Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

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

Vol. 18 | No. 4 | pp. 1265-1273 | 2019

Original Research Paper

Open Access

Performance, Emission and Combustion Characteristics of Safflower, Neem and Corn Biodiesels Fuelled in a CI Engine

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

Received: 06-06-2019
Accepted: 21-06-2019

Key Words:
Safflower oil
Neem oil
Corn oil
Biodiesel
Smoke emissions

ABSTRACT

Renewable fuels are desirable as alternate fuels with ignition quality equivalent to diesel and its combustion parameters, but unsuitable for direct operation in diesel engines as fuel because of their higher viscosity. Hence, fuel and engine-based modifications are being developed to improve the performance, emission and combustion behaviour of the compression ignition engines. The higher viscosity of fuel oil does not let it vaporize even after it is being injected into the combustion chamber. Therefore, converting the higher viscosity of vegetable oil into biodiesel improves the atomization resulting in better combustion. Issues related to the use of biodiesel as working fuel are its oxidation stability and performance. In this study, safflower oil, neem oil and corn oil are used as fuel oils. The experimental results displayed a significant increase in the brake thermal efficiency of 28.25% for corn oil methyl ester (COME). HC and CO emissions are lower with corn oil methyl ester. At full load, the smoke emission reduces slightly with corn oil methyl ester about 58% opacity respectively, but it is still lower than diesel having 66.2% opacity.

INTRODUCTION

In recent years, vehicles have become one of the major sources of pollution in urban areas, especially from diesel engines. The use of diesel engine is increasing especially in heavy vehicles due to its higher torque and better fuel economy compared to gasoline fuelled engines. The faster depletion of fossil fuels and stringent emission norms demand an alternate source, to replace the conventional fossil fuel. Factors much needed for this search of alternative fuel is lower emission, stability and availability of the fuel, distribution of the fuel, and its effect on the engine durability which ensures smooth operation of engine. Extensive prior research in last three decades, for using non edible oil (Agarwal et al. 2007, Edwin Geo et al. 2008, Sureshkumar et al. 2008, Nabi et al. 2009, Dhananmurugan et al. 2015, Thiyagarajan et. al. 2016 and Prakash et al. 2018) paves the fundamental understandings to make scientific conclusion and decisions.

Vlada et al. (2018) analyse the biodiesel production from corn oil as a feedstock via the transesterification, the obtained biodiesel was blended with diesel and respective fuel blends were formed. The fuel properties of the biodiesel were analysed, performances and exhaust gas emissions of corn-based biodiesel and its blends with diesel fuel were tested. Finally, issues related to the environmental and socio-economic impacts of corn-based biodiesel production and its distribution were also tackled. The increased biodiesel production from corn oil has reduced CO_2 emissions.

Jayashri et al. (2017) investigated the emission and performance characteristics of CI engine fuelled with blends of Neem oil biodiesel. Biodiesel is prepared from Neem oil by transesterification technique by adding 1% v/v H_2SO_4. The tests were conducted with the respective combination of B10, B20, B30 blends. The experimental results show that lower emissions and higher performance are seen in B10 blend than the other blends and diesel. The brake thermal efficiency was higher than diesel, and CO, HC and NO_x emissions were 23%, 8.5% and 22% lower than diesel.

Ali et al. (2013), made an analysis in considering the aspects related to the production of biodiesel from Neem oil and investigated the fuel properties. The seeds of Neem contain 30-40% of oil; the obtained biodiesel from the neem oil by transesterification are mono alkyl esters. The optimum conditions to achieve maximum yield of biodiesel were investigated at different temperatures and with different molar ratio of Neem oil and methanol.

Atuldhar et al. (2012) investigated the performance, emission and combustion behaviour of biodiesel and its various blends with diesel, and compared with baseline data in a direct injection CI engine. BSFC for biodiesel and its blends was higher than diesel, and BTE of all biodiesel blends was found to be higher than diesel. CO and HC emissions for biodiesel fuelled engine were lower than diesel but NO emissions were higher for biodiesel blends. Heat release rate for all biodiesel blends was almost identical to diesel. Combustion duration for biodiesel blends was found to be shorter than diesel.

Ilkılıc et al. (2011) converted the neat safflower oil into biodiesel using transesterification process with the catalysts of sodium hydroxide (NaOH) and methanol. The biodiesel was blended with diesel fuel by 5% (B5), 20% (B20) and 50% (B50) by volume. The tests were conducted in a single cylinder CI engine to compare biodiesel blends with diesel. The results show that the average performance reductions were 2.2%, 6.3% and 11.2% for B5, B20 and B50 fuels. BSFC was increased by 2.8%, 3.9% and 7.8% as average for B5, B20 and B50, respectively. Considerable reductions were seen in PM and smoke emissions with the use of biodiesel. CO emissions also decreased for biodiesel blends while NOx and HC emissions increased. But the increases in HC emissions can be neglected as they have very low amounts for all test fuels.

