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PERFORMANCE AND EMISSION CHARACTERISTICS OF A DIESEL ENGINE WITH A ZIRCONIUM DIOXIDE-COATED PISTON AND NERIUM AND MAHUA METHYL ESTERS USED AS FUELS

Summary

Diesel fuel has a limited resource and concerns over environmental pollution are leading to the use of 'bio-origin fuels' as they are renewable and environmentally benign. Jatropha methyl ester, as an esterified bio fuel, has an excellent cetane number and a reasonable calorific value. In its behaviour, it closely resembles the diesel. Biodiesel can be used more efficiently in the semi-adiabatic engine, in which the temperature of the combustion chamber is increased by a thermal barrier coating on the piston crown. In the present investigation, the piston crown was coated with a ceramic material, zirconium dioxide (ZrO_2), of about 0.5 μm, using the plasma spray method. The experiments were carried out with the 100% Nerium Methyl Ester (NME), the Mahua Methyl Ester (MME), and with diesel blends, in a four stroke, direct injection diesel engine, with and without a coated piston, at different load conditions. The 100% bio diesel results showed an improvement in the brake thermal efficiency (BTE) and a decrease in the brake specific fuel consumption (BSFC) of about 10 % at full load. The exhaust emissions, such as carbon monoxide (CO), hydrocarbon (HC), and smoke, were reduced and the nitrogen oxide (NO) emission increased in the case with a coated engine (CE) in comparison with the base engine (BE) with the use of diesel fuel.

Key words: *Zirconium dioxide, Performance, Emissions, Nerium methyl ester, Mahua methyl ester; Transesterification*

1. Introduction

Compression ignition engines are employed particularly in the field of heavy transportation and agriculture on account of their high pulling power, high thermal efficiency and durability. However, diesel engines are the major contributors of nitrogen oxides and particulate emissions. Hence, more stringent norms are imposed on exhaust emissions. Vegetable oils are considered as a good alternative to diesel as their properties are closer to those of diesel and can be used to run a compression ignition engine without any major modifications. They are renewable sources of energy, eco-friendly, widely available, they have low sulphur content, and are safe to store [1-3]. Attempts have been made in the last two decades to find suitable methods for using vegetable oils in diesel engines. Suresh Kumar et al. [4] studied the performance and emissions of a diesel engine using the nerium and the

Nomenclature

ZrO_2 (Zirconium dioxide); NME (Nerium Methyl Ester); MME (Mahua Methyl Ester); BTE (Brake Thermal Efficiency); BSFC (Brake Specific Fuel Consumption); CO (Carbon monoxide); HC (Hydrocarbon); NO (Nitrogen Oxide); CE (Coated Engine); BE (Base Engine)

mahua pinnatta methyl ester at various blends. They found out that 40% blends by volume provide better performance and improved exhaust emissions. Lakshmi NarayanaRao et al. [5] performed the combustion analysis of a diesel engine with various blends of rice bran oil methyl ester and their results showed that the ignition delay and the rate of heat release decrease. In addition, HC and CO emissions are reduced and NOx emissions are slightly increased with an increase in blends. Deepak Agarwal et al. [6] concluded that the 20% of linseed oil methyl ester blend improved the thermal efficiency and reduced the smoke density. The researchers in [7, 8] studied the performance and combustion characteristics of a diesel engine using rubber seed oil and its blends as fuels. They reported that the smoke, HC and CO emissions were higher and NOx emissions were lower at the peak load when 100% rubber seed oil methyl ester was used. Balusamy and Marappan [9] studied the performance and combustion characteristics of a diesel engine using the methyl ester of vetia peruviana seed oil as a fuel. They reported that the CO and HC emissions were reduced but the amounts of NOx and smoke were slightly larger than those of diesel (Puhan et al. [10]). In a normal diesel engine, approximately thirty percent of the total energy is taken away by the coolant. Some important advantages of the Low Heat Rejection Engine (LHRE) concept are improved fuel economy and reduced hydrocarbon, smoke and carbon monoxide emissions [11-13].

In this concept, the combustion chamber is insulated by using high temperature materials on engine components, such as pistons, cylinder head, valves, cylinder liners, and exhaust ports [14-17]. The objective of the present study is to improve the performance, combustion and emissions of a diesel engine with a ZrO_2 coated piston using the 100% nerium and the mahua oil methyl ester as a fuel in different load conditions.

