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RESEARCH ARTICLE OPEN ACCESS

Performance and Emission Analysis of a C.I Engine Fuelled with Neem and Mahua Biodiesel

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ABSTRACT-- The present research is aimed at exploring technical feasibility of sample biodiesel in compression ignition research engine without any substantial hardware modification. The investigations were performed on Compression Ignition engine at C.V. Raman College of Engineering, Bhubaneswar, India. The instruments fitted to the test bed were properly calibrated to minimize the possible errors during experimentation. The investigations were carried out by using selected blends of biodiesel and conventional diesel. The performances and emissions were investigated for the blends at different loads from no load to full load conditions and compared with diesel.

Index Terms—Neem, Mahua, Biodiesel, Performance, Emission, Diesel engine

I. INTRODUCTION

THE petroleum fuel causes severe environmental pollution due to combustion in vehicular engines. The fossil fuel mainly constitute of carbon and hydrogen in addition to traces of sulphur.It produces various gases, like CO, HC, NO_x, soot, lead compounds and other organic compounds during combustion which is released into atmosphere causing degradation of air quality as reflected in[1]-[2]. A light vehicular engine discharges 1 to 2 kg of pollutants during a day and heavy automobile discharges 660 kg of CO during a year. The carbon monoxide is highly toxic and the exposure for a couple of hours can cause impairments to physiological functions. Oxides of nitrogen and unburned hydrocarbons from the exhaust can cause environmental fouling by forming photo-chemical smog.

For India's economic growth achieving energy security is of fundamental importance. An energy balance gives a more complete picture of the gap between supply and use of energy. India was the fourth largest consumer of oil and petroleum products in the world in 2011. It was also the fourth largest importer of oil and petroleum products.

To meet the present energy crisis, one of the important strategies need to be adopted is to develop and promote appropriate technology for utilizing non-traditional energy resources to satisfy the present energy requirements.

Biodiesel is a clean burning alternative bio-fuel produced from domestic renewable resources. It contains no petroleum, but it can be blended at any level with diesel to create a biodiesel blend. It can be used in existing oil heating systems and diesel engines without making any alterations. Biodiesel has gained popularity due to its sustainability, low contributions to the carbon cycle and in some cases emissions of lower amounts of greenhouse gases. Other characteristics of biodiesels are that they are biodegradable, non-toxic and essentially free of sulphur and aroma. The better lubricating properties of biodiesel increase functional engine efficiency. Technically biodiesel fuel is composed of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats and is designated as B100. It meets the requirements of ASTM (American Society for Testing & materials) D6751 and European Standard EN-14214. In India the Standard was adopted by the Bureau of Indian Standards (BIS-15607).The major difference between diesel and biodiesel is that Diesel is extracted from crude oil and refined to different levels whereas biodiesel is extracted from plant, seed and animal fats. Diesel is a non-renewable fossil fuel by product while biodiesel is renewable. The use of biodiesel in a conventional diesel engine results in a substantial reduction of emissions of un-burnt hydrocarbons, carbon monoxide and particulate matter compared to emissions from diesel fuel. The ozone forming potential of biodiesel hydrocarbons is 50% more than that of diesel fuel. The exhaust emissions of sulphur oxides and sulphates (major components of acid rain) from biodiesel are essentially eliminated. The exhaust emissions of carbon monoxide (a poisonous gas) from biodiesel are on average 48% lower than that of diesel. The exhaust emissions of particulate matter from biodiesel are about 47% lower than overall particulate matter emissions from diesel.

Referring to [3], emissions of nitrogen oxides are either slightly reduced or slightly increased depending on the duty cycle of the engine and testing methods used.

Feedstock such as soybeans, palm, canola and rapeseed are considered as first generation feedstock for biodiesel production as they were the first crops to be tried for biodiesel production. Non-food bio-feed stocks such as jatropha, karanja etc. are considered as second generation feedstock for biodiesel production. Algae are considered to belong to the third generation of biodiesel feedstock.

The Indian Scenario is different from Europe and USA. The main sources of feed stock for biodiesel are from tree-borne oil seed. All the edible ornon-edible oils / fats have the potential to be a feedstock for bio-fuel production. The Govt. of India encourages the research on biodiesel production using non-edible oil seeds. The benefits of non-edible oil seeds are:most of these seeds are obtained from hardy plants, well adopted to arid and semi-arid conditions; low fertility and moisture demand; propagated through seed or cuttings; do not compete with plants meant for food; the seed cake after oil expelling may be used as fertilizer for soil enrichment.