Senthil Kumar et al. (2015) evaluated the use of kapok methyl ester in a single-cylinder direct injection CI engine. The investigation was made to analyse the performance and emission characteristics. The results show that exhaust gas temperature and specific fuel consumption are increased for rich blends of Kapok methyl ester, but dip in brake thermal efficiency. The NOx emission was higher than that of diesel at all load conditions. The lean blend of the Kapok methyl ester shows appreciable engine efficiencies, lower values of smoke, and lower CO and HC emissions.

SAFFLOWER, NEEM AND CORN OILS

Safflower Oil

Safflower is a highly branched, herbaceous, thistle-like annual plant. It is commercially cultivated for vegetable oil extracted from the seeds. The seed of safflower oil is white in colour and has a lot of proteins and fats. The extracted oil from these safflower seeds is colourless and flavourless. It is basically same as sunflower oil but safflower oil is more nutritious. It has less fatty acid than olive oil. Safflower seeds usually have 40% of oil by weight. The plant has yellow, orange or red flowers. Each branch will usually have from one to five flower heads containing 15 to 20 seeds per head. Safflower is native to arid environments having seasonal rain. It grows a deep tap-root which enables it to thrive in such environments.

Neem Oil

India is a largely agrarian society with more than a hundred million families dependent on farming for a living. The liberalized Indian economy still depends on the success of agricultural production and 35-40% of India's national income comes from agricultural sources. It is indigenous to India and found in tropical and subtropical regions like Pakistan, Bangladesh, Sri Lanka, and Myanmar. The Siwalik hills, dry forests of Andhra Pradesh, Karnataka and Tamil Nadu (India) are the main habitat of the wild population. Neem is a renewable source of various useful products, seeds and leaves being of particular interest. A fully-grown tree yields about 50 kg fruits and about 350 kg leaves annually. From about 14 million neem trees that grow in India, 0.7 million metric tonnes of fruits and about 5 million metric tonnes of leaves, besides, 83,000 tonnes of Neem oil and 3,30,000 tonnes of Neem cake are expected to be produced annually.

Corn Oil

In India, nearly 2.6 thousand quintals of corn oil is produced in corn-based factories. Average cumulative extraction capacity of these factories is 2.41 thousand tones/day. On an average these factories can extract 3.0-3.5% oil from corn, which contains 5-6% of oil. Thus, there is immense scope to increase the production of corn oil only by improving the efficiency of oil extraction from corn germs. The properties of test fuels as given in Table 1.

Table 1: Properties of test fuels.

PROPERTIES	DIESEL	SME	NOME	COME
Density@15˚C (g/cc)	0.840	0.8929	0.910	0.876
Kin. Viscosity@40˚C (cSt)	3.6	6.61	4.2	4
Lower Calorific Value (kJ/kg)	42,700	38,646	39,820	39930
Cetane Index	45-55	34	55	54

TRANSESTERIFICATION PROCESS

Fig. 1 shows the esterification test setup employed for the transesterification process. Neat safflower, neem and corn oil was converted into biodiesel through the alkaline transesterification reaction for which sodium hydroxide/potassium hydroxide (NaOH/ KOH) was used as a catalyst with methanol. One percent of sodium hydroxide catalyst was dissolved in methanol by 50% in volume and mixture was added to the safflower oil. Then the prepared mixture was stirred at 60ºC for 30 minutes. After that, the reactant material was poured into a transparent vessel and allowed for cooling at room temperature for 8 hrs. It was allowed to settle for separation of glycerol as the bottom layer. The upper layer of biodiesel was put into another transparent vessel for washing with an equal amount of water. The respective biodiesel was heated above 100ºC for 10-20 minutes to re-

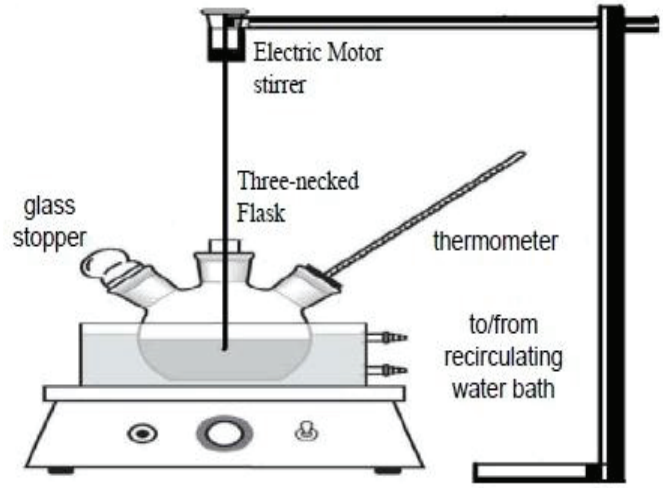

Fig. 1: Schematic diagram of the esterification test setup.