2. Transesterification of vegetable oils

Transesterification is the process of using an alcohol (e.g. methanol or ethanol) in the presence of a catalyst, such as sodium hydroxide (NaOH) or potassium hydroxide (KOH), which chemically breaks the molecule of the raw oil into methyl or ethyl esters with glycerol as a by-product, which reduces the high viscosity of oils. This method also reduces the molecular weight of the oil to one third of its original value. It reduces the viscosity and increase the volatility .The cetane number is comparable to that of the diesel fuel.

Table 1 Properties of pure diesel and methyl esters of nerium and mahua

PROPERTY	Diesel	Nerium	Mahua
Kinematic viscosity in cst at 40°C	3.1	3.6	6.4
Calorific value in KJ/kg	43200	42923	34597
Density at 15°C in kg/mm^3	830	850	910
Cetane no.	46.4	45	52
Flash point in °C	56	70	91
Fire point in °C	64	83	104

3. Experimental setup

A schematic diagram of the engine test rig used is shown in Fig. 1. The engine is fully equipped with measuring instruments to measure all operating parameters. In the study, the engine is operated with and without a coated piston at a constant speed of 1800 rpm using the 100% nerium and the 100% mahua methyl ester and the diesel fuel in various load conditions to evaluate the performance and combustion characteristics. The results obtained using the 100% nerium and the 100% mahua methyl ester were compared with the diesel fuel results including different combinations of conditions with and without a coated piston.

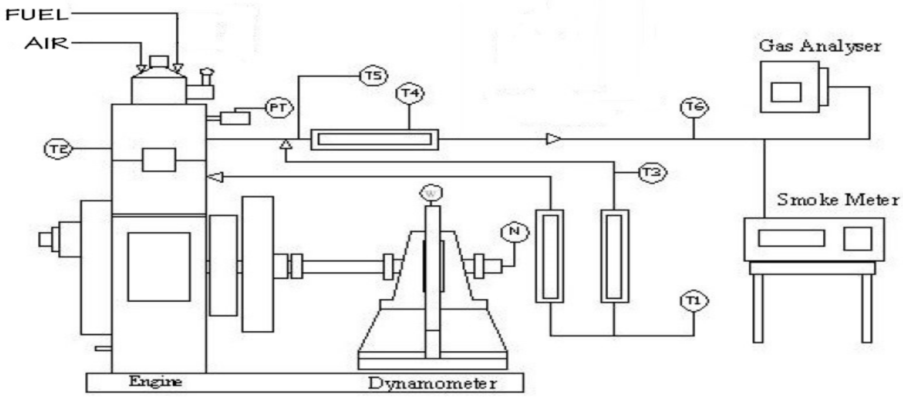

Fig. 1 Experimental setup

3.1 Specifications of the apparatus

In the test rig several instruments/pieces of equipment have been used for the purpose of the experiment. Brief specifications of the instruments are given below.

3.1.1 Diesel engine

Manufacturer	Kirloskar oil engines limited
Model	SV1
Type of engine	Vertical, 4-stroke single cylinder
Maximum power	8 HP
Maximum torque	23.342 Nm
Maximum speed	1800 rpm
Compression ratio	17.5:1
Bore and stroke	87.5 x 110 mm
Injection pressure	200 bar

3.1.2 Smoke meter

A smoke meter is used to determine the smoke density of the engine exhaust. The AVL 437 smoke meter has been fitted to measure either free acceleration or steady state test procedures. Any out-of-range parameters are automatically flagged to the operator. Brief specifications of the smoke meter are given below.

Type	AVL 437 smoke meter
Make	AVL India Pvt. Ltd
Measuring range	0 to 100 HSU

3.1.3 Exhaust gas analyser

Exhaust gas analyser is used to measure the amount of exhaust gases like hydrocarbon (HC), carbon monoxide (CO), nitrogen oxides (NOx), carbon dioxide (CO_2). The exhaust gas analyser details are given below.