The following points have been carefully analyzed for the importance of the study.

- The increasingcost of fuels, widening demand and supply gap, rapid depletion of world fossil fuel reserves.
- Drastic changes in environment due to combustion of fossil fuels.
- Grid power is not available for irrigation and electrification in remote parts.
- There exists a great potential for transport sector.

Considering the oil contents of seeds and availability potential of neem, mahua oils, the present investigation on ; engine performance; emissions with this biodiesel and its blends with diesel were undertaken.

II. METHODOLOGY

The compression ignition research engine used for the study was Kirloskar of M/s Apex Innovation Pvt. Ltd. Sangril Maharashtra, India. The engine was equipped with various accessories for various measurement purposes. The flow rates of fuel and air were measured by transducers. Thermocouples were installed at various locations for measurement of water and exhaust gas temperature. Cylinder pressure was measured by sensor mounted in the cylinder head. The schematic diagram of the diesel engine setup is shown in Fig. 1. The photographs of the experimental Set up of Diesel Engine Fig. 2. Research engine test set up parameters with specifications details in brief is given below. Engine specification is given in Table I.

TABLEI Engine Specification

Engine Parameters	Specifications
Cylinder diameter x Stroke Length	87.5 mm x 110 mm.
Compression ratio	18:1
Rated output	3.5 kW.
Injection pressure	240 bars
Fuel injection timing	25BTDC
Connecting rod length	234 mm
Orifice diameter	20 mm
Dynamometer arm length	185 mm

Dynamometer

The engine has a DC electrical dynamometer loaded by electrical resistance bank to measure its output. The dynamometer is calibrated statistically before use. The dynamometer has a rotor which is driven by the engine. The magnetic poles are located outside with a gap. The coil is wound in circumferential direction. When current runs through exciting coil, a magnetic flux developed around the coil through stator and rotor.The engine brake power or load is controlled by changing the field current.

The engine has a DC electrical dynamometer that measures mechanical force, speed, or power. In any engine testing application by DC dynamometer test cell testing, an engine, motor or transmission is coupled to the dynamometer via couplings and a driveshaft. When the device under test is running, the dynamometer can exert a braking force on it. The load cell and speed pick- up senson mounted on the dynamometer will measure engine (device under testing) torque and speed. Acquiring this values, the dynamometer can be used to calculate the engine load.The DC electrical dynamometer loaded by electrical resistance bank to measure its output. The dynamometer has a rotor which is driven by the engine. The magnetic poles are located outside with a gap. The coil is wound in circumferential direction. When current runs through exciting coil, a magnetic flux developed around the coil through stator and rotor.The engine load is controlled by changing the field current. I have applied 90% maximum load while testing. The maximum power it developed was 3.15 kW tested with diesel first.Load can also be expressed in Torque/ KPa or bars.

A Flue Gas Analyzer

Carbon monoxide (CO), nitrous oxide (NOx) and hydrocarbons were measured by a multi gas analyser, M/S Netel (India) Ltd. under varying operating conditions. HC, CO and CO_2 were measured by NDIR method where as NOx was measured by electro chemical method in the gas analyser used. The readings of CO and CO_2 were measured in % by volume where as NOx and HC were measured in ppm using gas analyser.

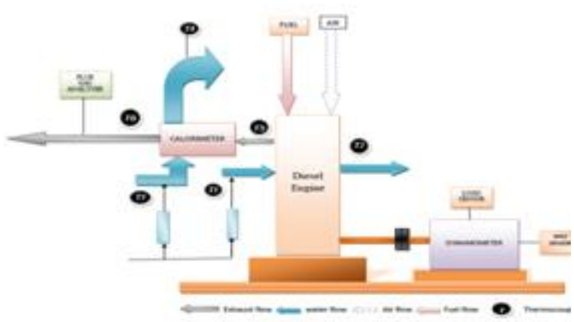

Fig. 1. Schematic Diagram of the Diesel Engine Setup

Fig. 2. Experimental Set up of Diesel Engine

The engine was started on neat diesel fuel and warmed up. The warm up period ended when the liquid cooling water temperature was stabilized. Then the fuel consumption and exhaust emissions of CO_2, CO, HC and NO_x were measured and recorded for different loads.