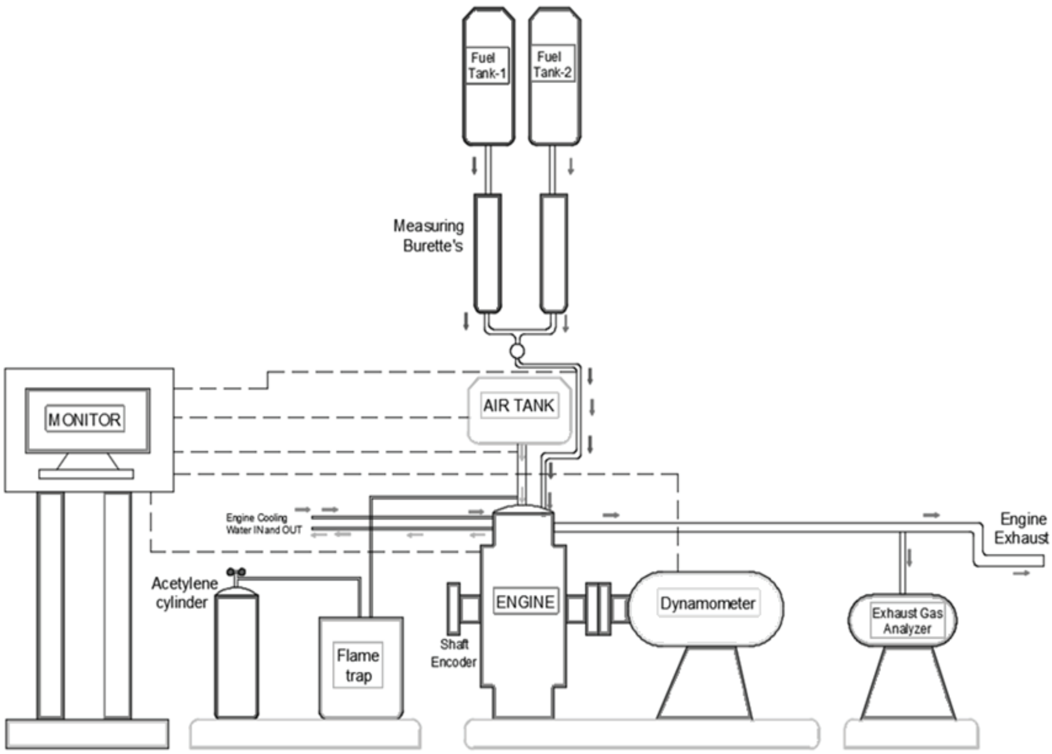

Fig. 2: Schematic diagram of experimental setup.

move excess water. Then the biodiesel was cooled down to room temperature for 10-20 minutes before use.

EXPERIMENTAL SETUP AND TEST PROCEDURE

The tests were conducted in a single cylinder 4 stroke compression ignition engine developing a rated power output of 5.2 kW at 1500 rpm. The specifications of the test engine are given in Table 2. Eddy current dynamometer was employed in loading the engine, the experimental setup was supported with the data acquisition system. In-cylinder pressure was measured using a piezoelectric transducer and charge amplifier. A schematic diagram of the experimental setup is shown in Fig. 2. A precision optical-electronic encoder with a resolution of up to 1°CA was used. An oxide of nitrogen and unburnt hydrocarbon emission was measured using a Non-Dispersive Infrared (NDIR) based exhaust gas analyser. Smoke was measured by % opacity using AVL smoke meter. K-type thermocouple was employed to measure the exhaust gas temperature. The optimum fuel injection timing has been set to 23°CA bTDC for diesel, SME, NOME and COME at various loading conditions. The 'Engine Soft' software was interfaced with the engine with the help of suitable hardware so that the sensors and transducers provided the required input to the software for the calculation of performance parameters.

