Comparative study of performance and emission characteristics of a CI engine using blends of corn oil methyl ester with diesel fuel

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Abstract: The rapidly increasing demand of energy and depletion of fossil fuel resources initiated developments to renewable energy in from of vegetable oils, animal fats and their derivatives. Biodiesel derived from vegetable oils such as their methyl esters and ethyl esters are promising as performance parameters are comparable with diesel fuel and exhaust emissions are lower than that of diesel fuel. In the present study, methyl ester of corn oil is prepared through transesterification using methanol. The physical and chemical properties of corn oil methyl ester (COME) are comparable with diesel fuel. Tests have been worked out to evaluate performance and emission characteristics of a stationary compression ignition (CI) engine using COME100 and its blends (COME25, COME50 and COME75) with diesel fuel. The acquired data are compared and analysed under different load conditions for the diesel fuel.

Keywords: compression ignition engine; biodiesel; corn oil methyl ester; COME.

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1 Introduction

The CI engine is a most important tool for transportation, agriculture and routine life of contemporary society. In India, the ratio of diesel to gasoline fuel is 7:1, depicting a highly skewed situation (Murugesan et al., 2009). In addition to that rapid depletion of conventional fuels and the impact of continuously increasing environmental pollution level through exhaust emissions by CI engines promoted research for alternative fuels for use in these engines. In this series, a number of researchers have tested compatibility of vegetable oils and biodiesels as fuel for CI engine. Use of vegetable oil is advantageous as it is easily available, eco friendly to the environment and renewable (Srinivasa and Gopalakrishnan, 1991). From Agarwal (1998) and Korus et al. (1985), it is noticeable that there are a number of problems associated with use of vegetable oils as fuel in CI engines, mainly due to their inherent viscosity. The high viscosity of vegetable oils leads to problems in pumping, combustion and atomisation in injector systems of CI engine. While in long term operation, vegetable oils introduce the development of gumming, ring sticking, injector deposits and incompatibility with regular lubricating oils (Pramanik, 2003). Therefore, vegetable oils are not recommended to be used directly in CI engines for long time operation. In order to lower down the viscosity of the vegetable oils, options have been identified as transesterification, blending and pyrolysis (Hazar and Aydin, 2010). Out of these projected solutions, transesterification is a convenient and most attractive option to lower down the viscosity of vegetable oils. Transesterification is the process to convert vegetable oils into their respective methyl ester and ethyl ester with the help of methanol and ethanol respectively in the presence of catalyst. A thorough description of the transesterification is available in the literatures (see Zheng and Hanna, 1996; Ramadhas et al., 2004; Nelson and Schrock, 2006).

From the literatures (Selvam and Vadivel, 2012; Varuvel et al., 2012; Baiju et al., 2009; Aliyu et al., 2011; Pillay et al., 2012), it is observed that research have been carried out on alternative fuels in CI engines especially biodiesels produced from different kinds of vegetable oils. Various non edible and edible oils have been used as feedstock for biodiesel. Sonar et al. (2015) experimentally evaluated effect of Mahua and Mahua oil methyl ester on a CI engine with varying injection pressure and reported significant reduction in HC and CO. Ahmed et al. (2014) investigated engine performance, emission and noise using *Brassica juncea* methyl ester (mustard biodiesel). NOx emission was reported increased by 9%–12% with use of mustard biodiesel. *Aphanamixis polystachya* methyl ester was tested by Palash et al. (2015). Results showed average reduction in brake power, torque, CO and HC but increase in brake specific fuel consumption (BSFC) and NO. Hosmath et al. (2016) conducted experiments on a CNG fuelled dual fuel engine operated on honge oil methyl ester and reported significant increase in brake thermal efficiency (BTE) and NOx emission but reduction in smoke.

It is evident from the reported literatures that BSFC increased for most of the biodiesel and its blends compared to diesel fuel. On the other hand, average drop was reported in BTE and torque of CI engines. Use of methyl ester of vegetable oils contributes towards cleaner environment by reducing CO and HC emissions. NOx formation was reported higher for biodiesel compared to diesel fuel. The enriched oxygen in biodiesel is responsible factor in the formation of NOx, because it increases the combustion temperature due to excess hydrocarbon oxidation (see Raheman and Ghadge, 2007; Fernando et al., 2006).