The important parameters measured from the experiment are listed below:

- Brake Power (BP)
- Brake Thermal Efficiency (BTE)
- Brake Specific Fuel Consumption (BSFC).
- Air Consumption Rate.
- Temperature Measurement
- Engine Speed.
- Exhaust Gas Composition

Brake Power (BP)

Brake Power is one of the most important measurement in the test schedule of an engine. The net power available at the shaft is known as brake power. It is defined as rate of doing work and is equal to the product of force and linear velocity or the product of torque and angular velocity. Thus, the measurement of power involves the measurement of force (or torqe) as well as speed. An electrical loading dynamometer was used for measuring brake power of the engine. It is measured in kW.

$$\mathbf{BP} = \frac{2\times\pi\times N\times T_e}{60} \quad (1)$$

Where,

N=Speed of the engine in rpm.

T_e = Torque in Nm =WxR=(9.81xNet mass applied in kg) x radius in m.

B. Brake Thermal Efficiency (BTE)

A measure of overall efficiency of the engine is given by the brake thermal efficiency. BTE is the ratio of energy in the brake power to the fuel energy.

$$\mathbf{BTE} = \frac{BP\times 3600}{m_f\times C_v} \quad (2)$$

Where,

B.P = Brake Power in kW.

m_f = mass of fuel in kg/Hr.

C_v= Calorific Value in kJ/kg.

C. Brake Specific Fuel Consumption (BSFC).

Brake Specific fuel consumption is defined as the fuel flow rate per unit power output. It is a measure of the efficiency of the engine in using the fuel supplied to produce work. It is desirable to obtain a lower value of BSFC meaning that the engine uses less fuel to produce the same amount of work. This is one of the most important parameters to compare variable fuels. It is expressed in kg/kW Hr.

$$\mathbf{BSFC} = \frac{m_f}{BP} \quad (3)$$

Where,

m_f = mass of fuel in kg/Hr.

BP = Brake Power in kW.

D. Air Consumption Rate.

Measurement of air consumption is quite difficult because the flow is pulsating due to reciprocating nature of the engine and compressible nature of air. Therefore a simple method of using an orifice in the induction pipe does not give reliable observation.

For air consumption measurement in the present experiment an air box with orifice was used. The water head difference of "U" tube manometer was calculated while the engine was running. Based on the head difference in the manometer, air flow rate was calculated. It is expressed in kg/Hr.

$$\mathbf{m_a = C_d \times A \times \sqrt{2 \times g \times h_w \times \frac{\rho_w}{\rho_a}} \times 3600} \quad (4)$$

Where,

m_a = mass of air flow rate in kg/Hr.

C_d= Coefficient of discharge of orifice.

$A = \frac{\pi}{4} \times d^2$ = Cross section area of orifice in m^2.

d = diameter of orifice in m.

g =Acceleration due to gravity, 9.81 m/s^2.

h_w= Pressure head difference in manometer.

ρ_w= Density of water in kg/m^3.

ρ_a = Density of air in kg/m^3.

E. Temperature Measurement

Thermocouples made of Chromel-Almunel were mounted at desired locations in the adopter specially developed for the set up. The base of each mounting was brazed to the engine component and the thermocouples were fitted with proper care to prevent any leakage. The cooling water temperature at inlet and outlet of the engine, calorimeter water inlet and outlet temperature and exhaust gas to calorimeter inlet and outlet temperature were measured. It is expressed in K.

F. Engine Speed (rpm)

Speed is a rate variable defined as the time rate of motion. It may be linear, i.e., along the axis of movement or angular i.e. around the axis. The angular speed is measured by Tachometer. Tachometer is an instrument used to measure angular velocity of the shaft either by registering the number of rotations during the period of contact or by indicating directly the number of rotations per minute. It indicates the value of rotary speed or displays a reading of an average speed.

An Enercon make digital panel tachometer was used for measurement of engine rpm. It has a measureing range of 1 to 10,000 rpm.

