Experimental Investigation of Mango Seed Methyl Ester With Additive in a Thermal Barrier Coated Direct Injection Compression Ignition Engine

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Abstract*—The objectives of the present work is on replacing the conventional diesel fuel with methyl ester of mango seed oil and compare the performance and emission parameters on the use of mangoseed methyl ester,with and without additive on a standared CI engine and TBC coated CI engine. Mango seed oil was prepared from waste mango seeds which are collected from various places. The methyl ester of mango seed oil was prepared by transesterification process. . It is the process of reacting the oil with methanol in the presence of catalyst (KOH). During the process, the molecule of raw MSO is chemically broken to form the ester and glycerol. The experiments were conducted using different blends of mango seed methyl esters with and without additive of 10% of 1,4 Dioxane with diesel (B25, B50, B75 and B100). The performance and emission tests were conducted with above blends on a single cylinder D.I compression ignition engine coupled with eddy current dynamometer. The regulated emission of NOx, and smoke density were measured with the help of exhaust gas analyzer. The experimental results proved that BTE for MSME 50% gives the maximum efficiency of about 29.95%.against the diesel value of 28.13%. There is no appreciable changes for brake thermal efficiency of mango seed methyl ester with additive and coating.In the emission test, it is found that smoke density is appreciably reduced for mango seed methyl ester when compared to diesel. The MSME 25% gives the maximum smoke reduction of about 45.24% than that of diesel. The effect of additive and coating with mango seed methyl ester increases the smoke density. The lowest smoke density of MSME 25% is 42 Hatridge Smoke Units(HSU). The NOx emission is decreased significantly about 180 ppm for MSME with additive. The effect of TBC coating on the piston, cylinder head valves appreciably reduces the NOx emission .The MSME+TBC gives the minimum NOx value of about 630 ppm while the diesel value is 815 ppm.

Keywords—Mango seedoil, Thermal barrier coating, Addtive

I. INTRODUCTION

The major problem focused in the world is on the global fuel shortage and increasing fuel prices and that of environment pollution. These problems can be addressed by many researchers by the use of renewable fuels. Today we find that the combustion from diesel engines produce incomplete combustion products that emit more emission from the exhaust which causes environmental pollution in the form of regulated and unregulated emissions.

Investigations have been carried out globally to replace conventional fossil fuel with suitable alternate fuel which is renewable in nature and available throughout the world. The advantages of biofuel apart from the renewability are: High oxygen content, higher flash point and higher lubricity that produces complete combustion in comparison with conventional diesel fuel.[1] further, the environmental benefit is another investigation factor due to a lesser green house effect, less air pollution, less contamination for water and soil and reduced health risk.[2] Biofuel contains sulfur free, thus the issue of acid rain is therefore ameliorated. Several authors have studied the biodiesel and its blends in diesel engine regarding the emission performance characteristics. Jose M Desantes, et al.,[3] evaluated the rape seed oil methyl ester to improve the combustion process in a high-speed direct injection(HSDI) diesel engine equipped with high-pressure common-rail injection system. Generally, using biodiesel in diesel engine reduces the CO, HC emission and increases the NOx emission. This is due to increase in oxygen level during the combustion. D.C Rakopoulos, et al[4] studied the use of four straight vegetable oils like sunflower, cotton seed, olive and corn oils on mini-bus engine. It is reported that the olive oil has very high content of the unsaturated oleic acid(one double carbon bond) and very low content of the unsaturated linoleic acid (two double carbon bonds), in contrast with, the other three vegetable linoleic acids. Further, the cottonseed oil has the highest content of palmitic acid(saturated) . These may play some role in the soot formation and oxidation mechanism. The previous study has mentioned some of the disadvantages using vegetable oil with high viscosity, low volatility and high aromatic compared to diesel. The solution to the above problems has been approached in several ways: Preheating the oil, thermal cracking, using fuel additives, thermal barrier coating, high pressure injection and transesterification process. Many researches are focused on non edible oil which is not suitable for human consumption due to the presence of toxic components present in the oil. Further non edible oil crops grow in waste lands that are not suitable for use as food [5,6,7] . The cost of cultivation is much lower because these crops can still sustain reasonably oils that contain free fatty acids. Thus they may require multiple chemical steps or alternate approaches to produce biodiesel, which will increase the production cost, and may lower the ester yield of biodiesel below the standards .The objective of the present work is the preparation of the biodiesel from mango seed oil a non edible oil and renewable nature. The performance and emission characteristics of mango seed methyl ester (MSME)blended with diesel (B25, B50, B75 and B100) and with additive of 1,4 Dioxane 10% are analysed on a standard engine and compared with TBC coated CI engine . The physical, chemical properties of biodiesel and its blends were analyzed.

