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Combustion and Emission Analysis of IDI-Diesel Engine operated with Neat Mahua Methyl Ester (MME) blended with Methanol as an Additive

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Abstract
Mahua methyl ester with methanol additive having higher latent heat and lower calorific value was tested on an IDI engine. This is to ensure both low temperature combustion and combustion dilution. Combustion pressure data was collected and the net and cumulative heat release rates have been calculated to analyze combustion in both the combustion chambers. Engine emissions and performance were studied to study the possibility of totally replacing the conventional diesel with the combination of the fuel tested. IDI engines are known for better performance in total combustion in the combustion chambers in succession and hence reduce HC emission to minimum level. The combo of 3% methanol additive in the bio-diesel proved better in gaining advantage in all aspects comprehensively leading to a conclusion to replace diesel fuel with the combo of the fuel tested.
Keywords - Combustion pressure, heat release rate, Indirect diesel injection engine, Mahua Methyl Ester, Methanol.

I. INTRODUCTION

As oil and gas reserves gradually dwindle and global warming due to CO_2 emissions become more obvious the world is going to need to consider alternative fuels, especially where road transport is concerned. Much research has been done to investigate the use of vegetable oils as a road transport fuel. Of the several renewable sources and yet not widely known, Mahua oil appears to be a promising diesel fuel with promising scope for cultivation. A large number of deciduous trees are found in Maharashtra, West Bengal, Orissa in South Indian Forests and Srilanka. The Orange brown pipe flesh berry (2.5 – 5.0 cm long) contains 1-4 shining seeds. Drying and decertification yield kernels (70% by wt). The yield of Mahua seeds various (5-200 kg/tree) depending up on size and age of the tree. The average yield of the sun-dried Mahua seeds is about 1.6 kg/tree. Mahua tree starts giving seeds after 10 years and it goes up to 60 years, when yield is 10 times more than the yield at the age of 10 years. Mahua is perhaps the second most widely known tree in India after Mango tree. Besides oil, flower and fruit give good economic returns. All most all parts of Mahua tree are saleable. The cake after oil extraction is used as fertilizer and sometimes as cattle feed Sukumar Puhan et al. [1]. Mahua Methyl Ester has already evaluated as substitute for diesel fuels. P. Ramesh Babu et al. [2], Prasad V.J.J et al. [3], Hawkins et al. [4] reported Similar findings for indirect and direct injection diesel engines using sunflower oil–diesel fuel blend (20:80 v/v %). They explained that injector coking was the problem by using sunflower oil in the direct injection (DI) diesel engines. Although the mentioned engine problems were generally related to the direct usage of vegetable oils, sometimes successful results were obtained for

long -term usage. Ryu K [5] evaluated the effect of antioxidants in bio-diesel on performances and

emissions of an unmodified 4-cylinder, 4-stroke, WC, indirect-injection (IDI) diesel engine and found that the BSFC of biodiesel fuel with antioxidants decreased more than that without antioxidants, although no specific trends were detected according to the type or amount of antioxidants. Vander Walt and Hugo [6] used the sunflower oil in direct and indirect injection diesel engines. In that study, indirect injection (IDI) diesel engines showed no Adverse effects when sunflower oil was used for over 2000 h. But, direct injected engines showed that the power loss due to severely coked injectors, carbon build-up in the combustion chamber, and stuck piston rings. Ali Turkcan and Mustafa Canakci [7] Investigated the combustion characteristics of IDI diesel engines are different from the DI diesel engines, because of greater heat-transfer losses in the swirl chamber. However, IDI diesel engines have a simple fuel injection system and lower injection pressure level because of higher air velocity and rapidly occurring air-fuel mixture formation in both combustion chambers of the IDI diesel engines. In addition, they do not depend upon the fuel quality and produce lower exhaust emissions than DI diesel engines. Kalam et al. [8] studied emission and performance characteristics of an indirect ignition diesel engine fuelled with 5% palm (P5) and 5% coconut oil (C5) with diesel fuel at constant 85% throttle position. The results show that there are reductions in brake power of 1.2% and 0.7% for P5 and C5, respectively, compared with B0. This reduction is mainly owed to their respective lower heating values. Compared with B0, P5 increases exhaust gas temperature by 1.42% and C5 decreases it by 1.58%. However, both C5 and P5 reduce CO by 7.3% and 21% respectively, and HC by 23% and 17% respectively. However, C5 reduces 1% and P5 increases 2% of No emission. It was noted that P5 produces higher CO_2 than C5 and B0 fuels. This is mainly the effect of high un saturated fatty acid in palm oil.