G. Exhaust Gas Composition

The factor effecting the emissions is the oxygen concentration and temperature of the burnt gases. The exhaust gases contain CO, CO_2, NO_x and HC. The relative amounts depend on engine design and operating conditions. NO_x forms throughout the high-temperature burned gases behind the flame through chemical reaction involving N_2 and O_2 atoms which do not attain chemical equilibrium. The rate of formation of NO_x is directly proportional to the burned gas temperature. As the temperature of gases falls during the expansion, the reaction involving NO_x freeze and leave NO_x concentration far in excess of levels. Exhaust gas emission levels (CO_2, CO, HC and NO_x) for the biodiesels tested at different engine loading conditions were compared with diesel.

If the combustions were complete, the exhaust would consist only of CO_2 and water vapours plus air and did not enter into the combustion process. But due to incomplete combustion carbon monoxide, un-burnt hydrocarbon and oxides of nitrogen are formed.

The unburned hydrocarbons in diesel exhaust consist of original fuel molecules, products of fuel compounds and partially oxidized hydrocarbons. In diesel engines, several events like liquid fuel injection, fuel evaporation, fuel-air mixing, combustion, and mixing of burned and unburned gases may take place concurrently and combustion is heterogeneous in nature. Thus, several processes are likely to contribute to unburned hydrocarbon emissions. As pointed out by [4] these processes are:

- Over mixing of fuel and air beyond lean flammability limits during delay period.
- Under mixing of fuel injected towards the end of injection process resulting in fuel-air ratios that are too rich for complete combustion.
- Impingement of fuel sprays on walls due to spray over-penetration.
- Poorly atomized fuel from the nozzle after the end of injection.
- Bulk quenching of combustion reactions due to cold engine conditions, mixing with cooler air or during expansion.

III. RESULTS AND DISCUSSIONS

A.Performance of Diesel Engine

Brake Thermal Efficiency (BTE):

The variation of BTE with respect to engine load for diesel and biodiesel blends (B10, B20, B30 and B40) of NOME (Neem oil methyl ester) and MOME (Mahua oil methyl estes is presented in Fig. 3 to Fig. 4 respectively.

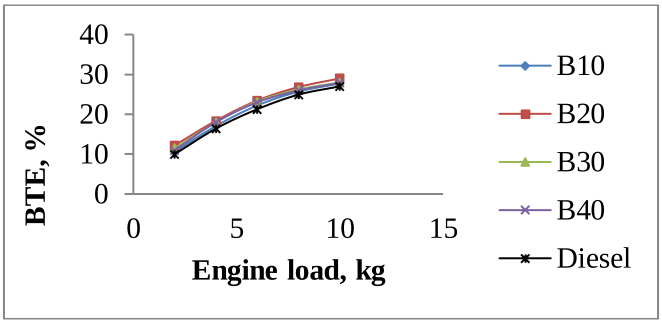

Fig. 3. Variation of BTE with Engine Load for Diesel and NOME Blends

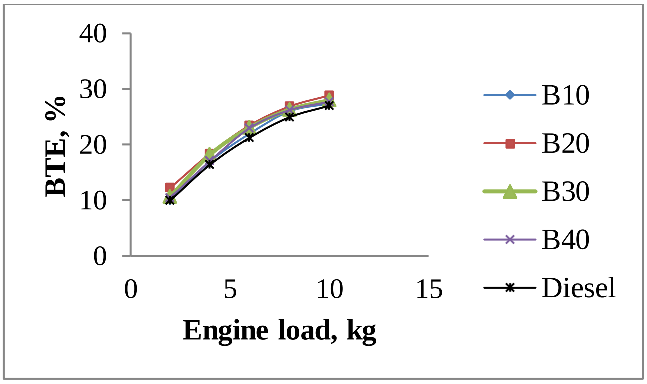

Fig. 4. Variation of BTE with Engine Load for Diesel and MOME Blends

From the above Fig. 4.1 and Fig 4.2, it was observed that the BTE shows an increasing trend with respect to engine load for all blends. The engine operations with tested biodiesels of NOME and MOME, yield approximately 7.40% and 6.85%, higher thermal efficiency as compared to diesel. It was noticed that the use of oxygen -rich biodiesel fuels promote a better combustion as a result the thermal efficiency was improved.

The BTE was improved with the engine load for the reason that relatively less portion of the power was lost with increase in engine load. Maximum BTE was observed in B20 blend in all the tested fuels.

The reduction in BTE beyond B20 biodiesel blends was due to higher viscosity, poor spray characteristics and lower calorific value. The higher viscosity of B30 and B40 led to decreased atomization, fuel vaporization and combustion and hence the thermal efficiency of the biodiesel blends was lower.