II. PREPARATION OF MSME

As per the source from the Bureau of Agricultural statistics, the mango production in 2010 is 825423 MT. Mango is used for mango juice, mango concentrates, mango pickles etc. It is pale yellow in colour. In India alone 3000 tons of oil extracted from fruit processing plant. Since mango seeds are considered product waste, they are generally cheaper. The oil yield from mango seed kernel is 8% to 15%. India is the highest producer of mango in the world. Raw mango seeds are collected from many places especially from mango juice centers and mango pickle industries. These seeds are dried at room temperature for about 15 days. The outer cover from the seed was broken to get the kernel from the seed. The mango seed kernel is dried again at room temperature for 5 days. The kernel is broken into pieces and then subjected to crushing with the crusher machine. During crushing at one stage the oil was derived. The raw oil is then filtered for using to the investigation. Raw mango seed oil (MSO) is slight yellowish in colour, less volatile and having the combustible mixture of hydro carbons. The raw MSO is converted to biodiesel by transesterification process. It is the process of reacting the oil with methanol in the presence of catalyst (KOH). During the process, the molecule of raw MSO is chemically broken to form the ester and glycerol. Initially 1 litre of MSO was taken for conversion from raw MSO to MSME. The raw MSO was heated to 65^0c. Then 180 ml of methanol was added and 14 gram of KOH was added as an alkali catalyst. The optimization of adding alcohol and catalyst was done to find out the required percentage of alcohol and catalyst for maximum conversion. The above mixture was stirred in the magnetic stirrer at 1500 rpm for 10 min. After 2 hours of reaction time, the product of glycerol and MSME obtained. The glycerol was settled at the bottom by its gravity and MSME was filtered to separate from glycerol. The properties of diesel, raw MSO, MSME and different blends with diesel are given in the table 1.

When comparing the properties, the specific gravity, viscosity, flash point, fire point of raw MSO and MSME with different blends are more than diesel fuel. However its values are decreasing order when the diesel blend increases. But its calorific values are less than that of diesel fuel.

Table 1. Physical, chemical properties of biodiesel and its blends

Property	**Diesel**	**Raw MSO**	**MSM E 100**	**MSME5 0**	**MSME 75**	**MSME + 1,4 DI 10%**
Specific gravity	0.829	0.917	0.879	0.8512	0.8646	0.8823
Kinematic viscosity @40^0 C in CST	2.57	20.97	5.18	3.80	4.42	5.62
Flashpoint ^{0}C	37	298	166	82	102	166
FirePoint ^{0} C	40	315	179	92	113	178
Gross calorific valuein Kj/KG	44738	41803	41924	43230.7	42606.9	42.4
Cetane number	50	50.6	51.6	52.2	51.8	51.8

III. EXPERIMENTAL SETUP

Single cylinder, vertical, naturally aspirated, water cooled, four stroke direct injection compression ignition engine with a displacement volume of 661cc, compression ratio of 17.5 and developing 5.2 kW at 1500 rpm was used for this experimental work. The overall view of the experimental setup is shown in figure 3.1. The engine was always run at its rated speed for different load tests. The injection timing recommended by the manufacturer was 23° bTDC (static). The operating pressure of the nozzle was set at the rated value of 220 bar. The engine had a combustion chamber with overhead valves operated through push rods. A provision was made in the cylinder head surface to mount a piezoelectric pressure transducer for measuring the cylinder pressure and heat release rate using AVL combustion analyser. Ambient pressure, temperature and humidity are noted and the load on the engine is controlled by the dynamometer by keeping the engine at constant speed. After the engine is stabilised for a particular operating point, fuel flow and exhaust gas temperature are recorded. The engine was allowed to run for 15 to 20 minutes to attain steady state condition to reach the cooling water temperature of 70°C and lubricating oil temperature of 65°C. The experiment was done three stages. In the first stage the engine was operated with different blends of MSME with diesel. Then the same engine was supplied with different blends of MSME with 10% of 1,4 Dioxane additive. Third stage of experiment was done with different blends of MSME on a same engine coated with TBC .For each and every fuel change, the fuel lines were cleaned and the engine is allowed to run at no load to attain a steady state condition.

