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IMPLEMENTATION OF DIOXANE AND DIESEL FUEL BLENDS TO REDUCE EMISSION AND TO IMPROVE PERFORMANCE OF THE COMPRESSION IGNITION ENGINE

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Abstract

Performance of a compression ignition engine fuelled with 1, 4 Dioxane- diesel blends is evaluated. A single-cylinder, air-cooled, direct injection diesel engine developing a power output of 5.2 kW at 1500 rev/min is used. Base data is generated with standard diesel fuel subsequently; five fuel blends namely 90:10, 80:20, 70:30, 60:40 and 50:50 percentages by volume of diesel and dioxane were prepared and tested in the diesel engine. Engine performance and emission data were used to optimize the blends for reducing emission and improving performance. Results show improved performance with B10 blends compared to neat fuel for all conditions of the engine. Other blends recorded marginal decrease in brake thermal efficiency. The maximum efficiency for B30, B50 blends at peak load are 26.3%, 25.2% respectively against 29.1% for sole fuel. NOx emissions were found to be high for the blends. Peak pressure and rate of pressure rise are increased with increase in dioxane ratio due to improved combustion rate. Heat release pattern shows higher premixed combustion rate with the blends. Higher ignition delay and lower combustion duration are found with all blends than neat diesel fuel.

Keywords: Oxygenated fuel, 1,4 dioxane, additives.

1. Introduction

Indiscriminate extraction and increased consumption of fossil fuels have led to the reduction in carbon based resources. Alternative fuels promise to harmonize sustainable development, energy conservation management of efficiency and the environmental preservation. Due to the shortage of petroleum product and its increasing cost, efforts are on to develop alternative fuels especially to diesel oil for full or partial replacement. The most promising substitutes for petroleum fuels

Abbreviations

BSFC	Brake Specific Fuel Consumption
BP	Brake Power
CO	Carbon Monoxide
CI	Compression Ignition
DEE	Diethyl Ether
HC	Hydro Carbon
MEA	Methoxyethyl Acetate
NO_x	Oxides of Nitrogen
SI	Spark Ignition

are the alcohols-mainly methanol and ethanol (renewable fuels). These renewable fuels can be made from several non-petroleum sources and they also considerably reduce the pollution problems associated with automobiles. Ethanol produced from biomass shows promise as a future fuel for spark ignition (SI) engines because of its high-octane quality. Ethanol is not suitable for compression ignition (CI) engines because of its low cetane number. But ethanol can be easily converted through a dehydration process to produce Diethyl Ether (DEE), which is an excellent CI fuel with higher energy density than ethanol by itself. Diesel engines have the advantages of high thermal efficiency lower emission of CO and HC. However, they have the disadvantage of producing smoke, particulate matter and oxides of nitrogen and it is difficult to reduce both NOx, and smoke density simultaneously in diesel engine due to trade-off between NOx and smoke. It follows; therefore, that substantial amount of effort has been directed at providing solutions to these problems. The addition of oxygen containing compounds to diesel fuel has been proposed as a method to complete the oxidation of carbonaceous particulate matter and associated hydrocarbons. In addition, many oxygenates have high cetane number and their association with diesel results in high cetane number and hence lower exhaust emissions. Due to these advantages, there is growing interest in the introduction of oxygenates into diesel fuel.

Methoxyethyl acetate (MEA) was considered as an ignition-improving additive to methanol powered diesel engines [1]. However, MEA is a gaseous fuel and therefore requires that a vehicle be adopted for gaseous operation [2]. In addition, the fuel delivery infrastructure is not currently suitable to distribute large quantities of a gaseous fuel. For these reasons, there is interest in new liquid compression ignition fuels or fuel additives, which have high cetane rating and reduce particulate emissions and at the same time they are compatible with current vehicle technology and fuel delivery infrastructure.