Attempt is made to reap the benefits of low temperature combustion and combustion dilution with methanol addition is taken up in the present work. Experiments are conducted on indirect injection diesel (IDI) engine run at constant speed of 1500 rpm running with Mahua Methyl Ester (MME) along with Methanol as an additive. Even though thermal efficiency suffers to some extent in IDI engine, there will be betterment in other aspects like crank case oil dilution and lower emissions from the engine. In this experiment, Methanol additive is mixed with the Mahua Methyl Ester (MME) at different proportions such as 1%, 2%, /3%, 4% and 5% by volume and tested at different load conditions (i.e. No load, 0.77 kW load, 1.54 kW load, 2.31 kW load and 2.70 kW load) on IDI diesel engine.

This study has been taken up in conceptualizing the combination of fuel keeping in view lesser or no review of work presented in the literature with the methanol & bio-diesel combination in IDI engines.

Bio-diesel acted like solvent to form inseparable solution with methanol when added in small quantities. Violent premixed combustion has been suppressed with the dilution because of its higher auto ignition temperature and smaller cetane number. The quantity of additive is limited to 5% of the main fuel keeping in view the performance drifting from the desirable estimation. 3% mixture of additive plays important role in saving fuel and running the engine smooth as per the Performance signatures investigated fulfilling the objective defined.

Table-1 Characterization of fuels used

S.No	property	Diesel	MME	Methanol (additive)
1	Viscosity (cSt)	2.75	4.25	0.59
2	Density (kg/m^3)	830	865	790
3	Cetane number	45	50	4
4	Calorific value (kJ/kg)	43000	38800	21489
5	Boiling temperature(^{o}c)	180-330	360	64.7
6	Auto ignition temperature(^{o}c)	235	>300	470
7	Latent Heat of Vaporization(MJ/kg)	0.280	0.262	1.11

II. EXPERIMENTATION

The experimental setup consists of the following equipments:

1. Single cylinder IDI-diesel engine loaded with eddy current dynamometer
2. Engine Data Logger
3. Exhaust gas Analyzer (1600L, German make)
4. Smoke Analyzer

The pressure transducer flushed in the cylinder head along with crank angle encoder fixed to the flywheel which will be transmitting data to the engine data logger and the synthesized data will be displayed in graphic form on the computer by ***C7117*** software designed by 'Apex Innovations', Pune, India.

The experimentation is conducted on the single cylinder Indirect injection (IDI) diesel engine operated at normal room temperatures of 28°C to 33°C in the Department of Marine Engineering, Andhra University, Visakhapatnam, Andhrapradesh, INDIA. The fuels used are neat diesel oil, neat methyl ester of Mahua oil (MME), and MME with 1%, 2%, 3%,4% and 5% additive Methanol. Engine is run at five discrete part load conditions viz. No Load, 0.77 kW Load, 1.54 kW Load, 2.31 kW Load and 2.70 kW Loads. The data collection is done independently for the above said oils.

Table-2 ENGINE SPECIFICATIONS

Engine manufacturer	**Bajaj RE Diesel Engine**
Engine type	Four Stroke, Forced air and Oil Cooled
No. Cylinders	One
Bore	86.00mm
Stroke	77.00mm
Engine displacement	447.3cc
Compression ratio	24±1:1
Maximum net power	5.04 kw @ 3000 rpm
Maximum net torque	18.7 Nm @ 2200 rpm
Idling rpm	1250±150 rpm
Injection Timings	8.5^0 to 9.5^0 BTDC
Injector	Pintle
Injector Pressure	142 to 148 kg/cm^2
Fuel	High Speed Diesel
Starting	Electric Start

III. Results & Discussions

3.1 Cylinder Pressure Signature Study and Heat Release rate Curves

Figure 1 represents the combustion pressure variation at maximum load operation for the fuel samples appended on the right side column. There is spurt in rise of pressure in neat bio-diesel operation where as 3% methanol solution with bio-diesel proved neat release of pressure throughout. Figure 2 demonstrates the delay period of the fuel samples. Figure 3 gives an idea about the net heat release rate derived with the pressure variation in the main chamber assuming the pressure prevailed at any time in both the chambers are same. 3% combo fuel Exhibited better combustion both in the premixed and diffused combustion zones assumed to be taking place in the pre and main chambers. Figure 4 envisage the combustion trend both in the premixed zone and diffused zone. As alcohol content is increasing, there is a drop in the cumulative heat release. 3% blend demonstrated better performance as can be observed from the graph.