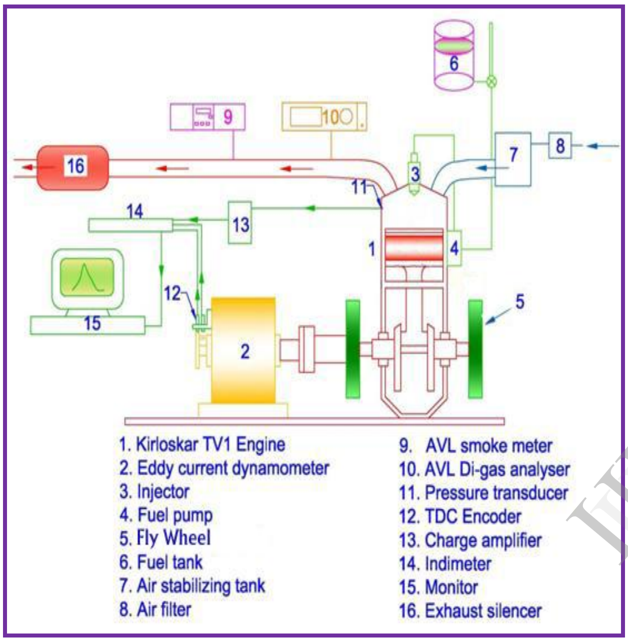

Fig.3.1 Experimental set up

IV. PREPARATION OF COATINGS

The engine components like piston crown, cylinder head and values are selected for coating. Commercially available ZrO_2 and Al_2O_3 ceramic feedstock powder (Sulzer Metco) with particle size ranging from 38.5 to 63 µm and Ni-20CrAIY-9 metal powder with particle size ranging from 10 to 100 µm were used. The surfaces were grit blasted using 400 meshes Al_2O_3 powder. The substrates were grit blasted until a surface roughness of alumina (Ra ~ 4) was achieved. The NiCrALY-9 bond coat of about 150µm in thickness was air plasma sprayed onto the substrate. The ZrO_2 coating of 150µm was deposited over the bond coat, and Al_2O_3 with a thickness of 150 µm was sprayed over the ZrO_2 coating. The air plasma spray system (ion arc of 40 kW) was used to deposit the coating. No air cooling on the back side of the substrates was applied during the spraying process.

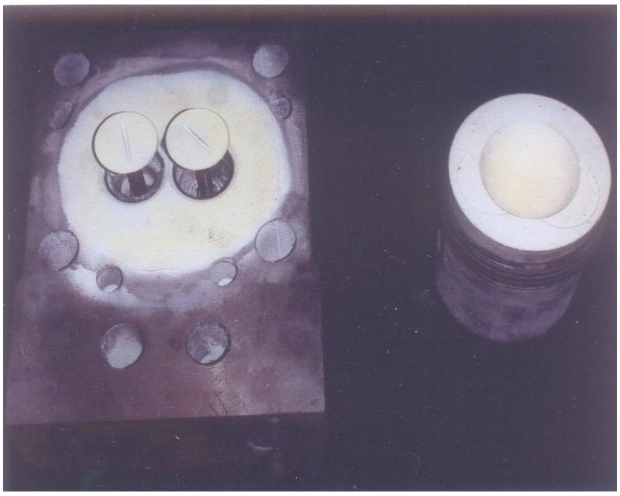

Fig. 4.1 Photographic view of ZrO2 and Al2O3 coated components

V. 1,4 DIOXANE

1,4 Dioxane often called dioxane because the 1,2 and 1,3 isomers of dioxane are rare, is a heterocyclic compound. It is a colourless liquid with faint sweet Odor similar to that of diethyl ether. It is classified as ether. It is used as an oxygenated additive with methyl esters in this research work.

