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Performance and Emission Analysis of an Indirect Injection Diesel Engine Operated with Palm Methyl Ester (PME) and 1, 4-Dioxane Additive Blend

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***Abstract*— Bio fuels are alternate fuels derived from renewable plant and animal resources. Biodiesel can be an alternate diesel fuel , because these are renewable, biodegradable, non-toxic and safe to handle as the flash point is more than conventional diesel fuel. It is an established fact that biodiesel reduces the green house gas emissions of Compression Ignition engines. In the present work, Indirect injection(IDI) diesel engine is employed because this engine contains two combustion chambers(swirl chamber and main chamber) which ensure better air-fuel entrainment and eliminate the problem of crank case oil dilution with the usage of additive in biodiesel. Neat Palm Methyl Ester(PME) substitute the conventional diesel fuel in an IDI diesel engine along with 1,4-Dioxane($C_4H_8O_2$) as an additive. Since 1, 4- Dioxane possesses higher latent heat [413kJ/kg] than that of diesel [280kJ/kg], its blending creates low temperature combustion and reduces the formation of NO_x. 1,4-Dioxane evaporates and ignites first because of its lower boiling point (101.1^{0}C) and auto ignition temperature (180^{0}C).It initiates combustion of rest of the vapor in pre combustion chamber. Four additive blends of 1, 4-Dioxane in PME viz. 1%,2%,3% and 4% by volume were tested. Brake Specific Fuel Consumption (BSFC), Brake Thermal Efficiency (BTE), Exhaust Gas Temperatures (EGT), Smoke and tail pipe Emissions are studied. 3percent 1,4-Dioxane in PME is considered as best choice and engine performance and emission characteristics was evaluated in comparison with neat PME and petro diesel fuels. BSFC is reduced by 2.64 percent compared with neat PME, an increase of BTE by 9.89 percent, EGT and smoke readings are decreased by 4^{0}C and 20 percent respectively for 3 percent 1,4-Dioxane in biodiesel with respect to conventional diesel fuel at maximum load. Engine emissions are decreased by 2ppm for HC, 40 percent for CO, 10.89 percent for CO_2 and 56ppm for NO_x with 3 percent additive in biodiesel with respect to diesel fuel. It can be concluded that 3 percent 1,4-Dioxane in POME is suitable fuel for IDI Diesel engine as a suitable replacement to the petro diesel fuel.**

Keywords*— Alternate fuel; IDI diesel engine; Palm Methyl Ester; 1,4-Dioxane additive; Performance; tail pipe emissions

I.INTRODUCTION

Vegetable oils are more promising alternate fuels as they have several merits like renewability, eco- friendly and easily cultivated in rural areas, where there is an acute need for modern forms of energy [1-3]. Therefore more research was done to investigate the feasibility of vegetable oils as an alternate fuel in diesel engines [4-6]. Obviously, the use of non-edible vegetable oils compared to edible oils is recommended because of the tremendous demand for edible oils as food and are too expensive to be used as fuel at present. Palm biodiesel blended with diesel fuel for certain percentage (up to30%) has significantly improved emission characteristics, as shown in the result of a 20,000 km road test carried out in Indonesia [7].Overall combustion phenomenon of an IDI engine running with soybean methyl ester are on par with diesel fuel except shorter ignition delay period for biodiesel [8].The specific fuel consumption and emission pollutants were reduced. Combustion pressures and combustion period was increased when the DI engine running with Palm biodiesel compared with diesel fuel[9].The tail pipe emissions like CO,HC and CO_2 were reduced, there is marginal decrement in NO, increase in BSFC and increase in brake power for DI engine fuelled with palmolein bio diesel [10]. Implementation of Palm biodiesel blend with diesel fuel produces lesser CO and HC pollutants but increase in NO_x [11]. Performance of an IDI diesel engine fuelled with Mahua biodiesel and methanol blend decrease the pollutants NOx, HC and CO to considerable extent, increases CO_2, decreases SFC and increases brake thermal efficiency [12]. Comparative studies on both DI and IDI diesel engines to know the effect of olive oil blend with petro diesel fuel with small penalty in fuel consumption [13]. 1-4 Dioxane additive with Ethanol-Diesel blend on DI engine would improve the performance, reduction in emissions except NO_x, improvement in SFC and brake thermal efficiency w. r. t diesel fuel [14, 15]. The effect of ethanol/diesel blends with 5%, 10% and 15% (by vol.)