In the present study, performance and emission characteristics have been evaluated and compared for various fuels such as COME100 (100% COME), COME25 (25%COME + 75% diesel), COME50 (50%COME + 50% diesel), COME75 (75%COME + 25% diesel), and D100 (100% Diesel) at various loads, i.e., 0%, 25%, 50%, 75% and 100% of full load of the CI engine. Performance characteristics such as BSFC, BTE and EGT have been chosen for study whereas emissions characteristics such as CO, HC, CO_2 and NOx emissions have been selected.

2 Production of biodiesel from corn oil

Corn oil is derived from the corn germ, which is the only living part of the corn. Firstly, Harvested kernels of corn are cleaned. These cleaned harvested kernels then steeped in water at a temperature of 50°C for 30 to 40 hours (Lin et al., 2009). In the process, moisture content of these kernels rises about 15% to 45% whereas their volume goes around double. Now, gluten bonds in the corn are destabilised and starch is released. The corn is freed from the germ and other components. The steep water is recycled for use in animal feeds because it has absorbed various nutrients in it. These corn germs constitute 8%–14% of the total weight of the corn grain. Corn germs are having 84%–86% oil content by weight (Singh and Singh, 2010).

In this research, a one step transesterification of corn oil with methanol was performed opting KOH as catalyst to produce corn oil methyl ester (COME). The corn oil was procured from Ashwin Vanaspati Ind. Pvt. Ltd. (INDIA). Whole process of transesterification carried out in a biodiesel reactor of 5,000 ml capacity equipped with speed and temperature controllers. Corn oil was converted into methyl ester by removing glycerol through transesterification process with methanol in presence of KOH as base catalyst. In this process, firstly, corn oil heated to around 70°C for 30 minutes to remove the impurities. After this, a sample of 1,000 ml corn oil, 200 ml of methanol and 10 g of KOH were placed in biodiesel reactor equipped with magnetic stirrer, heater and digital thermometer. The mixture is then stirred rigorously and heated to 60°C for 2 hours and then it is allowed to cool and settle at room temperature for 24 hours. Then glycerol and

COME layers are separated in a funnel. Finally COME is purified with distilled water and dried at room temperature.

2.1 Fuel properties

The properties of COME and diesel fuel are given in Table 1. The fatty acid composition of corn oil is presented in Table 2. It is observed from the data presented that the viscosity of biodiesel is slightly higher than that of diesel fuel. The density of the biodiesel is 5.42% higher whereas lower heating value is 11.1% is lesser than that of diesel fuel. Therefore, comparatively more amount of fuel quantity is needed to be injected into the combustion chamber to produce same amount of power.

Table 1 The properties of diesel fuel and COME (COME100)

Property	*Diesel fuel*	*COME100*
Density @ 25°C (gcm-3)	0.837	0.885
Viscosity @ 25°C (mm2s-1)	3.25	4.36
Calorific value (MJkg-1)	44.4	39.8
Cetane number	51.2	55.4

Table 2 The fatty acid composition of corn oil

Acid	*% composition*
Unsaturated fatty acids	86.7%
-Linoleic	56%
-Oleic	30%
-Linolenic	0.7%
Saturated fatty acids	13.3%

3 Experimental set up and procedure

The test rig set up for the experimental study is shown in Figure 1. Figure 2 shows the realised engine test rig. It consists of a test bed, a four stroke single cylinder stationary CI engine coupled with hydraulic dynamometer, a control panel, a five gas analyser, a computer and various sensors to measure the cylinder pressure, the exhaust temperature at the manifold, etc. Refer to Table 3 for technical specifications of the engine.

Figure 1 The design of the engine test rig

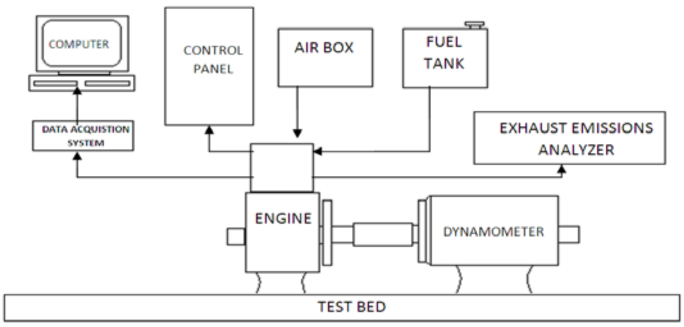


Figure 2 The realised engine test rig (see online version for colours)