Dioxane is produced by the acid-catalysed dehydration of diethylene glycol, which in turn arises from the hydrolysis of ethylene oxide. The molecule is centro symmetric, meaning that it adopts a chair conformation, typical of relatives of cyclo hexane. The molecule is conformationally flexible, and the boat conformation is easily adopted. Diethyl ether is rather insoluble is water, whereas dioxane is miscible and in fact is hygroscopic. At standard pressure, the mixture of water and dioxane is the ratio 17.9:82.1 by mass is a positive azeotrope that boils at 87.6^0 C. Dioxane is a versatile aprotic solvent. The Oxygen atom is Lewis basic, so it is able to solvate many inorganic compounds. The physical and chemical properties of 1,4 Dioxane are shown in table 2

Table 2. Physical and chemical Properties of 1,4 –Dioxane

Property	
Molecular weight (g/mol)	88.11[a]
Color	Clear[b]
Physical state	Liquid[a]
Melting Point	11.8^0C[a]
Boiling Point	101.1^0C[a]
Density	1.0329[a]
Odor	Faint pleasant odor[a]
Odor threshold	
Water	230ppm w/v[b]
Air	24 ppm v/v[b]
Solubility	
Water	Miscrible[C]
Other Solvents	Soluble in organic solvents[a]
Vapour pressure at $25\,^0$C	38.1mm Hg [e]
Flashpoint	$5\text{-}18^0C$[a]
Flammability limits at 25^0C	Lower:2.0%; Upper:22%[b]
Explosive limits	Vapour forms explosive mixtures with air over wide range[i]

Source: [a]O' Neil et al. 2001, [b]EC 2002, [c]Riddick et al. 1986, [e]Daubert and danner 1985, [i]Sciencelab 2005

VI. RESULT AND DISCUSSION

The experimental investigations were conducted on the different blends of MSME at a rated speed of 1500 rpm and standard injection timing 23° bTDC on Kirloskar TV-I engine. The tests were performed at different loads ranging from no load to 100% load. The optimization of each methyl esters blend was evaluated with respect to performance and emission characteristics. The results of load tests are shown in figure to figure .The results of 10% of fuel additive 1,4 dioxane added to the methyl ester and the engine with thermal barrier coating and their results are also compared in this chapter.. Further, the plots of cylinder pressure and the heat release rate against the crank angle of the engine were also drawn.

A.Brake thermal efficiency

Figure 6.1 shows the brake thermal efficiency of different blends for the MSME. The brake thermal efficiency increases with increasing brake power and almost equivalent to that of diesel fuel. Regarding the brake thermal efficiency for other blends there is no appreciable changes up to part load and beyond that there is slight increase in thermal efficiency than that of diesel. Among all the blends MSME 50% shows higher thermal efficiency than that of other blends. The reason for improved brake thermal efficiency may be more complete combustion and additional oxygen content of methyl ester that contains in MSME 50%. The increasing brake thermal efficiency is for MSME 50% added is 6.3% higher than that of diesel fuel at maximum load. Figures 6.2 shows the brake thermal efficiency with brake power of the engine of MSME with 1,4 dioxane. The results show that there is no appreciable change in the brake thermal efficiency when introducing the additive for all the three methyl esters. Among the blends MSME 25%+1,4 Di 10 resulted in increasing the brake thermal efficiency of 2.59%, than diesel in the entire power output range due to improvement of the combustion. For all the other blends decreasing the brake thermal efficiency noticed than diesel. It is due to post combustion oxidation reduction with help of additive and it reduces the combustion temperature and lowers the oxygen concentration. Figures 6.3 show the comparison of brake thermal efficiency of the methyl esters with coated engine against brake power. It is almost of similar trend in brake thermal efficiency of the standard engine. The lower thermal efficiency for TBC coating is due to incomplete combustion take place during the combustion. That is why coated engine produces more smoke. The thermal efficiency of MSME +TBC combination is 27.4% at maximum brake power of the engine.

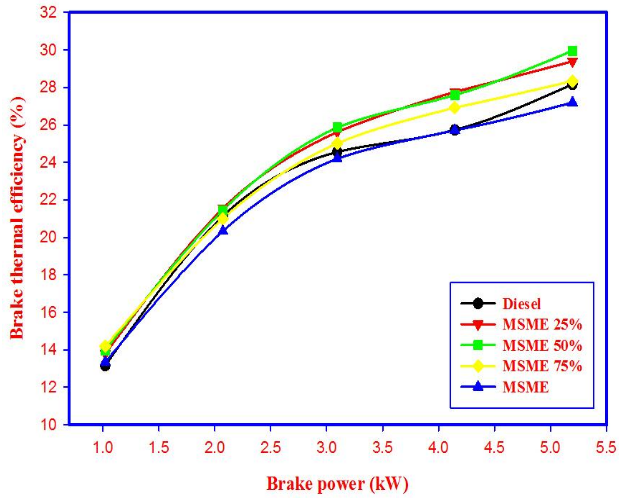

Figure 6.1. Brake thermal efficiency against brake power (MSME)