Manufacturer	SMS Auto line Equipments private limited
Type	Crypton 290 five gas analyser

3.2 Testing Procedure

The engine was started and warmed up at low idle for long enough time to establish the recommended oil pressure, and was checked for fuel and oil leaks. The engine was running on the no-load condition, and a constant speed of1800 rpm was maintained by adjusting the fuel injection pump. The engine was running to gain constant speed, after which it was gradually loaded. Experiments were conducted at different torque levels (0, 8, 16, 24, and 32 Nm). The engine was running for 10 minutes and data were collected during the last 3 minutes. For the 100% biodiesel, performance tests were carried out with and without the coated piston.

The exhaust gas is sampled from the exhaust pipe line and passed through a four gas analyser for the measurement of carbon monoxide, carbon dioxide, unburnt hydrocarbon, and nitrogen oxides present in exhaust gases. A smoke meter is used for the measurement of smoke opacity. The uncertainties of the measured parameters are shown in Table 2.

Table 2 Experiment Uncertainties

Parameters	Systematic Errors (±)
Speed	1 ± rpm
Load	± 0.1 N
Time	± 0.1 s
Brake power	± 0.15 kW
Temperature	± 1°
Pressure	± 1 bar
NO_X	± 10 PPM
CO	± 0.03%
CO_2	± 0.03%
HC	± 12 PPM
Smoke	± 1 HSU

4. Results and discussion

In the present investigation, tests were carried out on a single cylinder diesel engine with and without a coated piston using the 100% bio-diesel and the diesel fuel in varying load conditions. The values of performance and emission parameters using both pistons were measured and analysed for brake thermal efficiency, brake specific fuel consumptions, and emissions such as carbon monoxide, carbon dioxide, hydrocarbons, smoke, and nitrogen oxide. The properties of nerium and mahua methyl esters are compared with the diesel fuel, as shown in Table1.

4.1 Performance analysis

4.1.1 Brake Thermal Efficiency (BTE)

The variation in the brake thermal efficiency with the brake power for the diesel fuel, 100% NME and MME is shown in Fig. 2. It is observed that the brake thermal efficiency for the Coated Engine (CE) is higher than that of the base engine (BE) for both bio-diesel fuels. This is due to better vaporization of bio-diesel fuel at a higher combustion temperature, which leads to complete combustion. The brake thermal efficiency (BTE) of the coated Diesel engine was higher compared to the uncoated engine for both biodiesels. Though the thermal efficiency of an engine depends on many factors, it depends mostly on the calorific value and the specific gravity of fuel. Due to the presence of a substantial amount of oxygen, biodiesels have a 10% lower heating value than the diesel fuel.

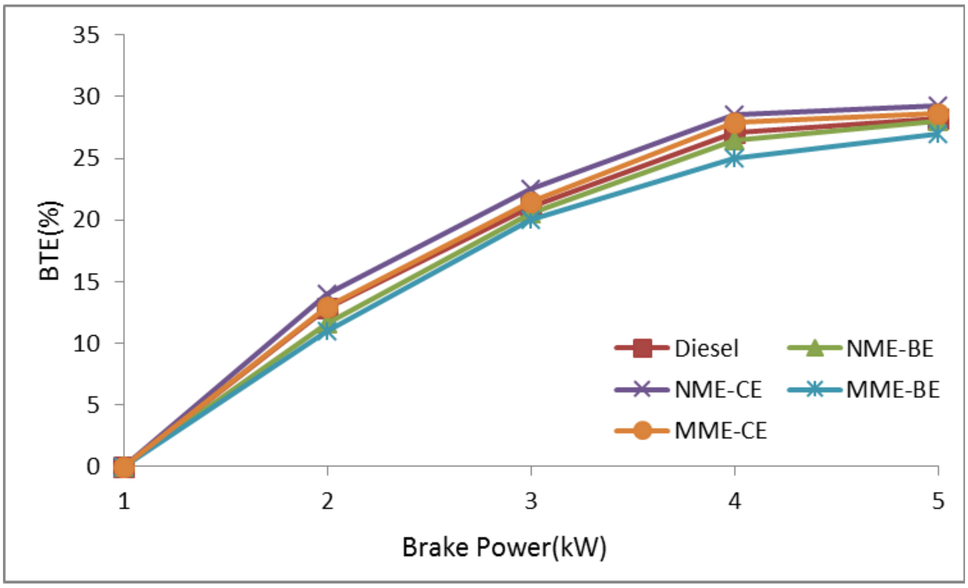

Fig. 2 Brake Power vs. BTE

4.1.2 Brake Specific Fuel Consumption (BSFC)

Fig. 3 shows the variation in the brake specific fuel consumption for all fuels, with and without a coated piston. The average BSFC decrease in the CE for 100% NME and MME is 8% compared with the BE. This may be due to higher viscosity and a lower calorific value, which enables better utilization of oxygen, which in turn leads to improved combustion.