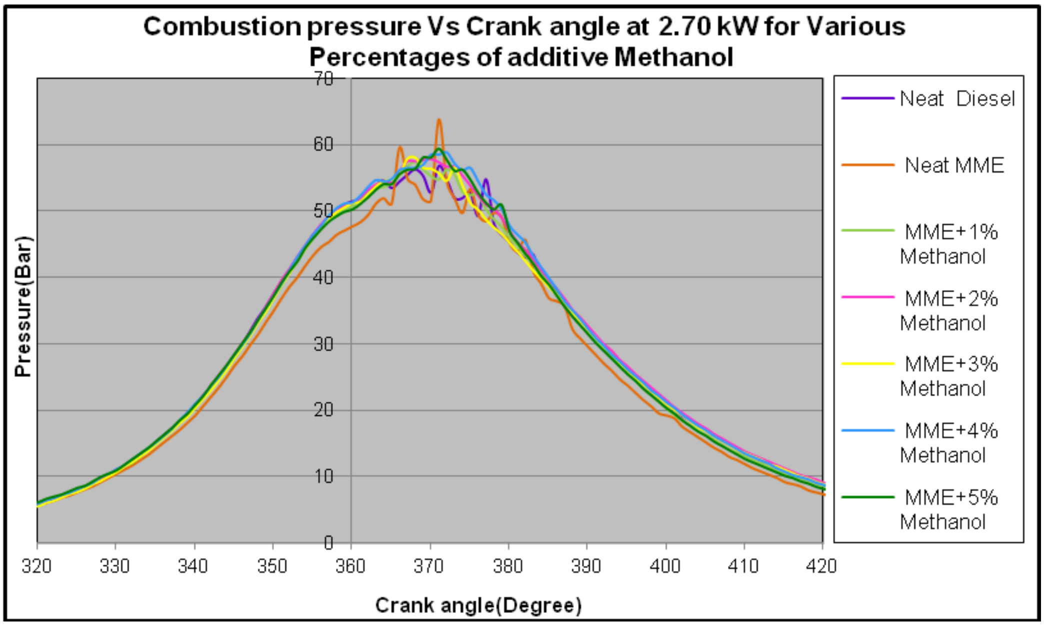

Fig.1.Combustion pressure Vs Crank angle at 2.70 kW for various percentages.

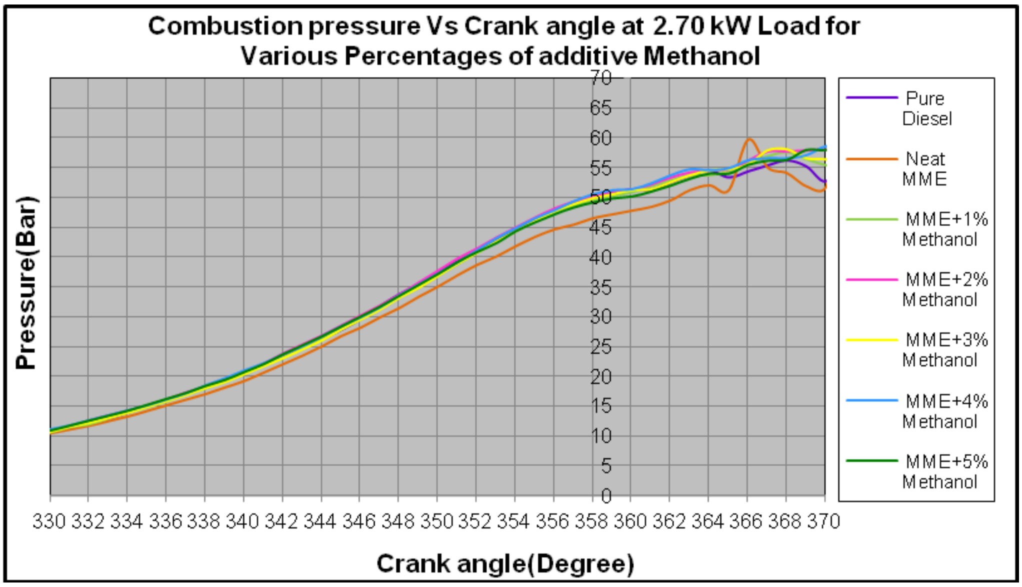

Fig.2.Pressure rise in the vicinity of TDC to monitor combustion delay.

