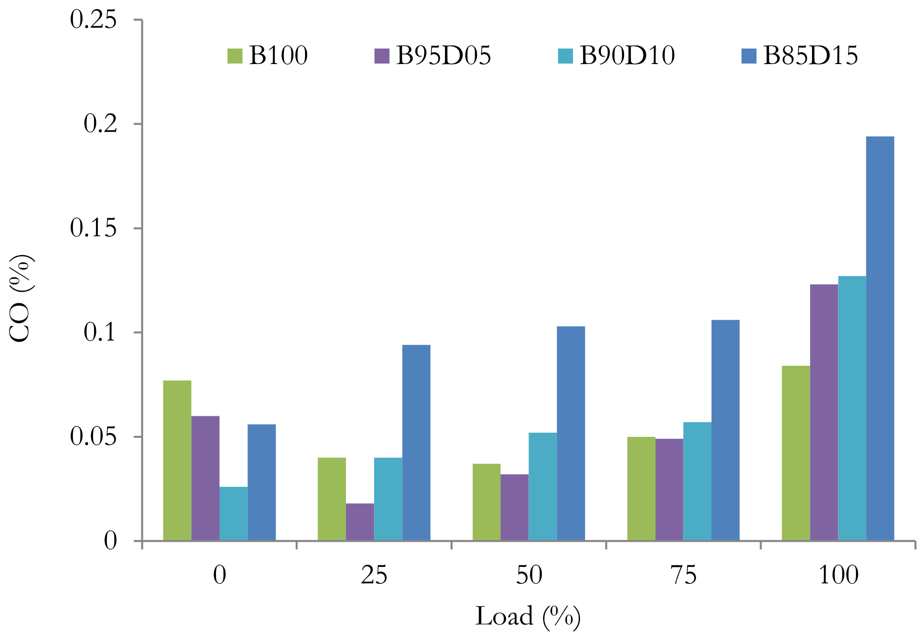

Fig. 6. CO versus load

The incomplete combustion of the fuel causes the formation of unburned hydrocarbon (UBHC) emission and is one of the important parameters which determine the emission behaviour of the engine. Figure 7 shows the UBHC emission of the engine with various fuels at different loads. From the figure it is observed that the UBHC emission of the engine increases with load due to supply of higher amount of fuel which results in insufficient oxygen to burn the fuel. The addition of DEE to the biodiesel affects the UHBC emission of the biodiesel. The blend B90D10 and B85D15 results in higher UBHC emission as compared to B95D05 and B100. The B95D05 results in lower UBHC emission as compared to other blends.

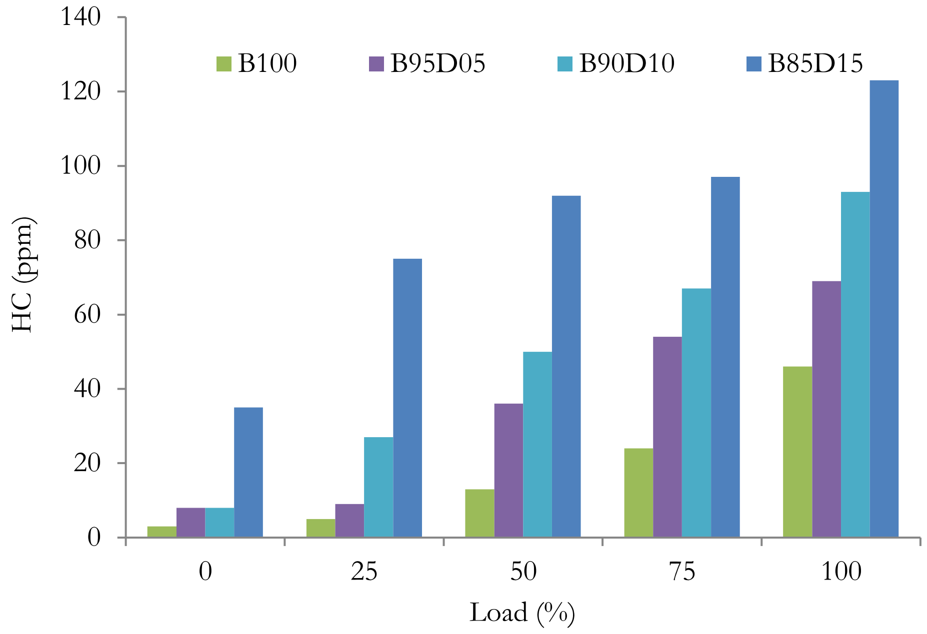

Fig. 7. HC versus load

The oxides of nitrogen (NOx) emission is one of the major emissions of the diesel engine. The NOx emission is produced from the reaction of nitrogen and oxygen in the air during combustion process and is affected by the maximum burned gas temperature, the relative concentration of oxygen and the reaction time. Figure 8 shows the NOx emission of the engine at different loads. From the figure we observe that the biodiesel result in higher NOx emission. The addition of DEE to the biodiesel results in higher NOx emission. The fuel blend, B85D15 and B90D10 results in lower NOx emission as compared to B95D05.