RESULTS AND DISCUSSION

Performance Characteristics

Brake thermal efficiency

Table 2: Engine specifications

Make	Kirloskar
Model	TV1
Type of Engine	4 stroke single cylinder, CI, Vertical, Water cooled
Rated power	5.2 kW @ 1500 rpm
Compression ratio	17.5:1
Engine bore	87.5mm
Stroke	110mm
Cubic capacity	661.5cm3
Loading device	Eddy current dynamometer

Fig. 3 shows the variation of brake thermal efficiency with respect to brake power for various test fuels at different load conditions. Brake thermal efficiency for diesel, safflower methyl ester (SME), neem oil methyl ester (NOME) and corn oil methyl ester (COME) is 30.74%, 26.10%, 27.27% and 28.25% respectively, at full load. The higher viscous and dense nature of SME leads to the poor combustion characteristics resulting in decrease in brake thermal efficiency, when compared to all test fuels. The poor spray characteristics with large size fuel particles, resulting in poor atomization and vaporization; mixing becomes improper leading to late and sluggish combustion. The properties of NOME and COME favour the combustion, having lower viscosity, density and higher calorific values when compared to SME. Hence, combustion and subsequent heat release are good, contributing to higher brake thermal efficiency for COME compared to SME and NOME. The brake thermal efficiency for COME at full load was 28.25% where for diesel it was 30.74%.

Brake Specific Energy Consumption (BSEC)

Fig. 4 shows the variation of brake specific energy consumption with respect to brake power for various test fuels at different load conditions. Brake specific energy consumption for diesel, SME, NOME and COME are 11.68 MJ/kWh, 13.65 MJ/kWh, 13.20 MJ/kWh and 12.75 MJ/kWh respectively, at full load. Brake specific energy consumption was lower for COME due to the better volatility, reduced viscosity and density leading to better combustion as a result of good air fuel mixture preparation. Brake spe-

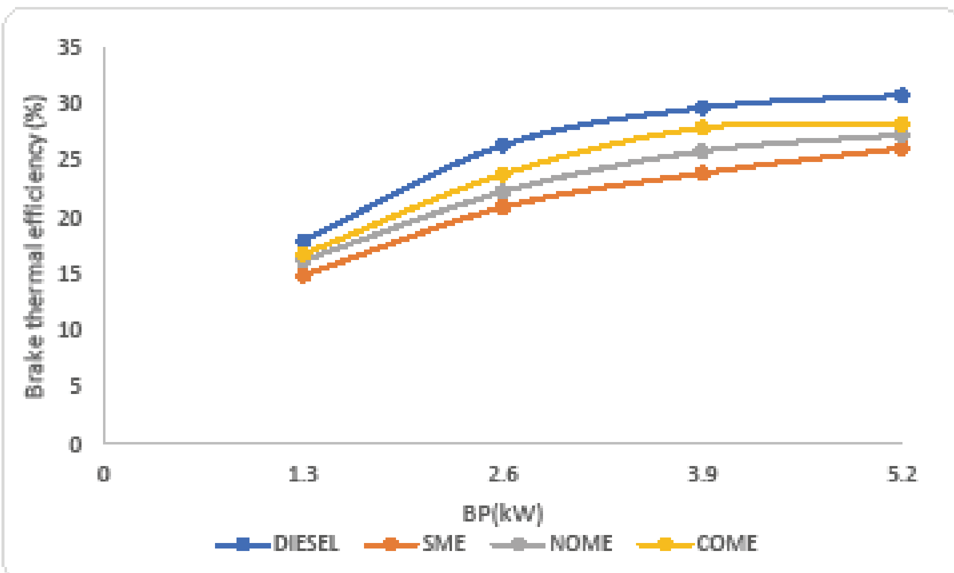

Fig. 3: Variation of brake thermal efficiency with brake power.

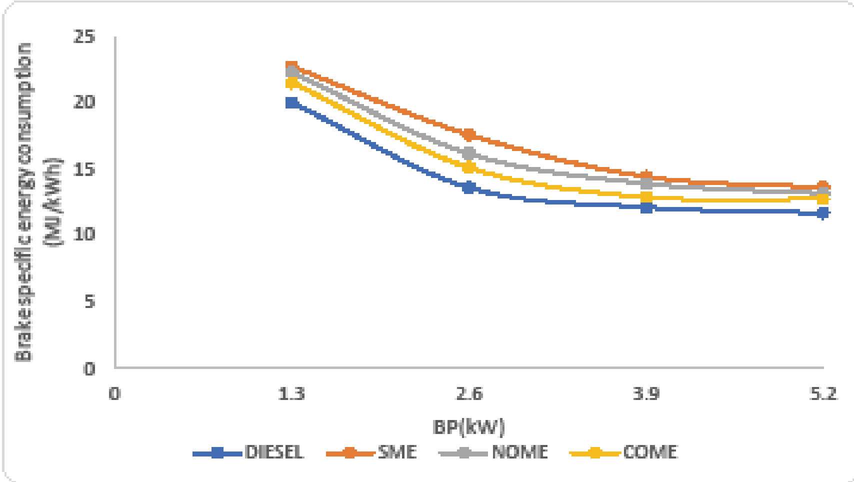

Fig. 4: Variation of brake specific energy consumption with brake power.