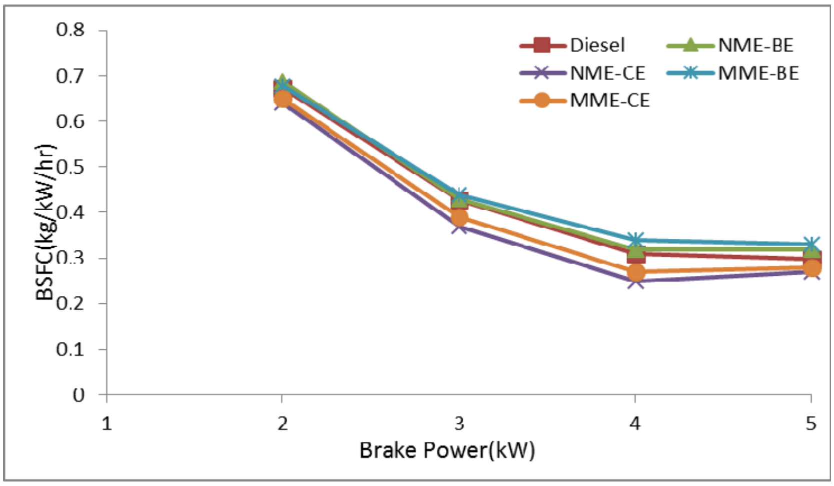

Fig. 3 Brake Power vs. BSFC

4.2 Emissions analysis

4.2.1 Exhaust Gas Temperature (EGT)

Fig. 4 shows the variation in the exhaust gas temperature. The exhaust gas temperature is increased in the coated engine, compared with the base engine. This may be due to the coating-related decrease in the amount of the wasted heat going into the cooling system and out and due to the transfer of this heat to the exhaust gas.

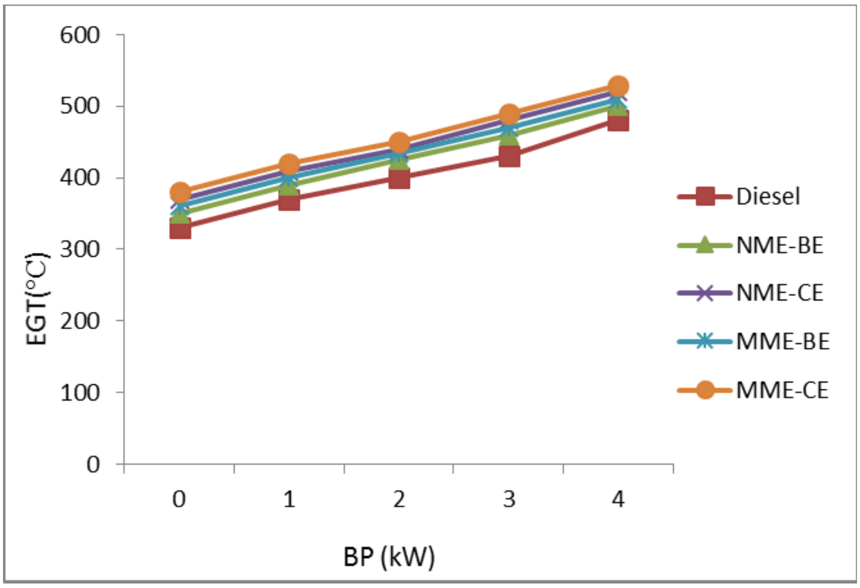

Fig. 4 Brake Power vs. EGT

4.2.2 Carbon monoxide (CO)

Fig. 5 shows the variation in the carbon monoxide emissions. Carbon monoxide (CO) emissions are formed due to incomplete combustion of fuels, predominantly of petroleum fuels which contain no oxygen in their molecular structure. The CO emission decreases in the CE were 20% for B100 (B denotes the biodiesel fuel indicating both the mahua and the nerium biodiesel) compared with that of the base engine. It is observed that the CO emissions for the test fuels used in the base engine are also significantly decreased in the CE. The decrease in CO emission in the CE may be due to the in-cylinder heat transfer reduction, an increase in the combustion duration, and richer oxygen content present in the biodiesel.