ethanol on the combustion and emissions characteristics of a DI diesel engine was studied and it is realized that the ignition delay for the E15 blend was more than pure diesel fuel. Also there was no remarkable difference between the peak pressures for each load condition. The combustion characteristics of IDI diesel engines are dissimilar from the DI diesel engines with the reality that heat-transfer losses are more in the larger surface area of the combustion chambers. But IDI diesel engines have their own advantages like a simple fuel injection system, lower fuel injection pressure, higher induced air velocity and better air entrainment in both chambers[16]. Pongamia biodiesel with 6% iso-butanol additive performed better as an alternative to the diesel fuel on IDI engine. There is decrease in Exhaust gas temperatures, Smoke levels and tail pipe emissions at maximum load [17]. Performance and emission characteristics of an indirect ignition diesel engine operated with 5% palm and 5% coconut oil with conventional diesel fuel at fixed 85% throttle position. The results show that there are reductions in brake power by 1.2% for 5/95% palm-diesel and by 0.7% for 5/95% coconut oil-diesel when compared with conventional diesel fuel. This reduction is owing to their lower calorific values. Compared with diesel fuel, 5/95% palm oil increases exhaust gas temperature by 1.42% and 5/95% coconut oil-diesel decreases it by 1.58%. But both 5% palm and 5% coconut oil in diesel reduce CO by 21% and 7.3% respectively, including HC reduction by 17% and 23% respectively. However, 5% palm increases NO by 2% and 5% coconut oil in diesel reduces NO by1%. 5% palm-diesel combo produces more CO_2 than 5% coconut oil in diesel and neat diesel fuels because of carbon rich fatty acids in palm oil [18].

II.EXPERIMENTATION

The experimental test rig (Fig.1) consists of the following equipments: 1. Single cylinder IDI diesel engine loaded with eddy current dynamometer. 2.Engine Data Logger(M/S. APEX Innovations Ltd, India) 3.Exhaust Gas Analyzer (AVL DI TEST) and 4. Smoke Analyzer(Diesel Tune 114). The engine specifications are given in the table 1.This work deals with investigation on the benefits of PME with 1,4-Dioxane additive blend on the engine performance and emission characteristics of variable speed IDI diesel engine. Experiments are conducted on IDI diesel engine running at fixed 1500 rpm operated with four fuel samples of PME with 1,4-dioxane as an additive. Properties of the fuels used in the experimentation are shown in the table 2. Engine tests were performed at five different engine loads 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.

Fig.1. Experimental test rig

Combustion pressures at each degree of crank revolutions are recorded with C7112 software with six samples averaging and heat release rates are computed using pressure data as the input data, displacement volume modeling and process coefficient calculation at every degree of crank revolution. Fuel consumption is recorded using U-tube manometer for characterized fuel to study the performance. The smoke values are recorded and calculated in HSU. The exhaust gas temperatures are measured by a suitable thermocouple fixed at the beginning of the exhaust pipe and exhaust gas analysis is taken up for comparison.

Table 1.Specifications of the engine test rig

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	447.3cm^3
Compression ratio	24±1:1
Maximum net power	5.04 kW at 3000 rpm
Maximum net torque	18.7 Nm at 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

Table 2. Properties of the Fuels Used

S.No	Name of the fuel → ↓Properties	*Diesel*	*PME*	*1,4-Dioxane*
1	Density at 33^{0}C (kg/m^3)	830	860.6	1033
2	Gross Calorific value (kJ/kg)	43000	38050	26960
3	Viscosity at 33^{0}C (cSt.)	2.75	4.545	1.16
4	Cetane Number	45-55	65	50
6	Flash Point (°C)	50	164	12
7	Latent Heat of Vaporization (KJ/Kg)	280	300	413
8	Auto ignition temperature (°C)	316	363	180

III.RESULTS AND DISCUSSION

A. Engine Performance

The performance test results of the engine were compared for conventional diesel fuel, PME and 1,4-Dioxane additive blends for different percentages.