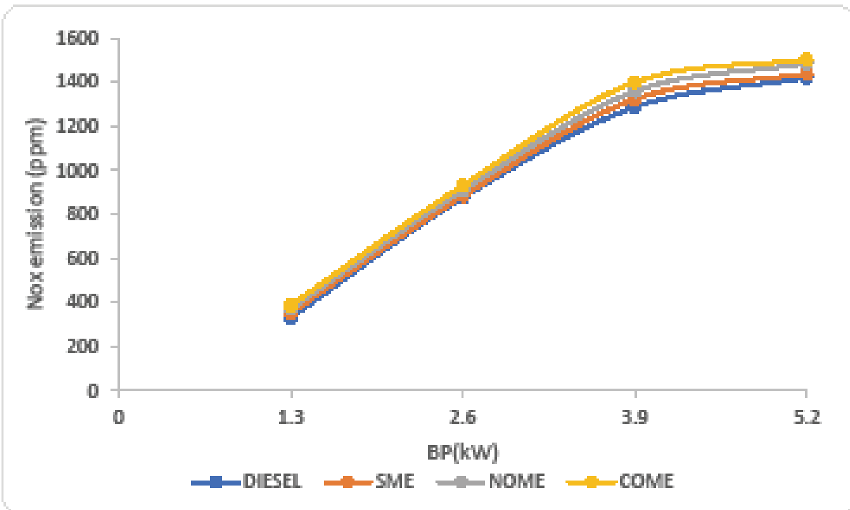

Fig. 5: Variation of nitric oxide emission with brake power.

cific energy consumption for the base diesel was 11.68 MJ/kWh. Lower heating value of SME requires larger fuel flow rates to maintain constant power output from the same engine.

Emission Characteristics

Nitric oxide emission (NO)

Fig. 5 shows the variation of NO emission with respect to brake power for various test fuels at different load conditions at a speed of 1500 rpm. NO emission for diesel, SME, NOME and COME was 1419 ppm, 1437 ppm, 1483 ppm and 1502 ppm respectively, at full load. NO emission was lower for SME in comparison with diesel, due to its increased viscosity and density, ending up in sluggish combustion. The heat released during the premixed combustion phase is less which results in lower in-cylinder temperature and hence lower NO formation. At full load, SME produces 1437 ppm NO emissions, which is lower compared to NOME and COME. The favourable conditions for NO emission are increased in-cylinder temperature and the availability of O_2 molecule, the increased trend of NO emission was visible in COME and other tested fuels. The fuel properties like viscosity and density favours along with oxygen availability in the fuel increases the heat release rate compared to SME. Producing NO emission of 1502 ppm for COME even higher when compared to diesel operation.

Smoke emission

Fig. 6 shows the variation of smoke emission with respect to brake power for various test fuels at different load condition. At full load, smoke emission for diesel, SME, NOME and COME is 66.2%, 64.5%, 60.93% and 58% opacity respectively. SME, NOME and COME emitted less smoke emission when compared to diesel due to the presence of oxygen available in the biodiesel which oxidises the soot particles at higher temperature.

Hydrocarbon Emissions (HC)

Fig. 7 indicates the variation of HC emissions with respect to brake power for various test fuels at different load condition. HC emissions for diesel, SME, NOME and COME was 52 ppm, 50 ppm, 48 ppm and 45 ppm respectively, at full load. The reduction in HC emissions with SME, NOME and COME is due to the presence of oxygen in the biodiesel molecular structure which oxidises unburnt HC emissions to CO_2 and H_2O at elevated temperatures.