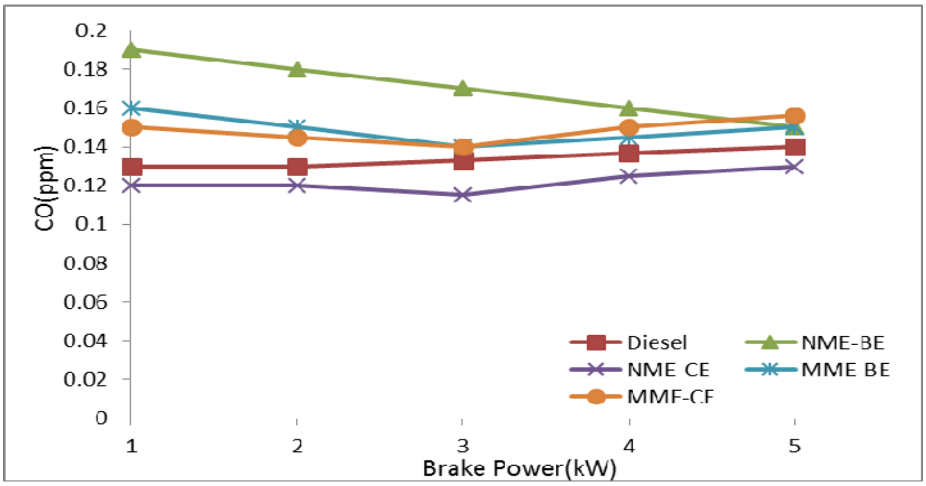

Fig. 5 Brake Power vs. CO

4.2.3 Carbon dioxide (CO_2)

Fig. 6 shows the variation in the carbon dioxide emission for both the biodiesel and the diesel fuel. It is observed that the carbon dioxide (CO_2) emission is increased with an increase in load due to complete combustion of the fuels. The CO_2 emissions increase in the case of the CE with the 100% NME and the MME used as fuels with respect to those of the base engine. It is observed that the CO_2 emissions for the test fuels used in the base engine and the CE are significantly reduced. The increase in CO_2 emission in the CE may be due to the higher combustion temperature and consequently to the reduction in the cylinder heat transfer and to the richer oxygen content present in the bio diesel.