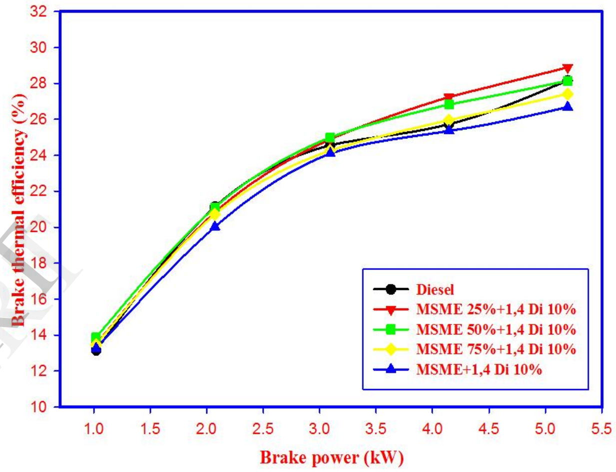

Figure 6.2. Brake thermal efficiency against brake power (MSME+ADD)

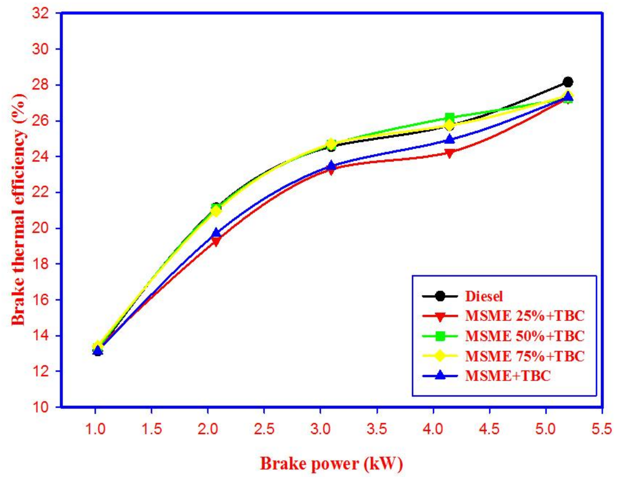

Figure 6. 3. Brake thermal efficiency against brake power (MSME+COAT)

B. Smoke density

The variations of smoke density with brake power of the engine for MSME 25%, MSME 50%, MSME75% and MSME are shown in figure 6.4. It is observed that the smoke density of MSME 25% is lower than that of other blends. The maximum smoke density for the diesel fuel is 76.7 HSU and 42.1 HSU for MSME 25% at maximum brake power. The reason is that the oxygen enrichment provided by various blends of MSME improves the fuel evaporation during diffusion combustion and reduces the smoke density and achieve the complete combustion. Figures 6.5 show the smoke density against brake power with addition of 1,4 dioxane for different blends of MSME. All the blends with additive of MSME marginally increases the smoke emission. The maximum reduction of Smoke emission decreased for MSME 25%+1,4 Di 10%, is 12.64%, Increase in smoke emissions is based on the oxygen content of biodiesel, biodiesel blends and additive. When the in-cylinder temperature reaches a certain level, smoke formation starts with the fuel pyrolizing process in the fuel rich regions of the fuel spray during the diffusion combustion. Variation of smoke density of MSME with brake power of the coated engine is shown in figures 6.6. The earlier investigation shows that the smoke level increases in some cases and decreases in few others. The effect of coating for the fuel MSME increases the smoke density. The reason for high smoke than standard engine is high temperature gas and combustion chamber wall.