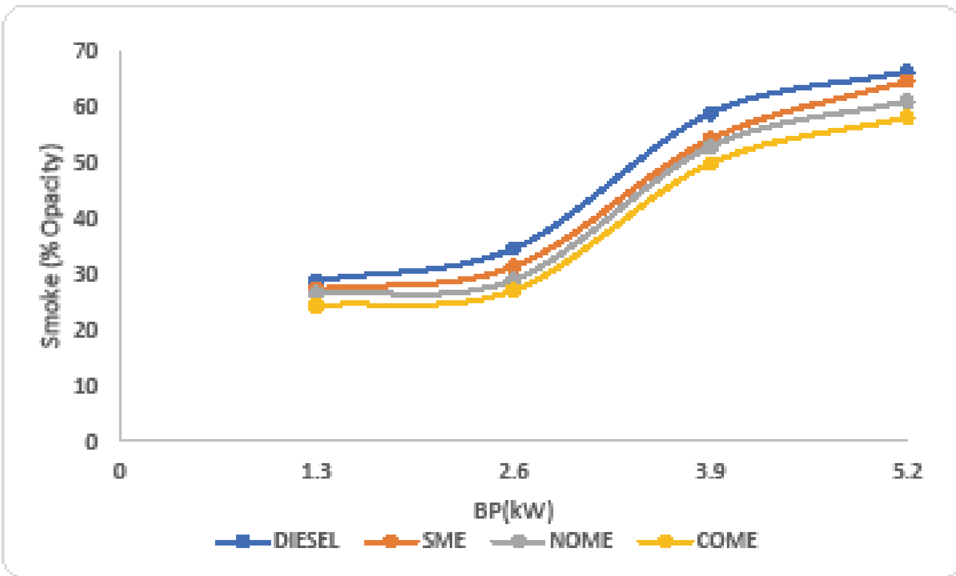

Fig. 6: Variation of smoke emission with brake power.

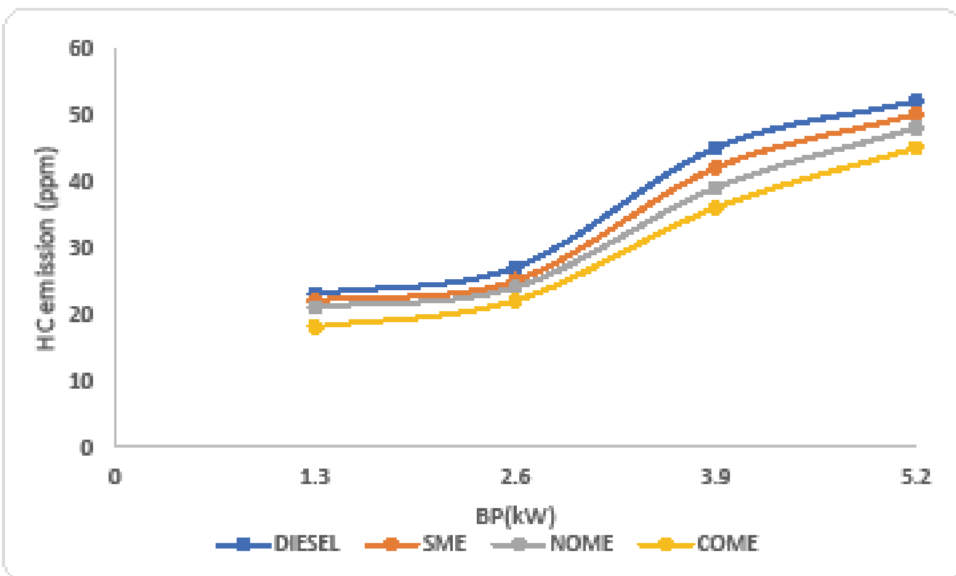

Fig. 7: Variation of hydrocarbon emission with brake power.

Carbon Monoxide Emission (CO)

Fig. 8 shows the variation of CO emission with respect to brake power for various test fuels at different load conditions. At full load, CO emission for diesel, SME, NOME and COME is 0.285%, 0.273%, 0.254% and 0.233% volume respectively. It was observed that SME, NOME and COME emitted less CO emission compared to diesel; the availability of oxygen in biodiesel causes the effect of reduced emissions. SME emitted higher CO emission compared to NOME and COME, which is mainly attributed to slow and incomplete combustion because of poor volatility and higher viscosity of SME that causes less atomization, vaporization and non-uniform air-fuel mixture preparation.

Combustion Characteristics

Heat release rate

Fig. 9 shows the heat release rate with respect to crank angle for various test fuels at full load. The heat release rate for diesel, SME, NOME and COME when fully loaded was 51.44 J/°CA, 40.92 J/°CA, 43.07 J/°CA and 44.49 J/°CA re-