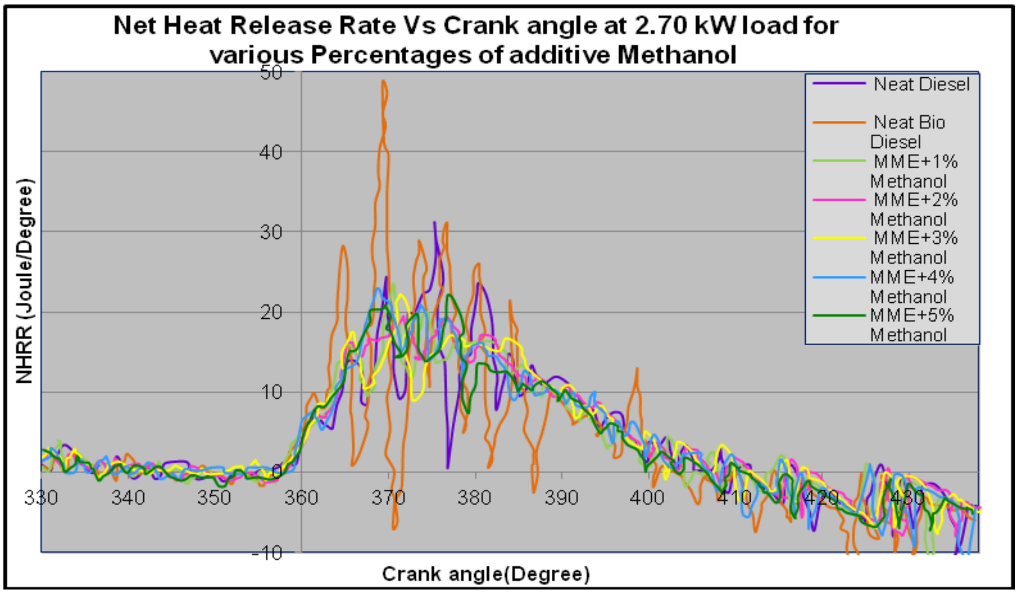

Fig.3.Net heat release rate comparison with various percentages of additives Methanol along with MME at 2.70 kW load.

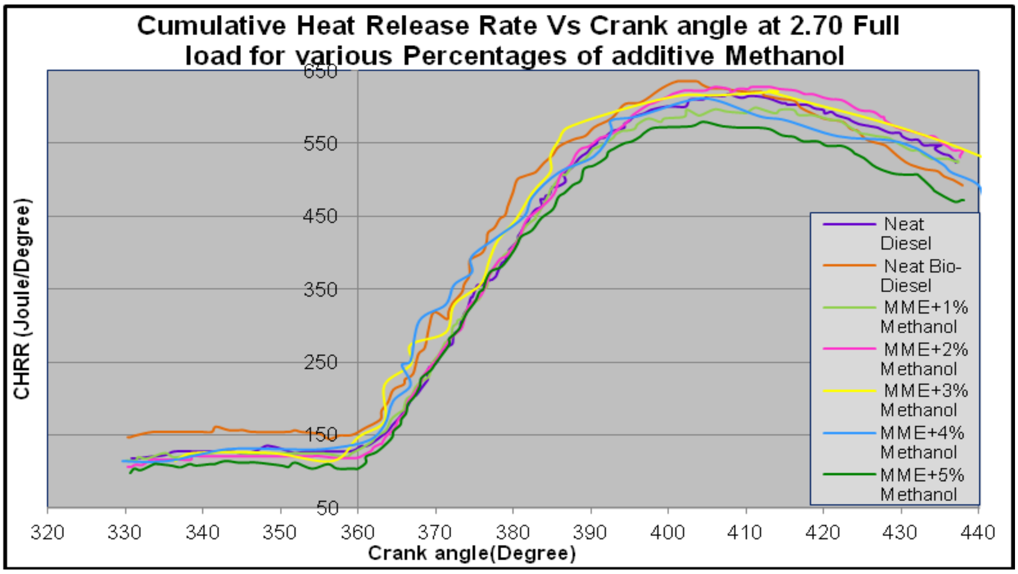

Fig.4.Cumulative heat release rate comparison with various percentages of additives Methanol along with MME at 2.70 kW load.

3.2 Engine Performance and Emissions

The performance test results of the engine were compared for diesel, Mahua methyl Ester (MME) and Methanol additive blends for various percentages.

- Brake Specific Fuel Consumption: Figure (5) envisages brake specific fuel consumption (BSFC) verses Break Power. The Brake Specific Fuel consumption is observed to be within limits for the part load operation of the engine at 1500 rpm. A smoother trend of the curve is observed for the additive blend of 3% (yellow line).The Brake Specific Fuel Consumption for the 3% additive blend is observed on higher side i.e. 0.3209, albeit not shown in the figure. The performance can be rated better when compared to other samples.
- Brake Thermal Efficiency: Figure (6) gives the details of brake thermal efficiency versus Break power of neat diesel, bio-diesel and additive blends. The figure shows that the thermal efficiency is increasing with Methanol additive percentage even though calorific value of additive is lower compared to the main bio-diesel. This is due to improvement in combustion with additive. At 3% Methanol additive Blend

yielded maximum Brake thermal efficiency of 29.33 % at a brake power of 2.31 kW.

Figures 7 and 8 explain the exhaust temperatures and smoke levels in Hat ridge Smoke Units for various samples of the fuels. The decrease of Exhaust temperature '-14^{0}C' is observed in the case of 3% additive with bio-diesel and this decrement is with respect to the diesel fuel. This observation of lower exhaust temperature is representative of lower combustion temperatures in both the combustion chambers.