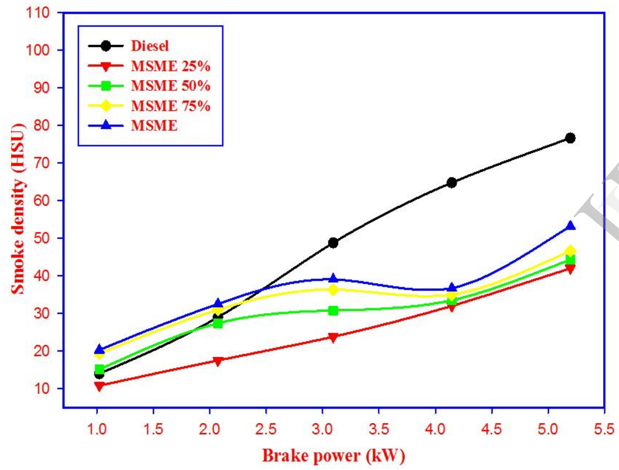

Figure 6.4. Smoke density against brake power (MSME)

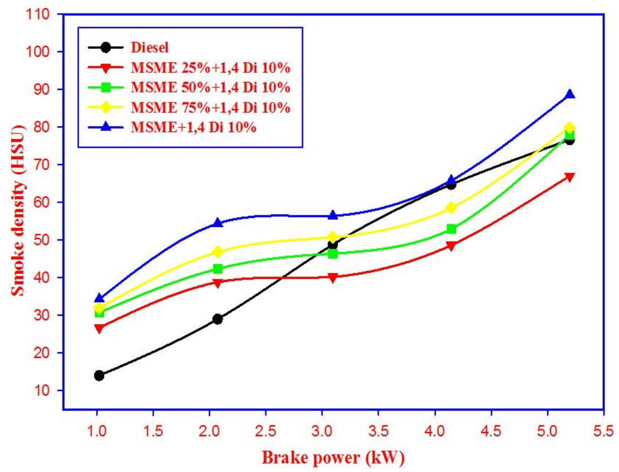

Figure 6.5. Smoke density against brake power (MSME+ADD)

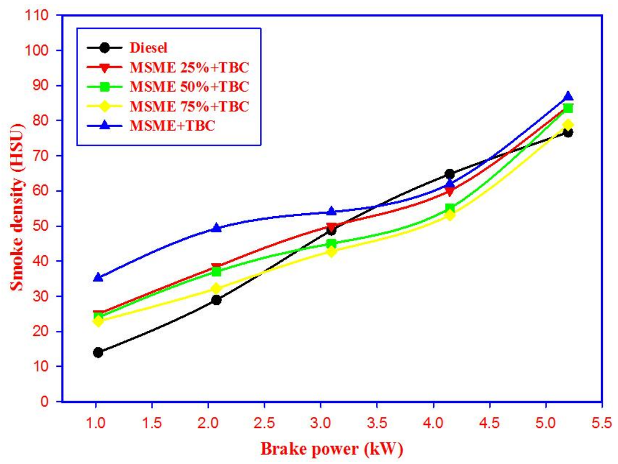

Figure 6. 6. Smoke density against brake power (MSME+COAT)

C. Oxides of nitrogen

Figure 6.7shows NOx emission with different blends of MSME. NOx is formed by chain reactions involving nitrogen and oxygen in the air. These reactions are highly temperature dependent. Since diesel engines are always operated with excess air, NOx is mainly a function of gas temperature and residence time. The most important factor in determining the NOx emission produced by the combustion process is stoichiometry and flame temperature. It can be seen that NOx emission increases with various blends of MSME than diesel. In this research all the blends of MSME resulted an increasing the NOx emission in entire power output range, due to high temperature promoted by combustion and oxygen enrichment. N.L.Panwar et al also experienced the increase of NOx emission when the engine operated with Caster methyl ester. Figures 6.8 show Oxides of Nitrogen with 1,4 Dioxane for different blends of MSME. The NOx emission gradually decreases for all the blends of methyl esters with the addition of 1,4 Dioxane. The reason for NOx reduction is the lower combustion temperature during the combustion. Among all the blends of MSME with additive shows significant reduction of NOx emission than diesel. The MSME+1, 4 Dioxane 10% shows the maximum reduction of NOx emission when compared with other methyl ester blends. Variation of oxides of nitrogen emission with respect to brake powerof MSME with coating is shown in figures 6.9 The NOx emission is the function of combustion temperature and is formatted in the spray region through the different concentration in different zones, which depends on local temperature and oxygen concentration. The results indicate that NOx levels for the thermal barrier coated engine are lower than standard engine. The main cause in lowering the NOx level in TBC engine is due to fact that a late combustion causes the decrease the heat release during the combustion. Since the peak pressure is lower for the above reason. The same trend is observed by E.Buyukkaya et.al during the experiment by changing injection timing. Absorption of nitrogen by Zirconia coating may be one of the reason for less NOx. It is also observed by P.Lawrence et al. It is concluded that MSME+TBC combination shows lower NOx level of about 184 ppm at maximum brake power.