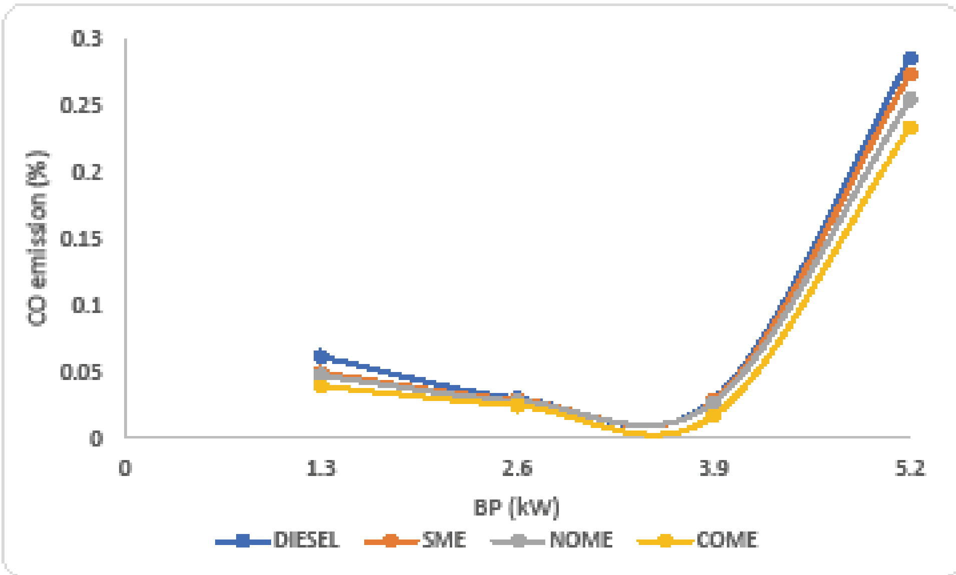

Fig. 8: Variation of carbon monoxide emission with brake power.

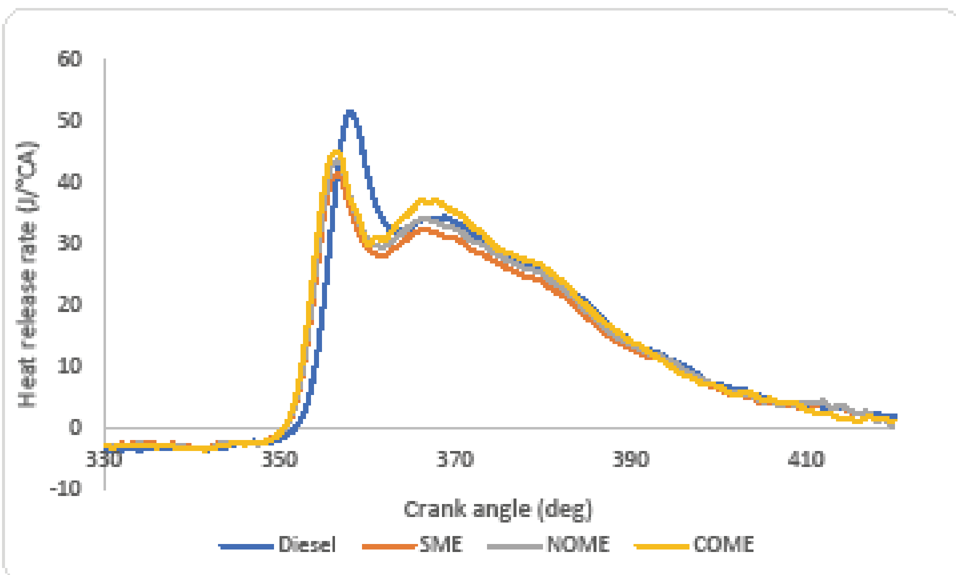

Fig. 9: Variation of heat release rate with crank angle at full load.

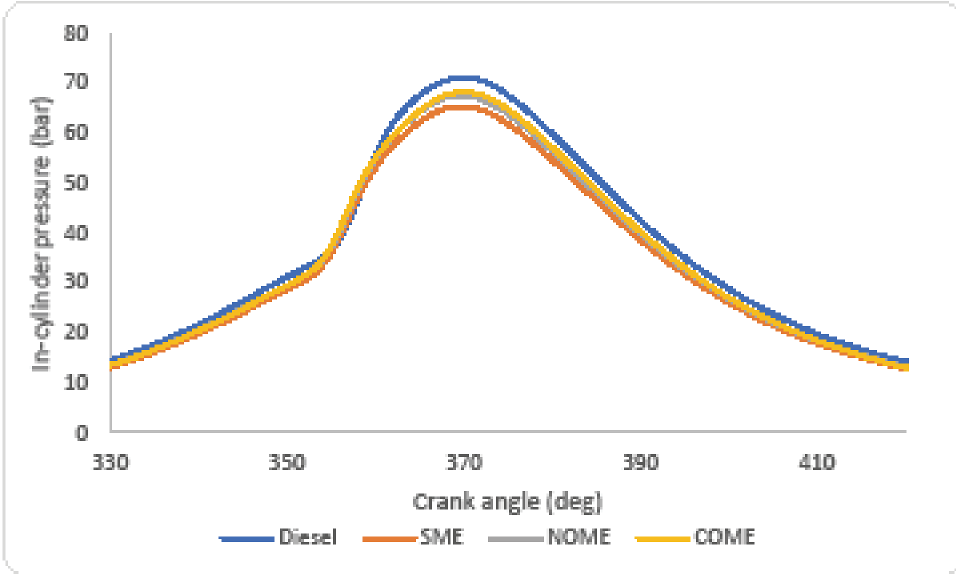

Fig. 10: Variation of in-cylinder pressure with respect to crank angle at full load.