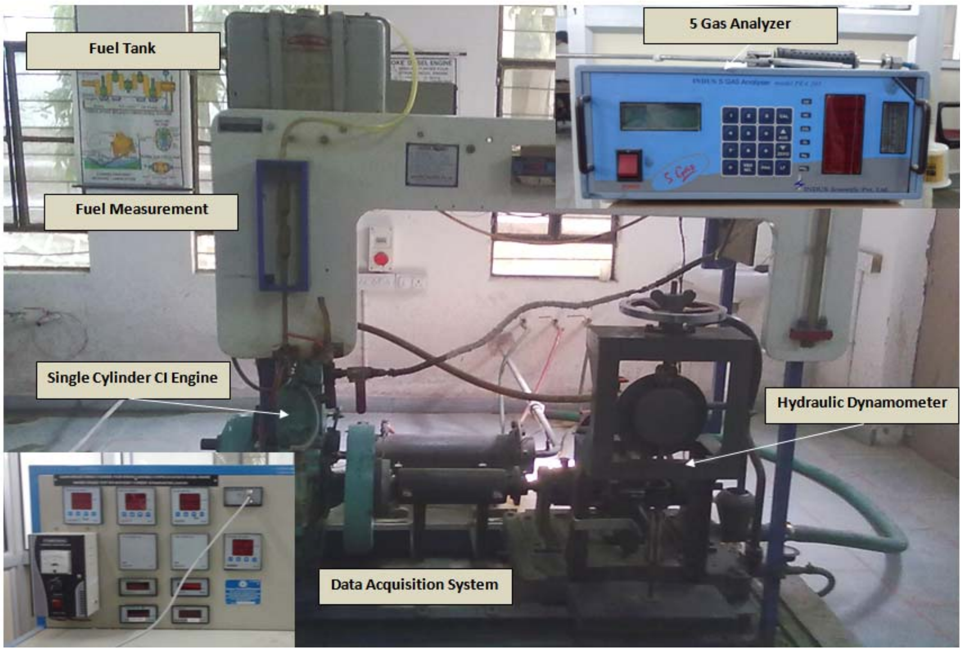


Table 3 Technical specifications of the engine

Specifications	*Description*
Make	Kirloskar
Model	AV1
Type	Water-cooled, four-stroke
Number of cylinders	s1
Swept volume	553 cc
Compression ratio	16.5: 1
Rotation	Clockwise
Bore	80 mm
Stroke	110 mm
Speed	1,500 rpm
Continuous power output	3.7 kW at 1,500 rpm

A five exhaust gas analyser of INDUS Scientific Private Limited (11/2B, Hennur Bande, Bangalore-560043, India) model PEA205 is used to measure the exhaust emissions from the engine, i.e., carbon monoxide (CO), carbon dioxide (CO_2), oxygen (O_2), hydrocarbon (HC) and oxides of nitrogen (NOx). Before testing gas analyser is calibrated for standards by the service person.

3.1 Test procedure

The fuels used in this experimental study include diesel fuel, biodiesel (COME) and its blends with diesel. The experiments is carried out using neat diesel fuel (denoted as D100), 25% COME + 75% diesel (denoted as COME25), 50% COME + 50% diesel (denoted as COME50), 75% COME + 25% diesel (denoted as COME75) and 100% COME (denoted as COME100) at different engine loads from 0%–100% rated engine load in approximate steps of 25%. Two separate fuel tanks are used for storing diesel and blends of COME with burette and three way cock (to measure fuel consumption). Engine is run on idling load for first 15 minutes to obtain stabilised working condition and then on every test load condition 10 minutes is allowed for this. Brake power is measured with the help of hydraulic dynamometer (Froude's dynamometer). The fuel consumption is measured with the help of burette (25 ml volume) and a stopwatch. The exhaust gas temperature is measured with a K-type thermocouple located on the exhaust manifold. The exhaust emissions have been measured using a five gas analyser INDUS make. The accuracy of measurements and calculated uncertainty values are shown in Table 4.