Based on these results it can be concluded that the BTE was comparable to that with diesel. This is in line with the findings reported by many researchers [5]-[6] and [7]-[8].

Brake Specific Fuel Consumption (BSFC):

The variation of BSFC with respect to engine load for diesel and biodiesel blends (B10, B20, B30 and B40) of NOME and MOME is presented in Fig. 5 and Fig. 6 respectively.

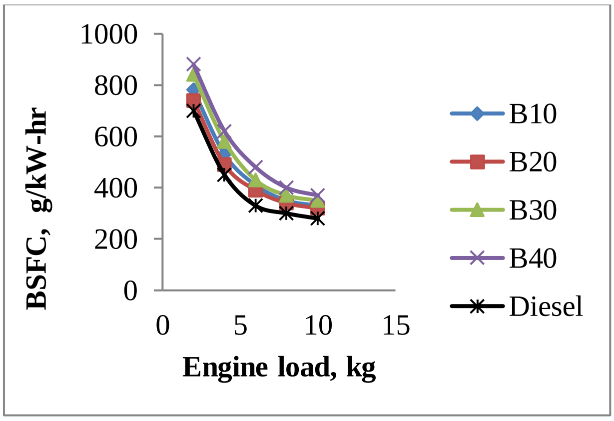

Fig. 5. Variation of BSFC with Engine Load for Diesel and NOME Blends

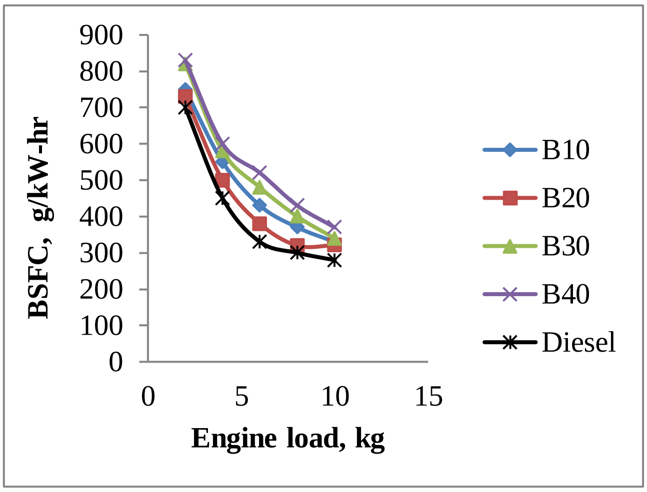

Fig.6. Variation of BSFC with Engine Load for Diesel and MOME Blends

From Fig. 5 and Fig. 6, it was observed that the variation in BSFC with load for different samples declined in BSFC with increase in load. The BSFC in case of blends were higher compared to diesel in the entire load range.

With increase in biodiesel percentage in the blends, the calorific value of fuel decreases. Hence, the specific fuel consumption of biodiesel in blends increases as compared to that of diesel. The variation was due to lower heating value and higher fuel flow rate due to high density of the blends and hence higher bulk modulus. The higher bulk modulus results in more discharge of fuel for same displacement of the plunger in injection pump there by resulting in increased BSFC.

The energy content of methyl ester was less than that of diesel. Since the engine runs at a constant speed, it has to produce a constant power at a particular load. In order to achieve this, it has to consume more biodiesel to cover up its lower energy content.

It was observed that the BSFC for the blend B20 was close to diesel in full load. However at part load condition the variation are appreciable for all the blends. The B20 blends of NOME and MOME, the BSFC was increased by 14.28% and 14.6% than diesel at maximum load respectively. The mean BSFC with B20 of NOME and MOME was found to be 0.456 kg/kW h and 0.45 kg/kW h respectively.

The above result showed a similar trend as other results [5] and [8]-[9].

B. Exhaust Emissions

CO_2 Emissions:

The variation of CO_2 emissions with respect to engine load for diesel and biodiesel blends (B10, B20, B30 and B40) of NOME and MOME is presented in Fig. 7 and Fig. 8 respectively.