The decrease in smoke level in exhaust with respect to the neat diesel fuel operation is appreciable (19 HSU reduction at maximum load Operation).This is an indication of better combustion with 3% additive in bio-diesel. Flameless combustion of methanol contributes much to the lowering of smoke.

Figures 9 to 12 envisage the tail pipe emissions. HC emission is lower when compared to diesel fuel. CO and CO_2 levels are almost same for the fuel samples where as NO level is decreasing with the increase of alcohol percentage and this is because of colder combustion entitled to the higher latent heat of alcohol.

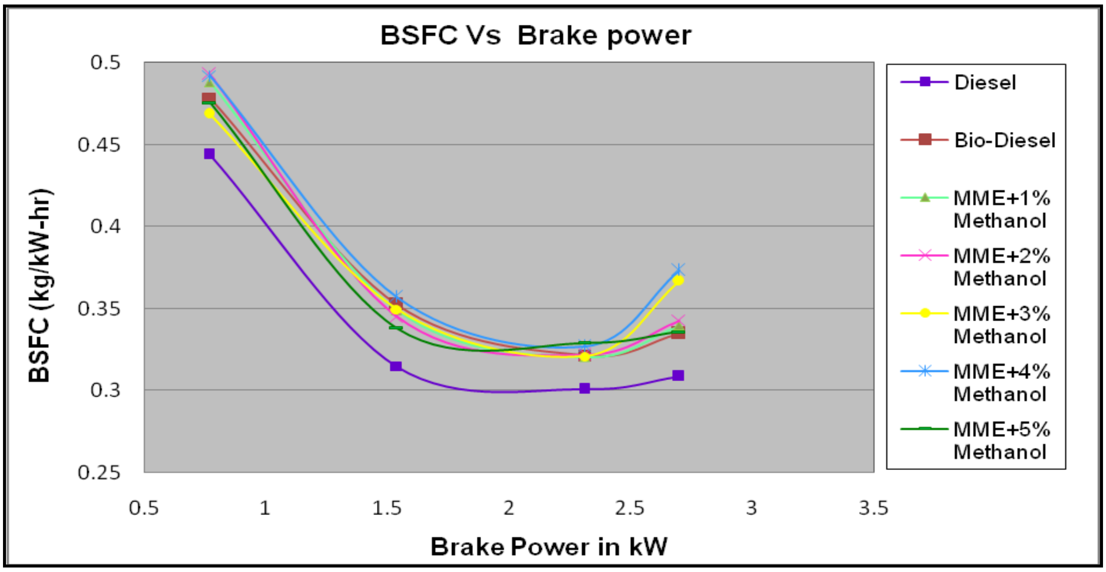

Fig.5. Brake specific fuel consumption Vs Brake power with various percentages of additive Methanol.

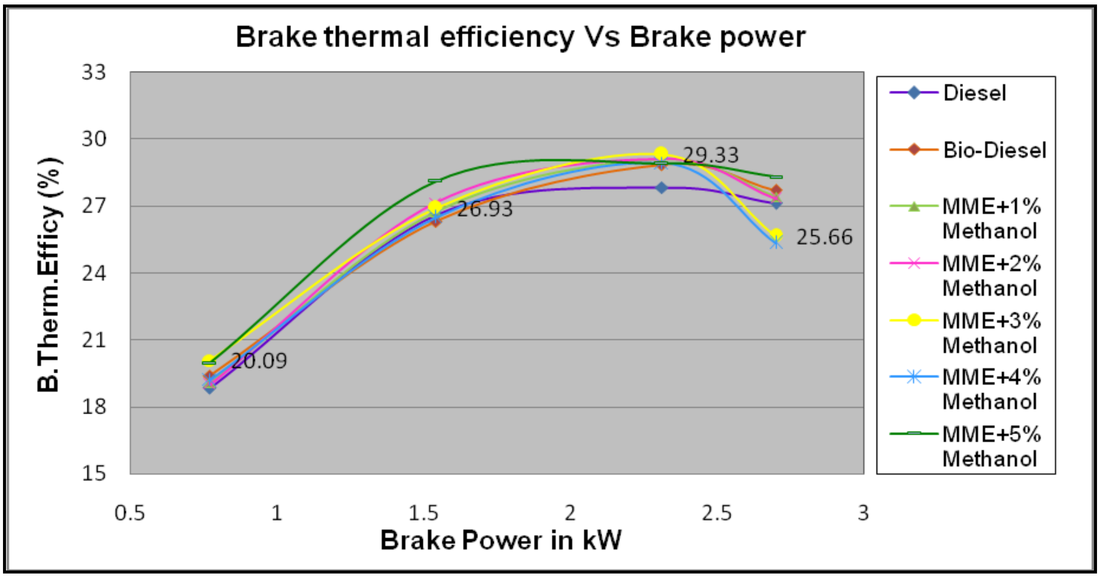

Fig.6. Brake Thermal Efficiency Vs Brake power with various percentages of additive Methanol.