Table 4 The uncertainties of instrumentation

Parameter	*Uncertainty*
Load	± 2N
Speed	± 5 rpm
Time	± 1 sec
Temperature	± 1°C
CO	± 0.06% vol.
CO_2	± 0.5% vol.
HC	± 12 ppm
NOx	± 12 ppm
Power	± 2% max
BSFC	± 2.5% max
BTE	± 2.5% max

4 Results and discussion

4.1 Engine performance characteristics

4.1.1 Brake specific fuel consumption

The variation of BSFC with varying load for biodiesel blends with diesel and diesel is shown in Figure 3. The BSFC is generally high for low load and low for high load and further high for very high load. For all test fuels BSFC is found to be decreased with respect to the engine load. Among the tested fuels, diesel fuel is having lowest BSFC at full load; it is due to low fuel consumption and high brake power. For other fuels it found increasing as the blending % of biodiesel COME increased. COME100 has the maximum BSFC at full load among all tested fuels; it is due to lower calorific value, high viscosity and high density of biodiesel and its blends compared to that of diesel. The BSFC for diesel fuel, COME25, COME50, COM75 and COME100 are 0.342, 0.353, 0.371, 0.392 and 0.416 kg/kW-hr respectively at full load of the engine.

Figure 3 The comparison of BSFC of different fuels (see online version for colours)

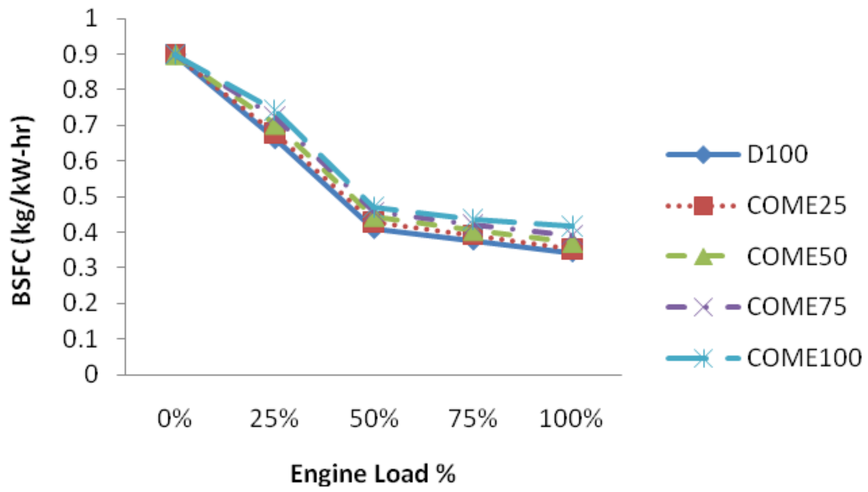
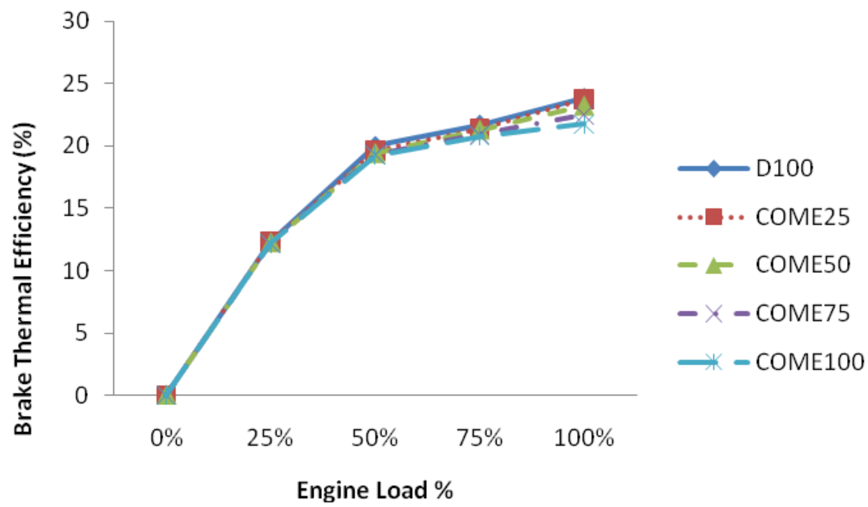


Figure 4 The comparison of BTE of different fuels (see online version for colours)