1)*Brake Specific Fuel Consumption (BSFC)*:

Figure.2 shows the BSFC verses Equivalence Ratio. The equivalence ratio is found to be within the range for the part load operation of the engine at 1500rpm for all fuels tested. A smoother tendency of the curve is observed for the additive blend of 3% (green line).The equivalence ratio for 3% of additive blend is found to be minimum i.e. 0.52215; however the performance can be rated better when compared to other fuel samples. The BSFC for the 3% additive blend is reduced by 2.64% compared with neat PME. This is because of the combustion refinement with the presence of additive with better atomization and lesser auto ignition temperature.

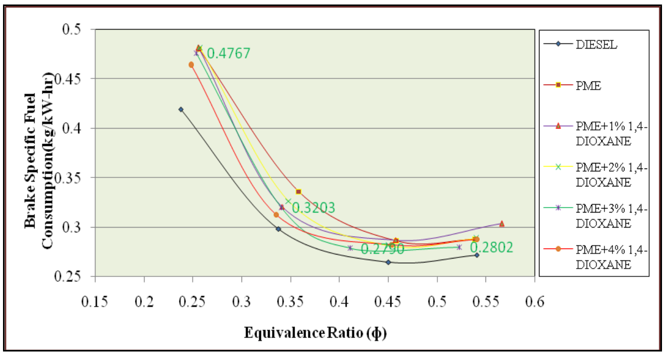

Fig.2.Brake Specific Fuel Consumption verses Equivalence Ratio for all fuel samples

2)Brake Thermal Efficiency (η_{th}):

Figure.3, shows Brake Thermal Efficiency curve which has better trend for POME with 3% 1,4-Dioxane additive blend and the maximum η_{th} attained is 33.79% at an equivalence ratio of 0.52215. Figure.4 depict the variation of Brake Thermal Efficiency w. r. t. Brake Power of neat diesel, PME and additive blends. Brake Thermal Efficiency has been increased with 1,4-Dioxane additive percentage despite the reason that the heat value of additive is lesser than both diesel and biodiesel with rational mass consumption of additive in biodiesel(PME) and improvement in combustion propensity. At 3% 1,4-Dioxane additive blend achieved maximum Brake Thermal Efficiency of 33.79 % at a Brake Power of 2.7 kW (i.e. maximum load on the engine) with an increase of 9.89% when compared with conventional diesel fuel at the same load.

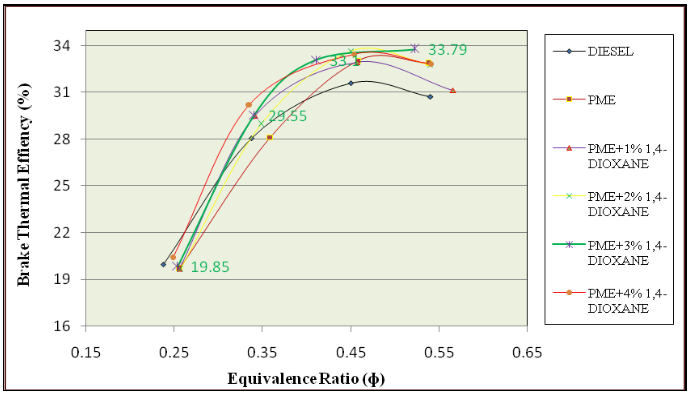

Fig.3. Brake Thermal Efficiency verses Equivalence Ratio for all fuel samples

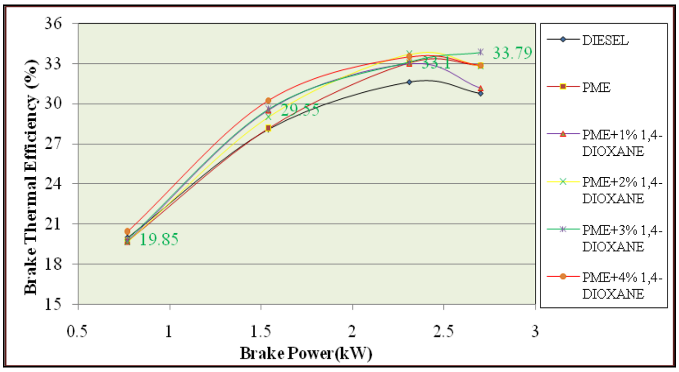

Fig.4.Brake Thermal Efficiency verses Brake Power for all fuel samples

B. Exhaust Gas Emissions

1) Exhaust gas temperature:

Figure.5 explains the exhaust gas temperatures for various fuel samples. Generally the exhaust gas temperatures for neat biodiesel are high when compared to conventional diesel fuel. There is no significant increase in exhaust temperatures with additive as portrayed in the figure 5. Exhaust gas temperature decrease of 4^{0}C with respect to the diesel fuel at maximum load is observed in the case of 3% 1,4-Dioxane additive with biodiesel .This may be due to higher latent heat of the additive. These lower exhaust gas temperatures connote lower combustion temperatures in both the combustion chambers.