spectively, at full load. The two segments of the heat release are the period of uncontrolled combustion and controlled combustion. Particular interest with combustion studies has been with uncontrolled combustion. It was observed that uncontrolled combustion for diesel, associated with high rate of heat release rate compared to SME, NOME and COME. Due to the high viscosity of SME and subsequently with a reduction in fuel-air mixing rates, less fuel is being prepared for premixed combustion with SME. Therefore, more burning takes place in the diffusion phase rather than in the premixed phase with SME. The rapid heat release is the indication of brake thermal efficiency and NO emission. A higher heat release rate correlating to higher NO emission, which can be realized from Fig. 5. Also, higher diffusion combustion is the indication of smoke emission which is evident from Fig. 6. The end of the rapid combustion has been defined as the dip after the premix spike leading to the diffusion combustion. Higher heat release rate in rapid combustion has been observed in COME compared to SME as a result of lower viscosity of the biodiesel. Higher heat release rate of COME in the rapid combustion phase results in higher peak pressure with lower smoke level and higher NO emission.

In-cylinder Pressure

Fig. 10 displays the variation of in-cylinder pressure with respect to the crank angle at full load. In-cylinder pressure of 71.1 bar, 65.29 bar, 67.4 bar and 68.2 bar was measured for diesel, SME, NOME and COME. It can be noted that higher heat release takes place for diesel operation in comparison with SME, NOME and COME due to better combustion, which results in higher peak pressure. In the case of SME, less fuel-air mixture is prepared during premixed combustion phase, resulting in lower heat release rate, and hence lower peak pressure. Heat release has been delayed and more heat release occurred during the diffusion phase which results in lower peak pressure, higher exhaust gas temperature and lowers useful energy conversion. With COME operation, combustion improves, and hence higher heat release takes place thereby cylinder peak pressure occurs closure to diesel operation.

CONCLUSIONS

A single cylinder four stroke CI engine run with various biodiesels such as safflower methyl ester (SME), neem oil methyl ester (NOME) and corn oil methyl ester (COME). Performance, emission and combustion parameters were examined at different loading conditions of 1.3, 2.6, 3.9 and 5.2 kW and a constant speed of 1500 rpm. The performance, emission and combustion data were examined and compared with diesel. The following conclusions are made:

- At full load, the brake thermal efficiency with SME is 26.10% whereas diesel shows 30.74%. With COME, the combustion improves with a lower viscosity of the fuel, which results in better fuel spray characteristics and air-fuel mixture formation leading to better brake thermal efficiency of 28.25% for COME, which is closer to diesel.

- Brake specific energy consumption of 13.65 MJ/kWh is measure for SME; higher than that of diesel (11.68 MJ/kWh). The increased viscosity of SME leads to poor and incomplete combustion. COME operation reduces the brake specific energy consumption to 12.75 MJ/kWh which is closer to diesel operation, at full load.
- At full load, NO emissions are 1437 ppm, 1483 ppm and 1502 ppm for SME, NOME and COME. With SME, less heat is released during the premixed phase due to poor air-fuel preparation. However, COME operation results in higher combustion temperature with improved combustion because of oxygen availability in the fuel structure. Hence, NO emissions for COME are higher than diesel (1419 ppm) respectively.
- At full load HC emissions are 52 ppm, 50 ppm, 48 ppm and 45 ppm for diesel, SME, NOME and COME. With COME operation HC emissions are lower when compared to diesel (52 ppm) operation. The oxygen present in the fuel molecular structure gets better combustion and also reduced HC emissions.
- At full load, CO emission is 0.285%, 0.273%, 0.254% and 0.233% for diesel, SME, NOME and COME. With COME operation, CO emission is lower when compared to diesel operation. The reduced CO emission with biodiesel is attributed to the presence of oxygen which oxidises CO to CO_2.
- At 100% load, smoke emission is 66.2%, 64.5%, 60.93% and 58% opacity for diesel, SME, NOME and COME. SME, NOME and COME emit less smoke emission when comparison to diesel due to the presence of oxygen in biodiesel which oxidises the soot particles at a higher temperature.
- HRR for diesel, SME, NOME and COME is 51 J/°-CA, 40.92 J/°CA, 43.07 J/°CA and 44.49 J/°CA respectively, at full load. Heat release rate is higher for COME compared to SME and NOME due to increases the premixed combustion phase leading to higher BTE.

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