4.1.2 Brake thermal efficiency

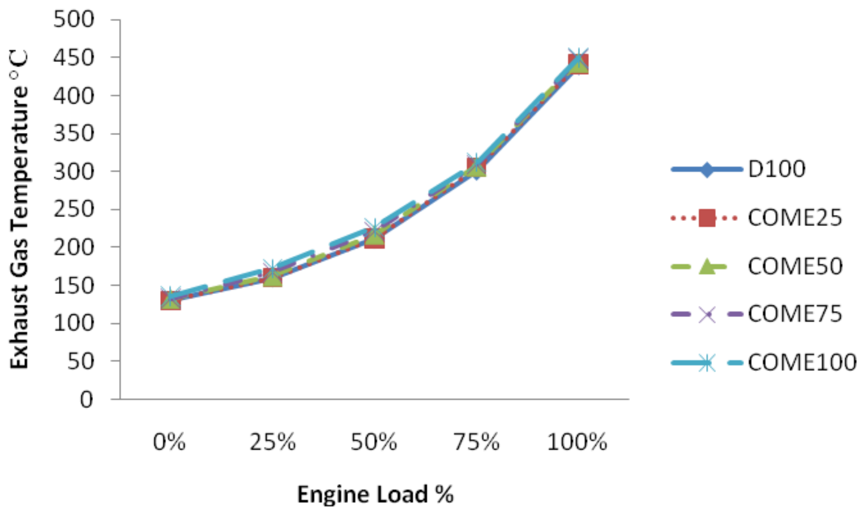
The BTE is a very important performance parameter for engine. The variation of BTE for blends of COME with diesel and diesel with respect to the engine load is shown in

Figure 4. The BTE in general decreases with increase in blending% of COME in diesel and maximum for the diesel fuel. High viscosity, high density and lower calorific value of fuel are the reason for this. The higher viscosity of biodiesel leads to poor atomisation and fuel vaporisation that is responsible for low BTE than the diesel fuel, refer to Srivastava and Verma (2008). The BTE for D100, COME25, COME50, COME75 and COME100 are 23.83, 23.71, 23.21, 22.49 and 21.73% respectively at full load of the engine.

4.1.3 Exhaust gas temperature

The variation of exhaust gas temperature with respect to load for various fuels is shown in Figure 5. Exhaust gas temperature is a measure of temperature of exhaust gases just after the combustion chamber and measured with the help of a thermocouple placed just after the exhaust manifold. The EGT increases with respect to the load. The EGT of COME blends were found slightly higher than that of diesel fuel. This may be because of longer after burning stage (see Puhan et al., 2005). The EGT for D100, COME25, COME50, COME75 and COME100 are 440, 441, 444, 448 and 450°C respectively at full load of the engine.

Figure 5 The comparison of exhaust gas temperatures of different fuels (see online version for colours)



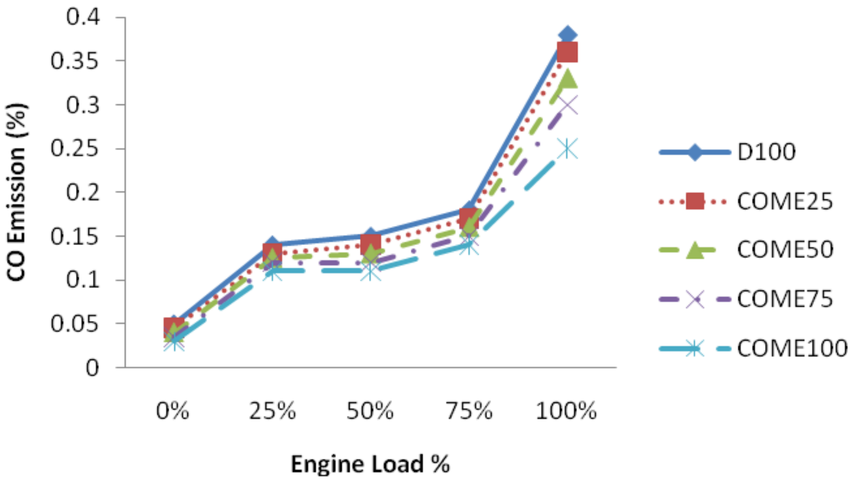
4.2 Exhaust emission characteristics

4.2.1 Carbon monoxide

Figure 6 represents the variation of CO emission for diesel fuel and blends of COME with respect to the engine load. CO is found to be increased with respect to load for all test fuels. The differences of CO emission are fairly small for COME blends and diesel. Although, at higher load the CO emission of COME and its blends are lower than that of diesel fuel due to presence of higher oxygen content in biodiesel (Palash et al., 2015).