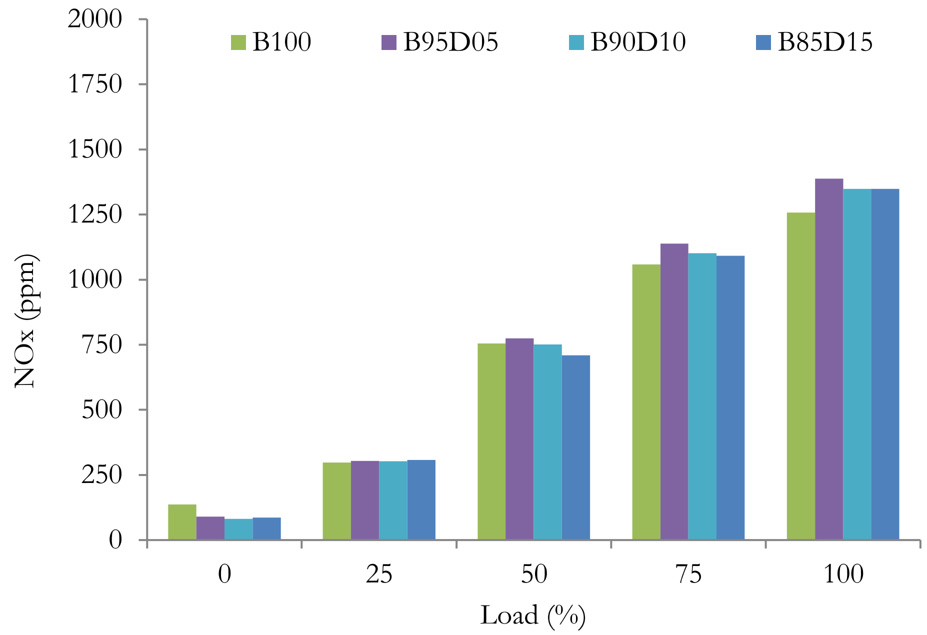

Fig. 8. NOx versus load

Figure 9 shows the smoke opacity of the engine with different fuels at different loads. From the figure, it is observed that as the load increases the smoke emission increases. This is due to consumption of higher amount of fuel at higher loads. The addition of DEE to the biodiesel reduces the smoke emission at higher loads. This may be due to improved oxidation process of fuel and presence of oxygen in the fuel which minimizes the smoke formation. The rapid flame propagation and extended duration of combustion are the other reasons for reduced smoke emission. The smoke emission of B95D05 is lower than the other blends.

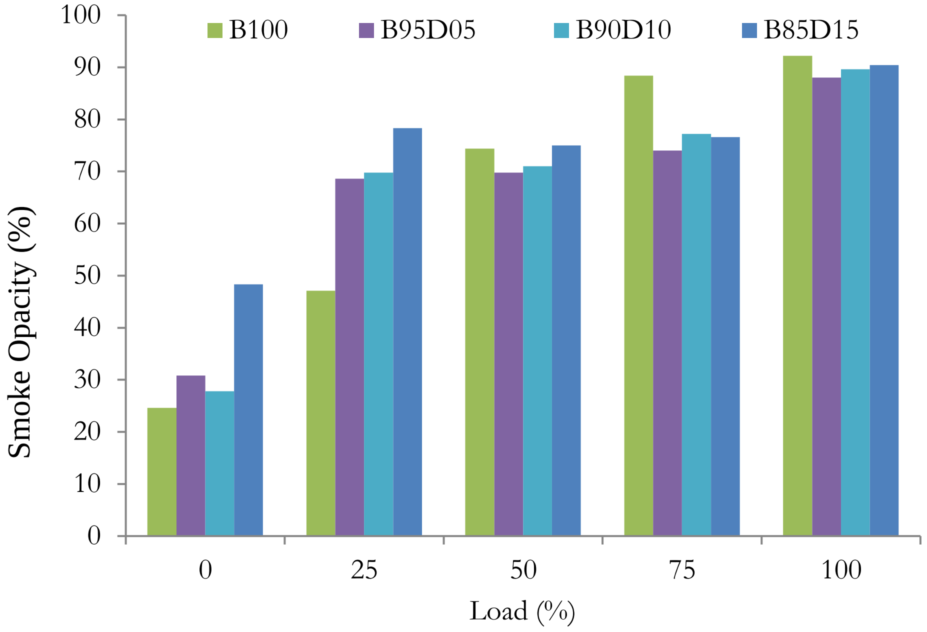

Fig. 9. Smoke opacity versus load

The pressure rise with different fuel blends at full load is shown in the Figure 10. From the figure we observe that the pressure rise is lower with the blend B85D15. There is a slight difference was noticed with B95D05 and B90D10. This is due to the shorter ignition delay resulting in an earlier combustion duration and higher maximum cylinder pressure.