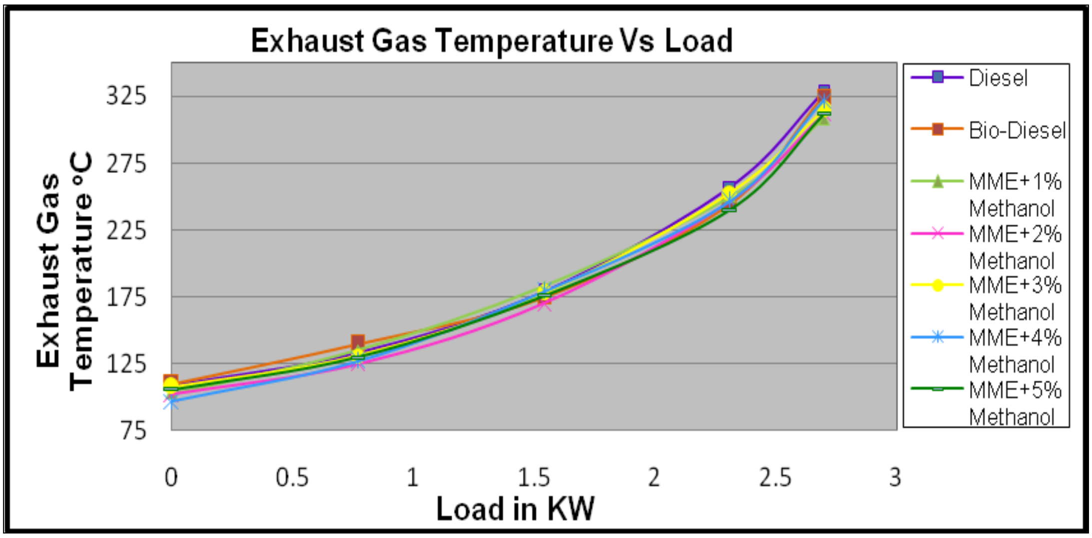

Fig.7. Exhaust Gas Temperature Vs Load with various percentages of additive Methanol.

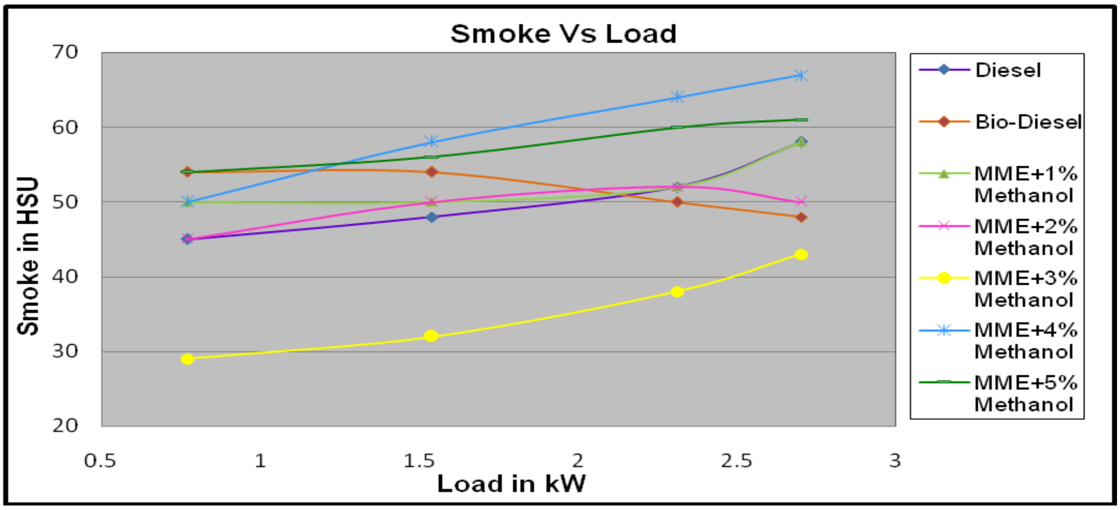

Fig.8.Smoke Vs Load with various percentages of additive Methanol.