The CO emissions for D100, COME25, COME50, COME75 and COME100 are 0.38, 0.36, 0.33, 0.30 and 0.25% respectively at full load of the engine.

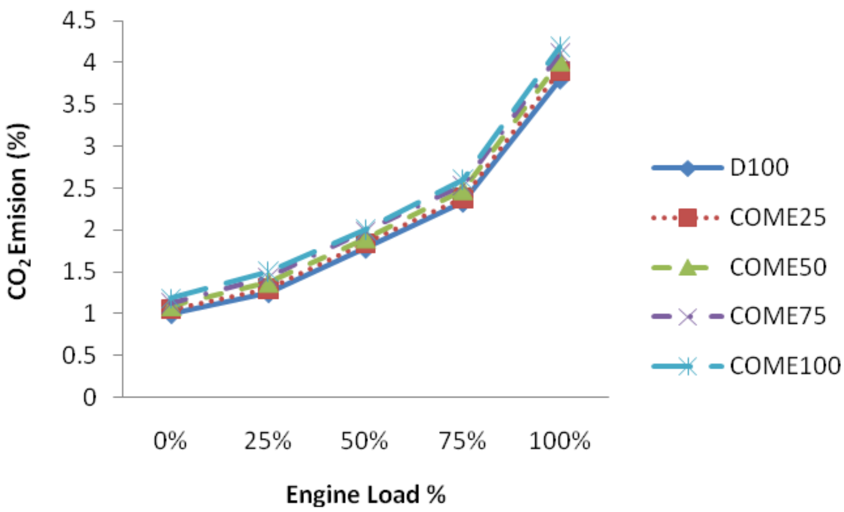
Figure 6 The comparison of CO emissions of different fuels (see online version for colours)



4.2.2 Carbon dioxide

CO_2 is a major contributing element in the global warming as it forms blanket effect on the atmosphere (Aliyu et al., 2011). The CO_2 emissions with the blends of COME at various loads is shown and compared with diesel fuel in Figure 7. The CO_2 emissions from COME blends are higher than that of diesel fuel. Possible reasons are lower calorific value and lower hydrogen-carbon ratio of COME. The CO_2 emissions for D100, COME25, COME50, COME75 and COME100 are 3.8, 3.9, 4.02, 4.11 and 4.19% respectively at full load of the engine.

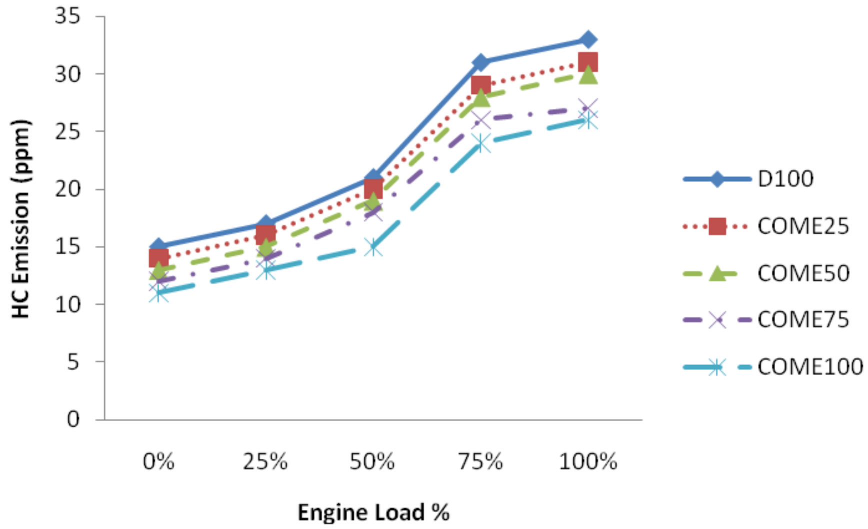
Figure 7 The comparison of CO_2 emissions of different fuels (see online version for colours)



4.2.3 Hydrocarbon emission

The HC emission from engine is due to poor and improper combustion. The variation of HC emission with respect to load for all test fuels is shown in Figure 8.