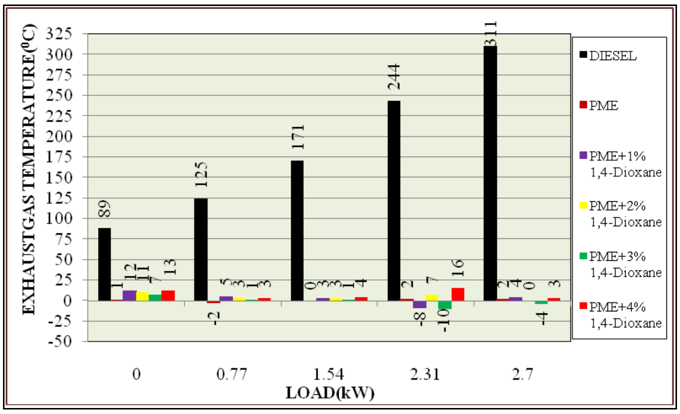

Fig.5.Exhaust Gas temperature verses Load

2)Smoke Levels:

Figure .6, shows the details of Smoke levels versus load with neat diesel, bio-diesel and additive blends. Reduction in smoke level in exhaust with respect to the neat diesel fuel operation is appreciable (i.e.10 HSU or 20% reduction at maximum load condition).This is an indication of better utilization of oxygen in combustion with 3% 1, 4-Dioxane additive in biodiesel. Smoke level decrement can be ascribed to smaller boiling point, lesser auto ignition temperature and reasonably higher cetane number of additive.

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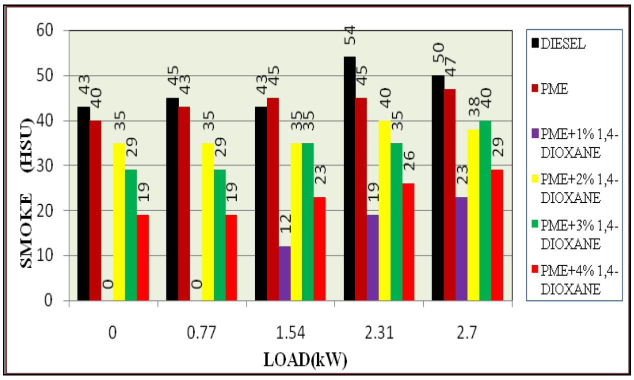

Fig.6.Smoke verses Load

3)Hydrocarbon(HC) and Carbon monoxide (CO) emissions:

Studies on IDI engine indicates lower emissions in exhaust. Additive mixing further reduced the HC emission and CO emission to greater extent which can be observed from the figures (7&8). 3%1,4-Dioxane in PME were compared with conventional diesel fuel at maximum load and these are decreased by 2ppm in case of HC, 40% for CO. This result can interpreted with the properties of additive which has got lower boiling point and auto ignition temperature. The above properties encourage combustion initiation more in advance than biodiesel making the progress of the combustion very smoother in both the chambers. This combustion process reduces the heterogeneity and reduces pollutant formation leading to complete combustion.