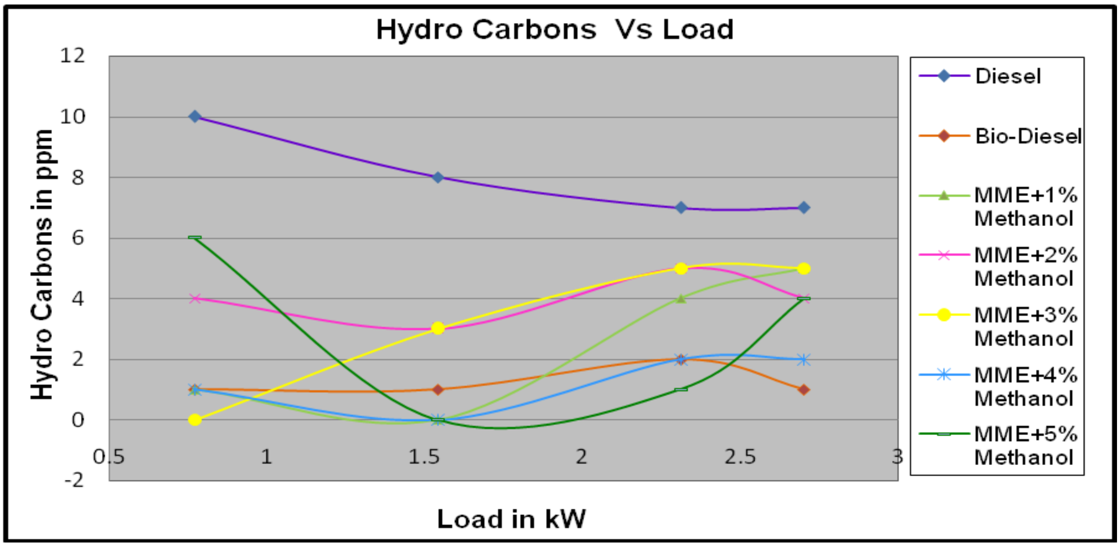

Fig.9. Hydro carbons Vs Load with various percentages of additive Methanol.

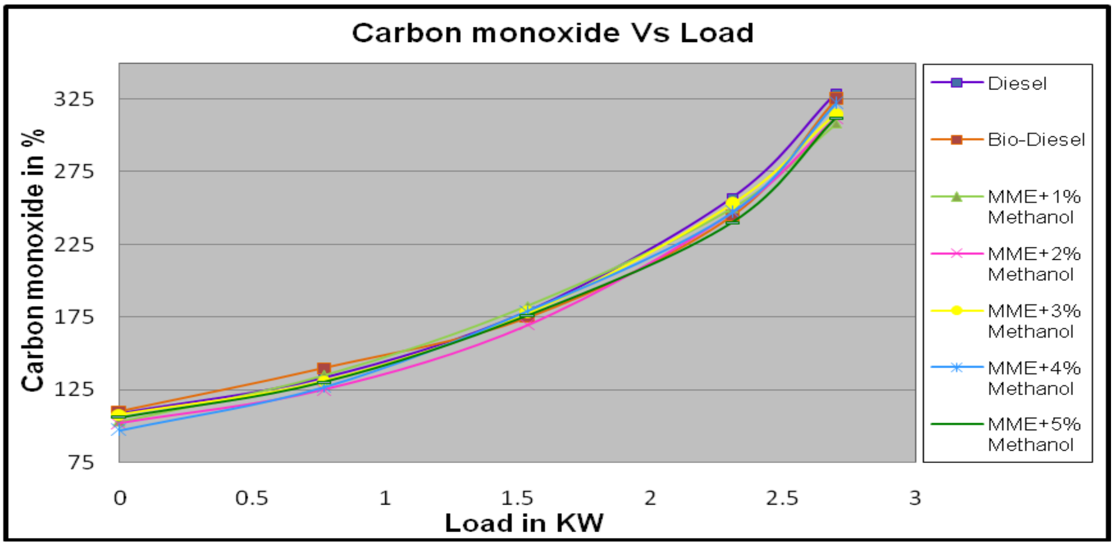

Fig.10. Carbon monoxide Vs Load with various percentages of additive Methanol.