Figure 8 The comparison of HC emissions of different fuels (see online version for colours)

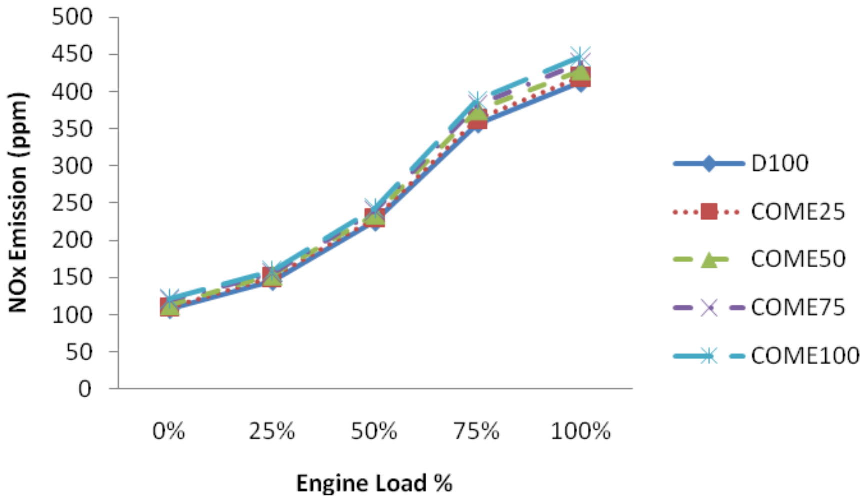


The HC emissions increase with increase in load, in general. This is due to rich fuel mixtures at higher loads. The HC emissions are found to be higher in case of diesel fuel for all test load conditions compared to blends of COME and COME. This may be due to presence of higher oxygen content in biodiesel and high combustion temperature, which also promotes oxidation of hydrocarbon emissions (see Mofijur et al., 2013). The HC emissions for D100, COME25, COME50, COME75 and COME100 are 33, 31, 30, 27 and 26 ppm respectively at full load of the engine.

4.2.4 Oxides of nitrogen emission

Figure 9 expresses the NOx emissions versus engine load graph for all test fuels. The NOx emissions are found more in case of COME and its blends compared to diesel fuel for all test load conditions. Most probably higher viscosity, increased heat release rate and higher oxygen content are the reason for the higher NOx emissions in case of COME and its blends than that of diesel fuel (see Saravanan et al., 2016). High cetane number also influences on the NOx emissions as shortened ignition delay period would be happened (Yoon and Lee, 2011). This allows less time for air/fuel mixing before the premixed combustion phase. Therefore, a weaker mixture would produce low NOx formation. But in case of biodiesels extra oxygen content in the molecules are responsible for high NOx emissions. The NOx emissions for D100, COME25, COME50, COME75 and COME100 are 412, 420, 429, 438 and 447 ppm respectively at full load of the engine.

Figure 9 The comparison of NOx emissions of different fuels (see online version for colours)



5 Conclusions

In this study, the engine performance and exhaust emission characteristics of a CI engine using COME as biodiesel and its blends with diesel have investigated and compared with diesel fuel. Based on this experimental study, the following conclusions are summarised as follows:

- The BSFC values for biodiesel COME25, COME50, COME75 and COME100 are respectively 3.21, 8.47, 14.61 and 21.6% higher than that of diesel fuel.
- The BTE is having a slight decrease in case of biodiesel and its blends than diesel fuel. The BTE of biodiesel and its blends are respectively 0.5, 2.6, 5.6 and 9.2% lower than that of neat diesel fuel.
- The NOx emission is higher than diesel fuel for biodiesel and its blends. This is due to higher oxygen content in the biodiesel than the diesel fuel, which would result in better combustion. The maximum value of NOx emission is 8.5% higher than diesel fuel for neat biodiesel at full load conditions.
- For biodiesel and its blends significant reduction is observed in HC and CO emissions. The values of HC and CO emission are respectively 35% and 22.1% lower for biodiesel compared to diesel fuel at full load conditions. CO_2 emission is found increased in case of biodiesel and its blends than diesel fuel by 10% at full load.

On the whole, the methyl ester of corn oil and its blends can be used as an alternative fuel in CI engines with any major modifications in existing setup of CI engine. It favours lower CO and HC compared to diesel fuel. BTE decreases and BSFC increases for biodiesel and its blends compared to diesel fuel.

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