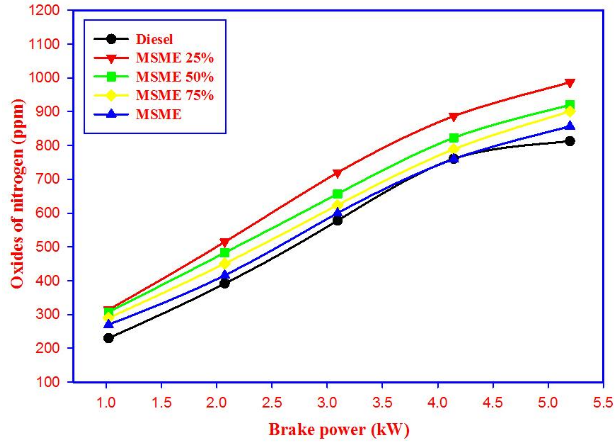

Figure 6.7. Oxides of nitrogen against brake power (MSME)

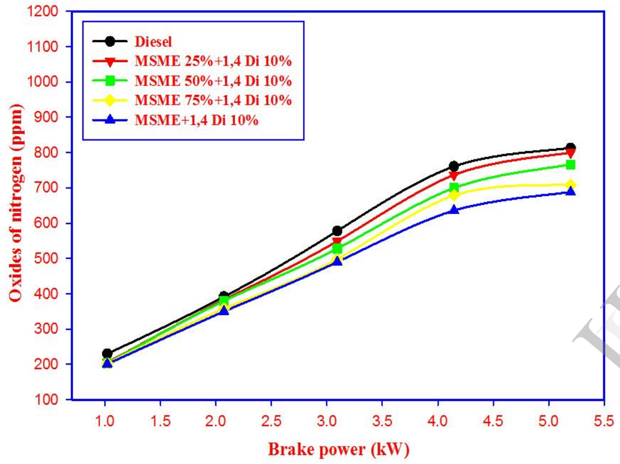

Figure 6.8. Oxides of nitrogen against brake power (MSME+ADD)

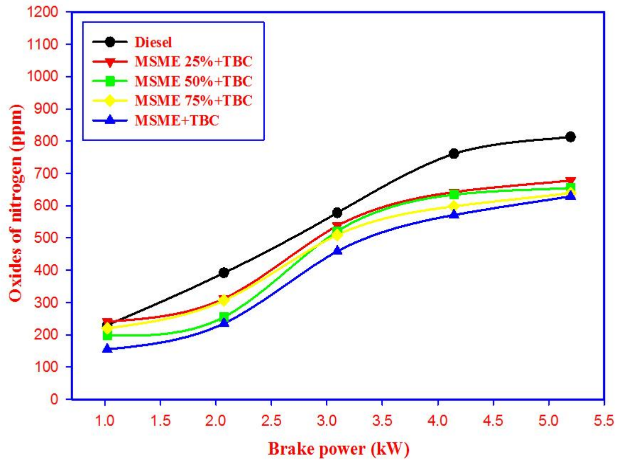

Figure 6.9 oxides of nitrogen against brake power (MSME+COAT)

CONCLUSIONS

- From the experimental investigations of MSME, MSME with additive and MSME with coating, the following conclusions are arrived.
- Among all the blends, MSME 50% shows higher thermal efficiency than that of other blends.The increasing brake thermal efficiency is for MSME 50% added is 6.3% higher than that of diesel fuel at maximum load.
- Among the blends, MSME 25%+1,4 Di 10 resulted in increasing the brake thermal efficiency of 2.59%, than diesel in the entire power output range
- All the blends with additive of MSME marginally increases the smoke emission The effect of coating for the fuel MSME increases the smoke density
- The NOx levels for the thermal barrier coated engine are lower than standard engine Among all the blends of MSME with additive shows significant reduction of NOx emission than diesel. The MSME+TBC combination lower the NOx level of about 184 ppm at maximum brake power than diesel.

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