Some oxygenated compounds like ethers or methyl carbonates have been tested as additives to improve the performance of some petroleum derived diesel fuels. Ethers, that have been proposed and or tested for use as blends with diesel fuel include dimethoxymethane, 1,2-diemthoxyethane, 1,2 -dimethoxypropane, butyl ether, 2-ethoxyethyl ether, 2-ethoxyethyl ether, pentyl ether and dibutoxymethane [3-5]. Bailey et al. [6] suggest that DEE as a potential replacement fuel for CI Engines. The molecular weights of DEE are low; the molecules have high hydrogen to carbon ratios and a low number of carbon-to-carbon bonds [7-9].

All these properties lower the tendency of forming solid carbon particulate during combustion. The molecules contain oxygen, which also suppress the formation of soot. The molecular bonds break up to radicals at reasonable activation energy, which leads to high cetane numbers. DEE has long been known as a cold start aid for engines, is an oxygenated renewable fuel, which is completely miscible with diesel. Mohanan et al., [10] studied the effect of DEE on the performance and emissions of a four-stroke direct injection diesel engine and found that 5% DEE can be blended with diesel fuel to improve the performance and to reduce emissions of the diesel engine even though experiments were carried out successfully up to 25% DEE blend.

Gong Yanfeng et al., [11] proved 15% of 2-methoxyethyl acetate (MEA) can be used to decrease exhaust smoke as a new oxygenated additive of diesel with marginal increase in efficiency 1, 4 dioxane (1,4-dioxacyclohexane) a new oxygenate is investigated in this study. Dioxane at present using as a solvent for organic compounds is miscible in diesel. The hydrocarbon moieties of these molecules constitute the hydrophobic portion of the structure due to their strong affinity over diesel fuel while the two oxygen molecules form very strong hydrogen bond with ethanol as shown in Figure 1, therefore it is non-ionic and can form a stable, homogenous emulsion with ethanol.

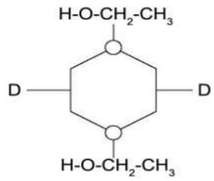

Fig. 1. Bond between the dioxane, diesel (D) and ethanol (E).

Zhenkun Lin et al., [12] studied combustion intermediates of a cyclic oxygenated hydrocarbon, 1,4-dioxane at low pressure with an equivalence ratio of 1.80 and found no aromatic intermediates, that was a prominent difference between the fuel-rich flames of 1,4-dioxane and previously studied noncyclic oxygenated hydrocarbons. Literature review reveals that most of the work has been done with MEA and DEE on a single cylinder direct injection diesel engine. Hence, the present experiments have been undertaken to evaluate the performance, combustion and emissions of a single cylinder direct injection diesel engine operating on 1,4 dioxane diesel blends.

2. Fuel Properties of 1, 4 Dioxane and Diesel

General fuel properties of 1, 4 dioxane, and diesel are presented in Table 1. As a compression ignition fuel, dioxane has several favourable properties for on board storage.

3. Parameter Tested and Experimental Procedure

Experiment were conducted on kirloskar TV1, four stroke, single cylinder, air cooled diesel engine. The rated power of the engine was 5.2 kW at 1500 rpm. The engine was operated at a constant speed of 1500 rpm and standard injection pressure of 200 bar pressure. The fuel flow rate was measured on volume basis using a burette and a stop watch. K-type thermocouple and a digital display were employed to note the exhaust gas temperature. AVL smoke meter was used for measurement of smoke density. NOx emission was measured by five gas AVL analyser. In cylinder pressure was measured with help of AVL combustion analyser.

Table 1. Chemical properties of diesel, 1, 4 dioxane.

	Molecular Formula	Molecular weight	Density at 20°C ($\times 10^3$ kg/m^2)	Boiling point (C°)	Flash point (°C)	Viscosity (mPa s)	Cetane Number	% of oxygen by weight
Diesel	C_xH_y	190–220	0.829	180–360	65–88	3.35	45–50	0
1,4-Dioxane	$C_4H_8O_2$	88	1.034	101	12	1.20	50	36