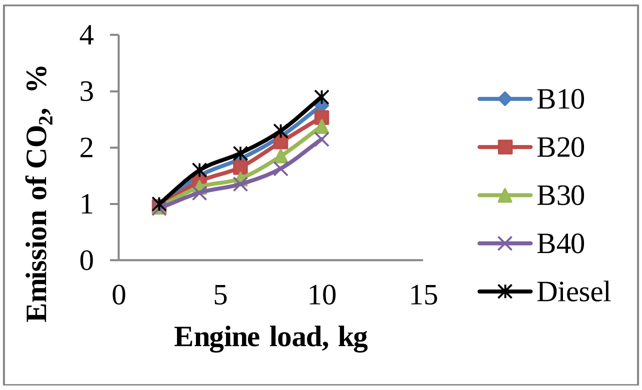

Fig. 7. Variation of CO2 with Engine Load for Diesel and NOME Blends

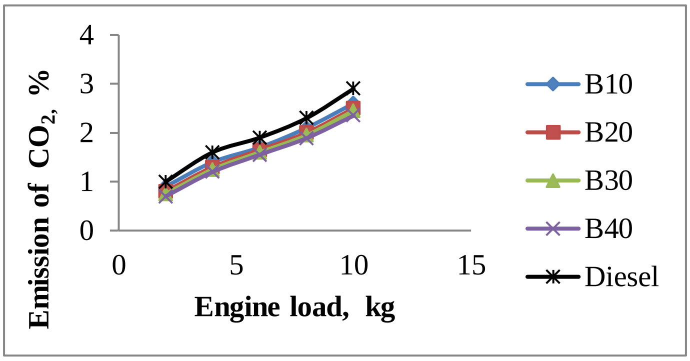

Fig. 8. Variation of CO_2 with Engine Load for Diesel and MOME Blends

From Fig. 7 and Fig. 8, test emission report reveals that the CO_2 emission for all blends was less as compared to diesel at all loads. The rising trend of CO_2 emission with load was due to the higher fuel entry with increase in the load.

The maximum CO_2 obtained from NOME and MOME were 2.75% and 2.6% respectively as compared to 2.9% from DIESEL. As the load increases blends show higher emission. It was due to complete combustion. The combustion of fossil fuels produces higher CO_2 which gets accumulated in the atmosphere and leads to many environmental problems.

The higher emission was also due to availability of extra oxygen in biodiesel as the air fuel mixture increases with load resulting in better combustion. Though biodiesel contain more carbon than diesel but all carbon in the biodiesel cannot be converted to CO_2 and same will come out in the form of CO. Similar results were reported by various researchers [5], [8] and [10] for different biodiesels.

CO Emissions:

The variation of CO with respect to engine load for diesel and biodiesel blends (B10, B20, B30 and B40) of NOME and MOME is presented in Fig. 9 and Fig. 10 respectively.