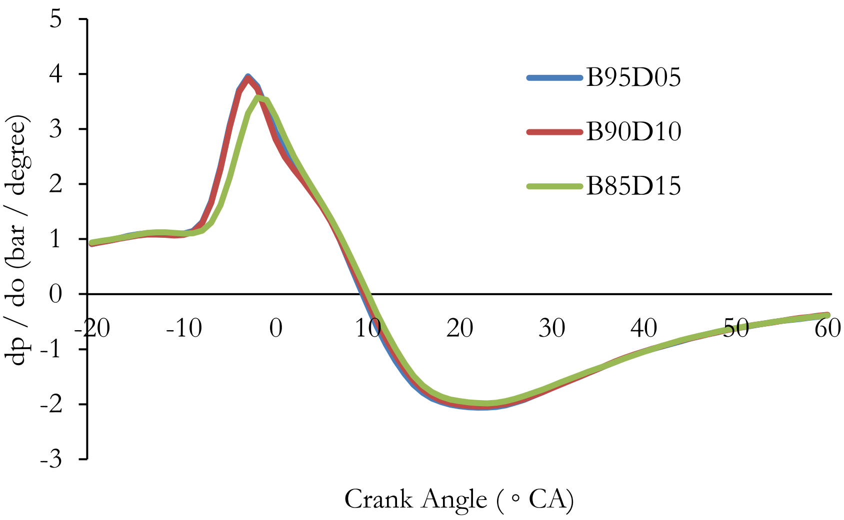

Fig. 10. dp / do versus crank angle

The heat release variation with different fuels at full load is shown in the Figure 11. It is observed that the blends B95D05 and B90D10 showed an improvement in the heat release rate during the pre-mixed combustion period. The addition of DEE in the biodiesel may increase the cetane number and volatility of the fuel which has decreased the ignition delay period and might have caused better combustion and better heat release.

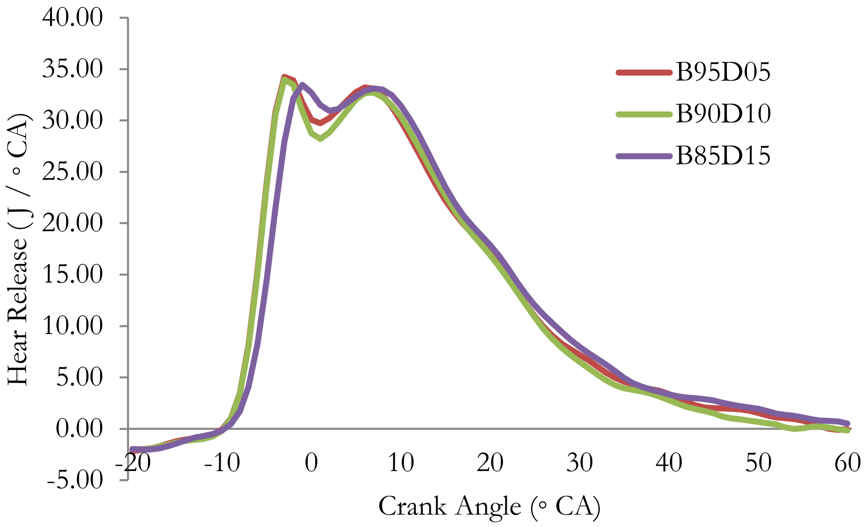

Fig. 11. Heat release rate versus crank angle

4. Conclusion

In this work, biodiesel was produced from non-edible honge oil and DEE was used as additive for the biodiesel. From the property analysis, it was found that the properties of the biodiesel improved with the addition of DEE to the biodiesel. The flash point and viscosity of the honge biodiesel improved with the addition of DEE. The engine tests were carried out on a single cylinder compression ignition with diesel, biodiesel and various blends of biodiesel and DEE. From the engine tests, it is observed that the addition of DEE to the honge biodiesel improves the thermal efficiency and reduces the engine exhaust emissions of the diesel engine. The blend, B95D05, gives higher thermal efficiency and lower engine exhaust emissions such as CO HC and smoke emission as compared to other blends. However, it slightly increases the NOx emission as compared to other blends. Since DEE can be produced from renewable energy sources, DEE can be used as a renewable additive to the honge biodiesel.

Acknowledgement
The authors thank the management of NCET for providing necessary facilities to carryout biodiesel production and fuel testing.

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