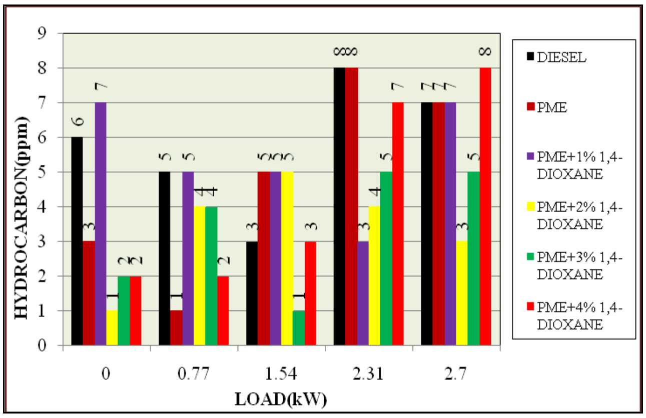

Fig.7 Hydro Carbon verses Load

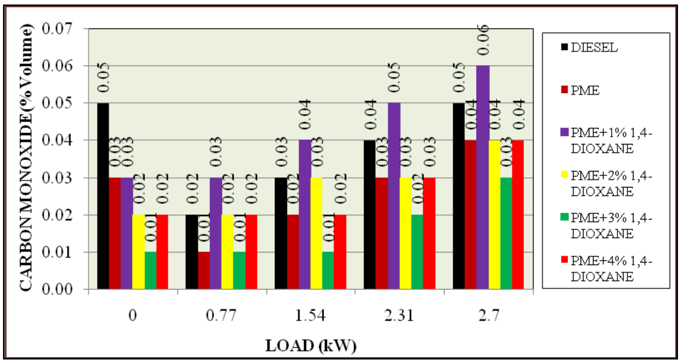

Fig.8.Carbon Monoxide verses Load

4)Carbon Dioxide (CO_2) emission:

CO_2 emission decreased by 10.89 % as envisaged in Fig.9. This can be acclaimed to sharing of free and molecular Oxygen by carbon and hydrogen. The molecular carbon content in the additive is lesser and hence the result for CO_2 formation.

5) Oxides of Nitrogen (NO_x):

This emission is reduced by 56 ppm (or 18.42%) at high loads with the 3% 1,4-Dioxanel additive in PME compared with conventional diesel fuel as shown in Fig.10.This may because of colder combustion owing to higher latent heat of the additive and earlier evaporation which encourages low temperature combustion and hence lesser formation of NO_x.

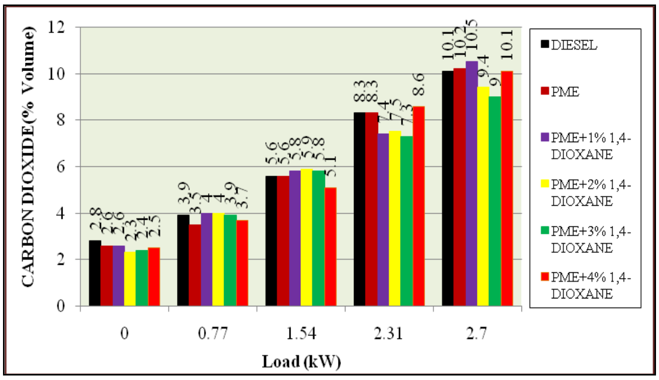

Fig.9 Carbon Dioxide verses Load

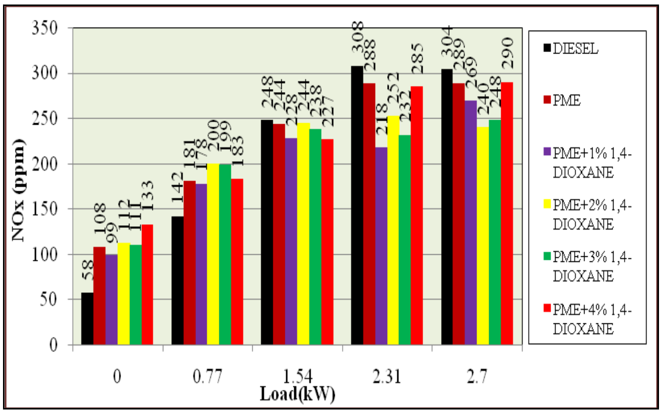

Fig.10 Oxides of Nitrogen verses Load

III.CONCLUSIONS

The performance and emission characteristics were evaluated. 3% 1,4 Dioxane additive in PME performed maximum as replacement to conventional diesel fuel. The inferences are evolved at maximum load on the engine.

- BSFC is reduced by 2.64% compared with neat PME
- An increase of Brake Thermal Efficiency by 9.89%
- Exhaust Gas Temperature and smoke readings are decreased by 4^0C and 20% respectively for 3percent 1,4-Dioxane in biodiesel with respect to conventional diesel fuel.

- Engine emissions are decreased by 2ppm for HC, 40 percent for CO, 10.89 percent for CO_2 and 56ppm for NOx with 3 percent additive in biodiesel.

With the advantages enumerated above, It can be concluded that 3percent 1,4-Dioxane in PME is suitable fuel for IDI Diesel engine as a total replacement to the petro diesel.

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