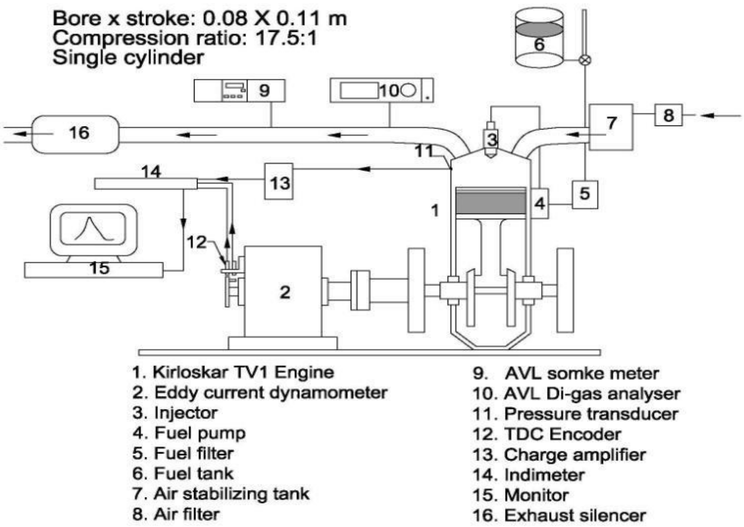

Fig. 2. Experimental setup.

Experiments were conducted with five different blends of diesel with dioxane ranging from 10 to 50% by volume to sole fuel. The schematic experimental setup is shown in Figure 2. Readings were taken, when the engine was operated at a constant speed of 1500 rpm for all loads. Parameter like engine speed, fuel flow and the emission characteristics like NOx and smoke were recorded. The performance of the engine was evaluated in terms of brake thermal efficiency, brake power, specific fuel consumption from the above parameters. The combustion characteristics like cylinder pressure and heat release rate were noted for different blends.

4. Results and Discussion

4.1. Performance parameters

Figure 3 shows the specific fuel consumption for different 1,4 dioxane additions. The BSFC is less for B10 blend as that of neat diesel and other blends. This is due to better combustion of diesel fuel, which results in higher heat release. As the amount of dioxane in the blends increases, heat value of the blends decreases [13]. To maintain the same power, more fuel is consumed. Thus, BSFC will increase as the blended fuels with high dioxane concentration are used. The BSFC of B50 blend is higher than other blends. The stoichiometric air requirement for the combustion of dioxane is lower, since they already contain oxygen in its structure. This means that a larger amount of fuel can be burnt in a given amount of air and hence the BSFC decreases for the blend. However, the lower heat value of the dioxane makes heat value of the mixture to decrease and hence the BSFC to increase for higher blends. The increase in BSFC with respect to addition of dioxane indicates that there is no cavitation in the injector nozzle and choking of flow up to 50% addition.

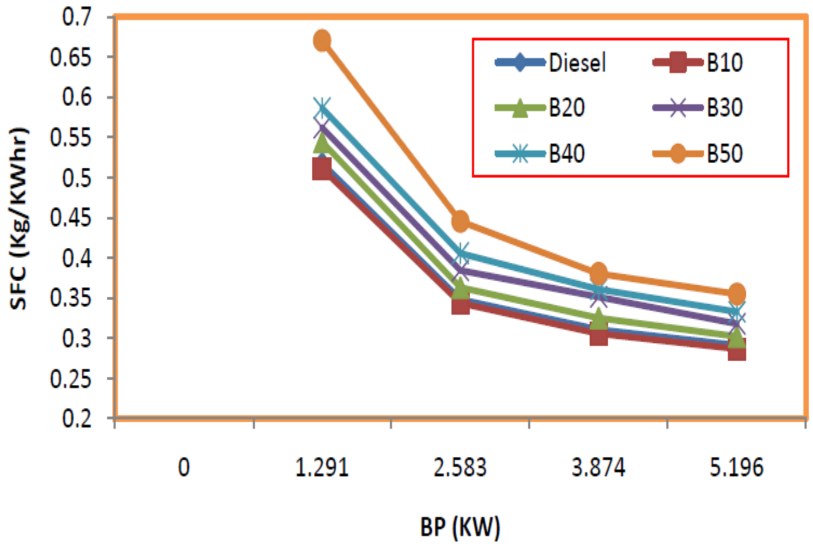

Fig. 3. Specific fuel consumption vs. BP for different blends.