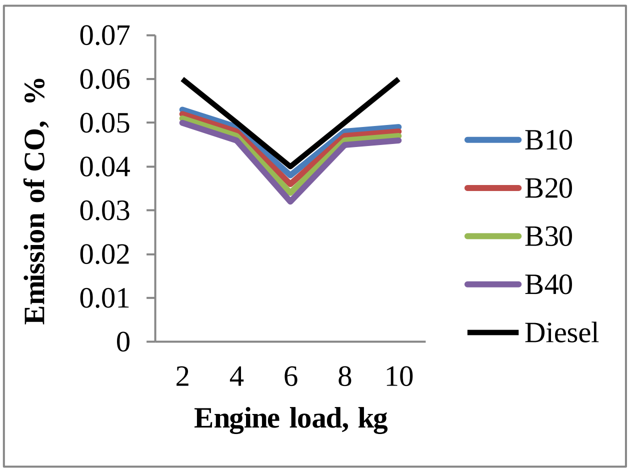

Fig. 9. Variation of CO with Engine Load for Diesel and NOME Blends

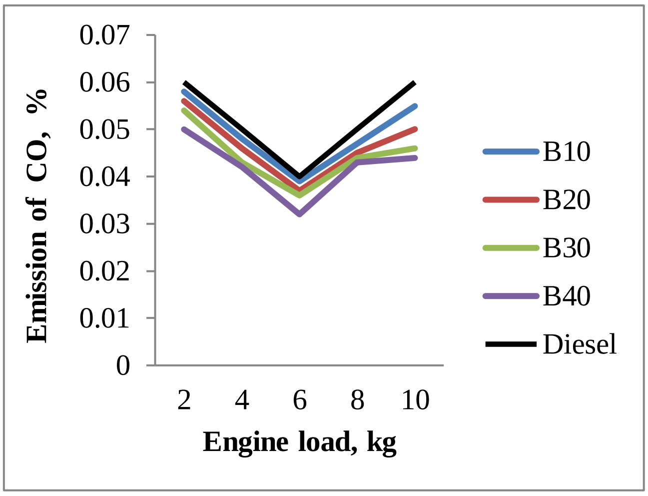

Fig. 10. Variation of CO with Engine Load for Diesel and MOME Blends

If the combustion was complete the exhaust would consist of only CO_2 and water vapours plus air that did not enter into the combustion process. However, for several reasons oxidation of fuel during combustion remains incomplete and produces CO, un-burnt hydrocarbons and oxides of N_2 other than particulate matter in the form of smoke.

CO was a product of the incomplete combustion due to either inadequate oxygen or insufficient time for the completion of reaction or poor atomization or uneven distributions of small portion of fuel across the combustion chamber. Generally in case of diesel engines, the percentage of CO in the exhaust gas varies from 0 to 2%.

In the present study, the CO emission from diesel engine was found to produce a maximum of 0.06%, 0.053% and 0.058% when operated with DIESEL, NOME and MOME respectively. It was observed that CO initially decreased with increase in engine loads and later it increased with increase in engine loads. CO emission decreased significantly with increase in the concentration of biodiesel in the blend.

Similar findings of CO emission were also reported by other researchers such as [5], [7], [11] and [12]-[13].

HC Emissions:

The variation of HC with respect to engine load for diesel and biodiesel blends (B10, B20, B30 and B40) of NOME and MOME is presented in Fig. 11 and Fig. 12.

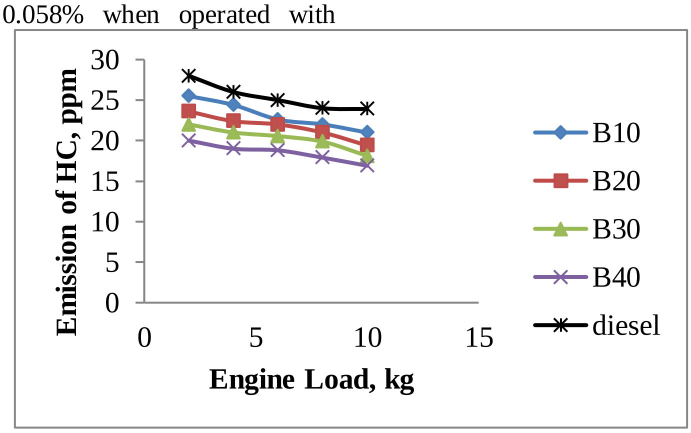

Fig. 11. Variation of HC with Engine Load for Diesel and NOME Blends

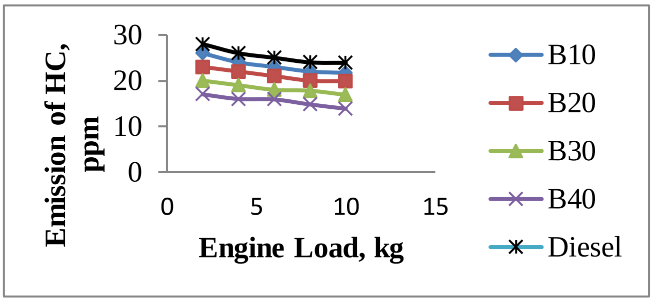

Fig. 12. Variation of HC with Engine Load for Diesel and MOME Blends

It was observed that the HC emission for all the fuel blends was found to be lower than that of diesel. The emission of HC mostly depends on the combustion process. Incomplete combustion produces more HC emission or un-burnt hydro carbon fuel emissions. Also the higher cetane number of biodiesel results in decrease in HC emission due to shorter ignition delay. It can be observed that the HC emission decreased with increase in engine load. Also HC emission was found to be decreased with increase in the concentration of biodiesel blends.

The mean HC for diesel was found to be 25.38 ppm. The minimum HC emission was observed in MOME at full load. Similar results were reported by various researchers like [5], [8] and [12]-[13] for different biodiesels.

The emission of HC mostly depends on the combustion process. Incomplete combustion produce more HC emission or unburnt fuel emission. In case of high concentration of biodiesel i.e. fuel rich mixture have enough oxygen to react with the carbon. So complete combustion produce less HC emission.