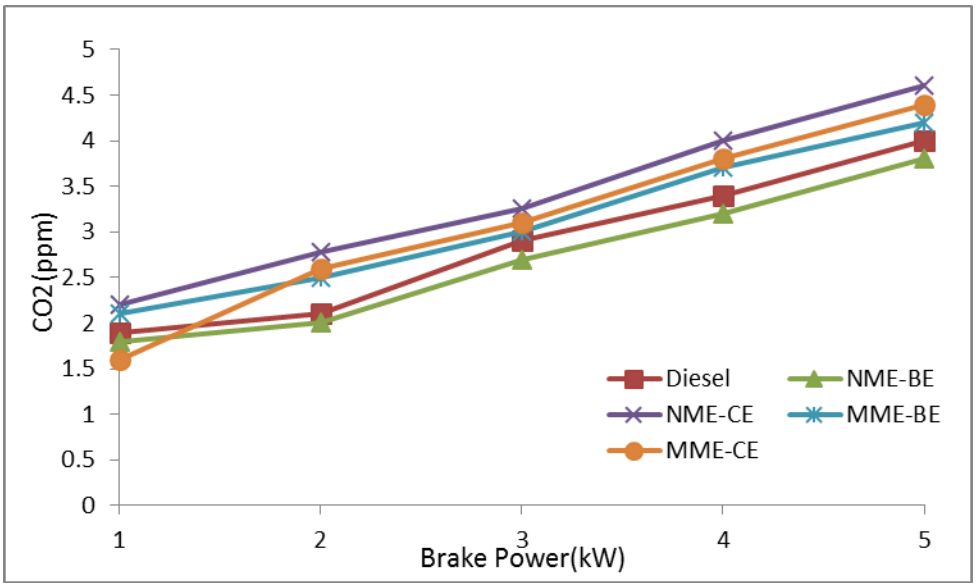

Fig. 6 CO_2 vs. BP

4.2.4 Hydro Carbon Emission (HC)

Variations in the hydrocarbon (HC) emission are shown in Fig. 7. The emission of hydrocarbon from the coated engines is more likely to be reduced because of the decreased quenching distance and the increased lean flammability limit. It is observed that the HC emissions for the biodiesel used in the CE decreased by 25% at full load compared with the base engine. This may be due to higher temperatures of exhaust gases in both engines (the coated and the base engine) and due to the fact that the combustion chamber walls of the coated engine assist in permitting the oxidation reactions to proceed close to complete combustion.

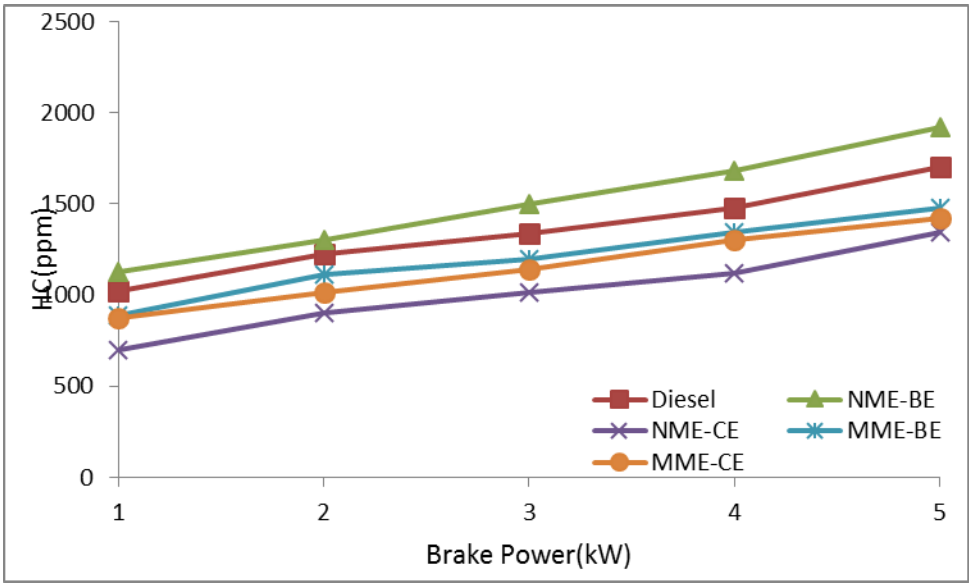

Fig. 7 Brake Power vs. HC

4.2.5 Nitrogen Oxides (NOx)

Variations in the nitrogen oxide emissions are shown in Fig. 8. The nitrogen oxide emissions are formed by chain reactions involving nitrogen and oxygen in the air. These reactions are highly temperature-dependent. Since Diesel engines always operate with excess air, NOx emissions are mainly a function of temperature and residence time. It is observed that the nitrous oxide (NO) emission increases in both the CE and the BE when the biodiesel is used. The increase in the NO emission for the CE may be due to a higher combustion temperature and a longer duration of combustion than for the Diesel engine and the BE.