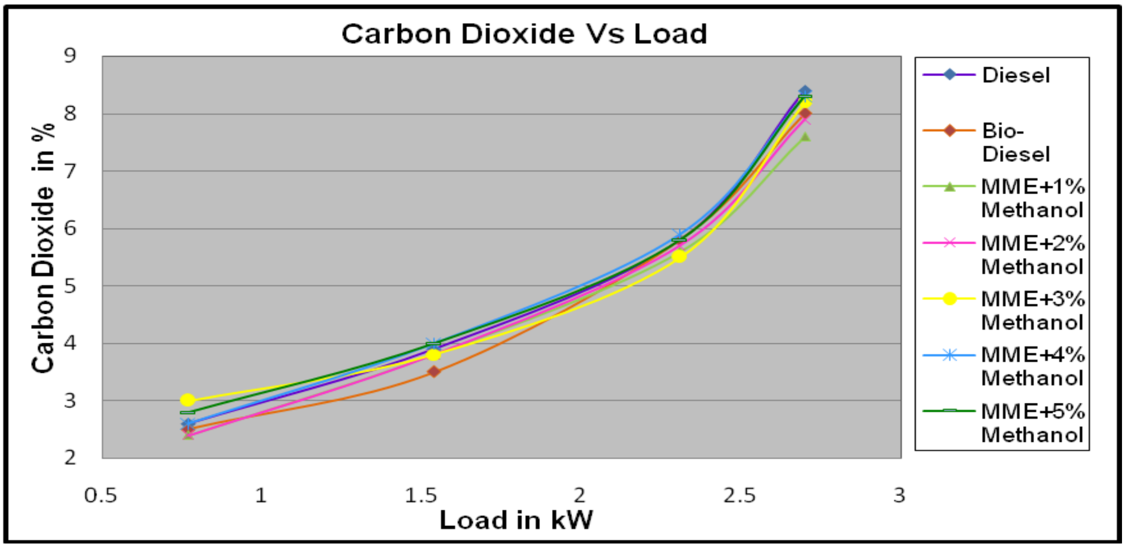

Fig.11. Carbon Dioxide Vs Load plot with various percentages of additive Methanol.

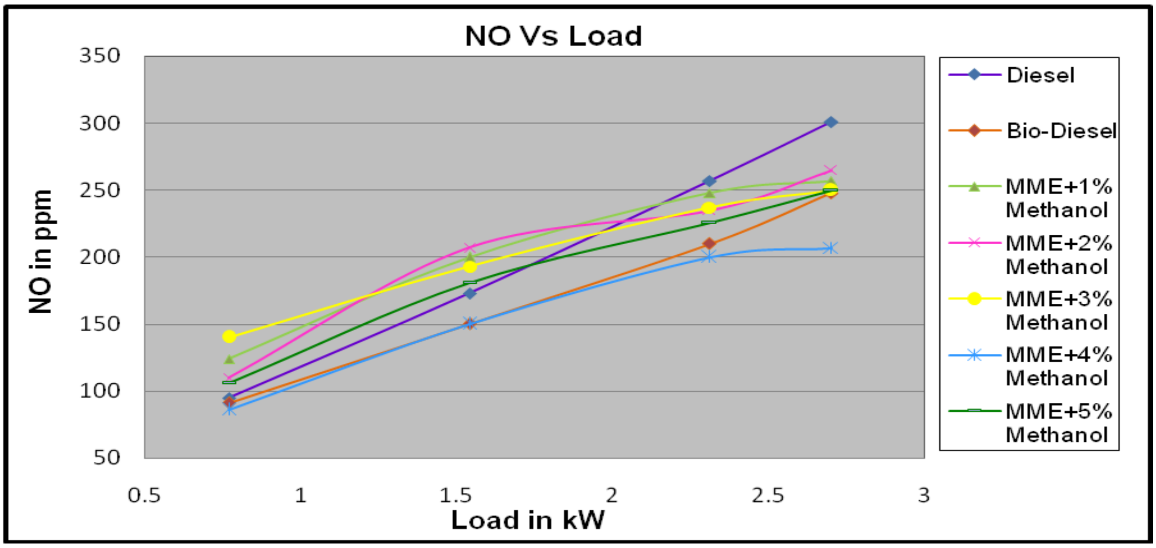

Fig.12. NO Vs Load with various percentages of additive Methanol.

IV. Conclusion

The performance, emissions and combustion were evaluated. 3% methanol percentage in bio-diesel solution gives maximum benefits in the aspects mentioned above and is being justified as befitting replacement for conventional diesel with enhanced benefits. The benefits are as follow:

1. The engine load of 2.70kW was tried at 1500rpm for stable operation and it is observed that 3% additive in bio-diesel has given smoother performance in combustion pressure development.
2. The net heat release rate and cumulative heat release rate quantities were derived from combustion pressure signatures using first law of thermodynamics and mass fractions burned in the pre-combustion and main chambers envisage better combustion phenomena for 3% additive. There is maximum relief of exhaust temperature for 3% additive which indicates that the ensued combustion is low temperature combustion in which methanol has burned at later stages because of lower cetane number.
3. Research on IDI engine indicates lower emissions in exhaust. Additive mixing further reduced the HC emission and CO emission to greater extent.
4. NO emission has also reduced at higher loads especially with the additive Methanol.
5. CO_2 emission increased because of combustion improvement.
6. Thermal efficiency and specific fuel consumption are improved with 3% additive in bio-diesel.
7. Hence 3% additive in MME gives optimum performance indicating suitability to replace diesel fuel with additional advantages over neat bio-diesel.

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