No_x Emissions:

The variation of NO_x with respect to engine load for diesel and biodiesel blends (B10, B20, B30 and B40) of NOME and MOME is presented in Fig. 13 and Fig. 14.

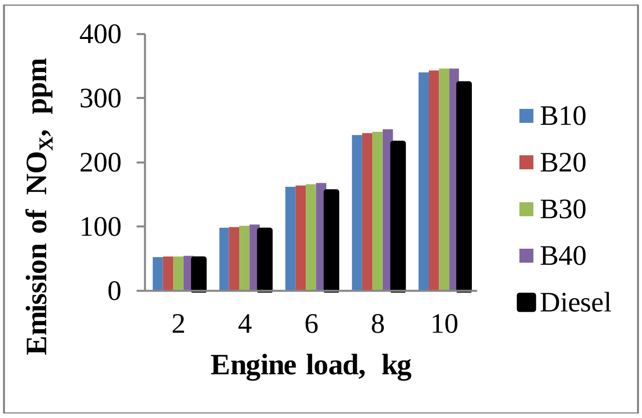

Fig. 13. Variation of NO_x with Engine Load for Diesel and NOME Blends

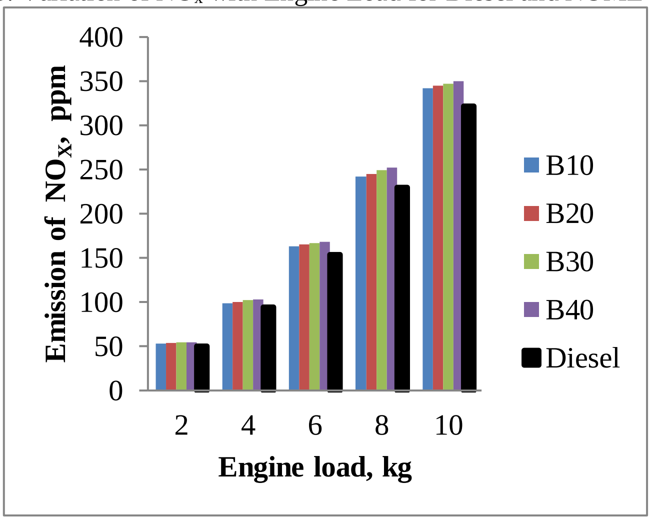

Fig. 14. Variation of NO_x with Engine Load for Diesel and MOME Blends

The result shows that the diesel fuel was having lower NO_x emission than blended oil samples. The NO_x emission for diesel and all the blends followed an increasing trend with respect to engine load. The NO_x emission in biodiesel and its blends was observed to be 5%-10% more than that of diesel. This could be attributed to: Increase exhaust gas temperature due to lower heat transfer and the fact that biodiesel has some oxygen content in it which facilitates the NO_x formation; an advance of fuel injection timing in engine operating on mechanical type fuel injectors while using biodiesel which has lower compressibility compared to diesel. Hence, lower compressibility and higher speed in biodiesel shorten ignition delay permitting more NO_x; higher cetane number of biodiesel shortens ignition delay advancing combustion.

At minimum load condition the NO_x range varies with diesel within the range of 5.4% - 8.4% and, 6% - 9.6%, for NOME and MOME respectively, and at full load the NO_x emission range varies with diesel was within the range of 5.6% - 7.5% and 6.2% - 8.63% for NOME and MOME respectively.

The higher emission trend of NO_x of biodiesel with respect to diesel was similar to other researchers' reports [5], [11] and [10].

IV. CONCLUSION

Maximum BTE was observed in B20 blend at maximum load in all the tested fuels. The brake specific fuel consumption of biodiesel in blends increases as compared to that of diesel.

Test emission revealed that the CO_2 emission for all blends were less as compared to diesel at all loads. The CO emission from diesel engine was found to produce a maximum of 0.06, 0.053 and 0.058, percent when operated with diesel, NOME and MOME respectively.

The minimum HC emission was observed in MOME at full load.

At minimum load condition the NO_x varies within the range of 5.4 to 8.4% and 6 to 9.6% NOME and MOME respectively, and at full load the NO_x emission was within the range of 5.6 to 7.5% and 6.2 to 8.63% for NOME and MOME respectively.

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