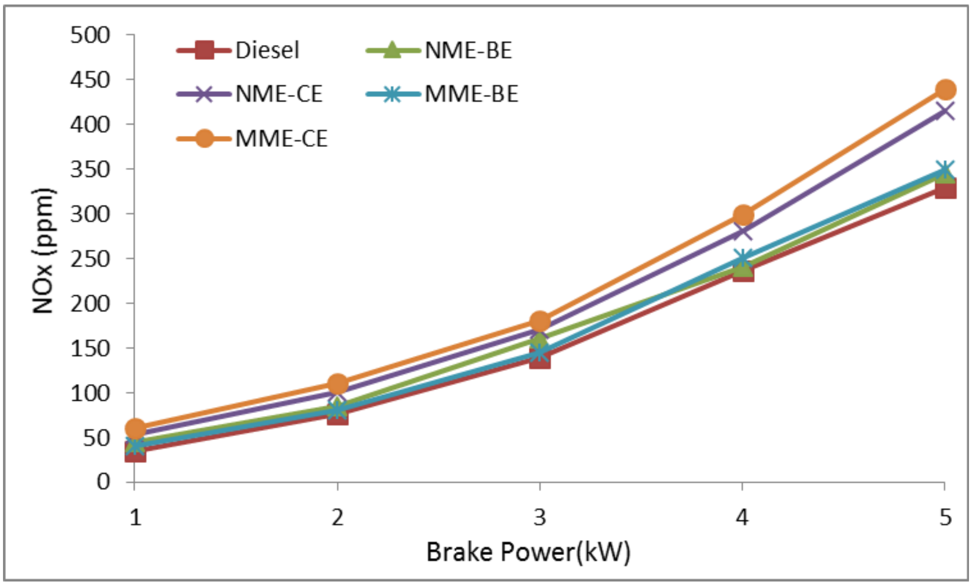

Fig. 8 Brake Power vs. NO_x

4.2.6 Smoke

Variations in the smoke density are shown in Fig. 9. It might be expected that coated engines (CE) would produce less smoke than the base engine because of the high temperature of the gas and of the combustion chamber wall. However, the smoke density of the NME and the MME is lower than that of the diesel for both engine operations. Lower smoke density of

NME may be caused by richer oxygen content present in the biodiesel. The oxygen content of fuel can contribute to improved soot oxidation in locally fuel-rich combustion zones, hence the resulting reduction in smoke density.

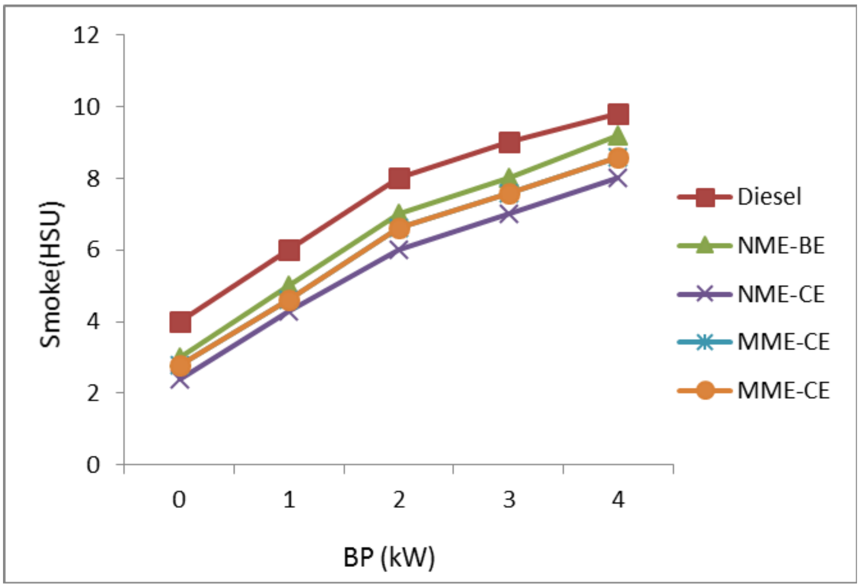

Fig. 9 Brake Power vs. Smoke

5. Conclusion

In order to decrease the exhaust emissions of internal combustion engines and to improve the combustion and thermal efficiency, thermal barrier coatings are applied. In the Coated Engine (CE), due to a reduction in BSFC, the brake thermal efficiency was increased approximately by 2.8% for the pure biodiesel compared with the base engine. The BSFC decreases for all the test fuels in the CE compared with the base engine. The BSFC is reduced approximately by 8% for the pure biodiesel compared with the base engine. The CO and HC emissions decreased approximately by 28% and 23%, respectively, for the pure biodiesel compared with the base engine. The CO_2 emissions are increased for the bio diesel used in the CE due to a higher combustion temperature. The NO emission increases for the test fuels in the CE compared with the base engine. The NO increase in the CE was determined to be approximately 10% for the pure biodiesel compared with the base engine at full load. The smoke density decreases for all the test fuels in the CE compared with the base engine. It was determined that the smoke decrease in the CE was approximately 30% for the pure biodiesel compared with the base engine. In this study, the ZrO_2 ceramic coating may be applied successfully without requiring any modifications to the engines. This helps increase the temperature inside the combustion chamber, resulting in improved vaporization and combustion with reduced emissions. It is concluded that the ceramic-coated engine with the biodiesel as a fuel may increase the thermal efficiency and reduce the harmful emissions.

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