The increase in SFC reflects on brake thermal efficiency. Figure 4 shows the variation of brake thermal efficiency for different blends with brake power. From the figure, it is observed that 10% dioxane blend gives better performance over the entire load range compared to neat diesel and other blends. This may be due to the addition of oxygen containing compounds to the diesel fuel. This excess oxygen helps in oxidation of carbonaceous particulate matter and associated hydrocarbons [14].

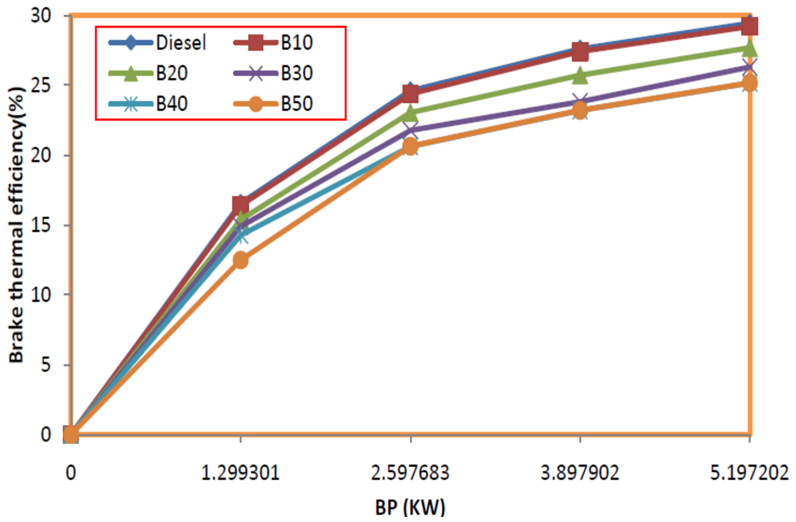

Fig. 4. Brake thermal efficiency vs. BP for different blends.

The maximum efficiency for B30, B50 blends at peak load are 26.3%, 25.2% respectively against 29.1% for sole fuel. Since B10 blends recorded comparable results for BSFC and brake thermal efficiency with diesel it is taken as the optimum blend and the emission parameters of the optimum blend for different load.

4.2. **Emission parameters**

The variation of smoke density is shown in Figure. 5. The smoke emission is reduced with all blends compared to neat diesel. The smoke reduction is 18% for B10 blends and 33% for B50 blends.

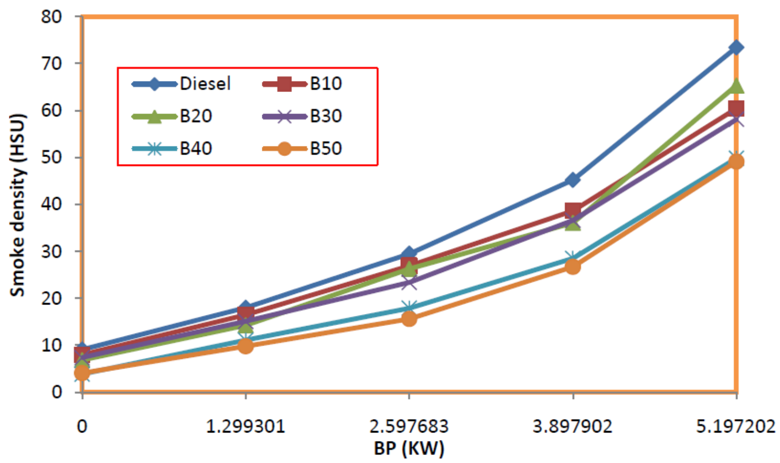

Fig. 5. Smoke density vs. BP for different blends.

The presence of excess oxygen and complete combustion results in lower smoke. The results reveal that the tendency to generate soot from the fuel-rich regions inside diesel diffusion flame is decreased by dioxane in the blends [15]. Figure 5 illustrate that the smoke reduction rate is high at higher loads than the medium and low loads as the combustion temperature is high between 75 to 100% load.

Figure 6 illustrates the NOx emission with brake power of the engine. Nitrogen oxides emissions are predominately temperature phenomena. NOx emissions of blends increase than those of sole fuel as dioxane proportion and load increase. The maximum increase in NOx emissions occur at 80~100% load conditions because of long ignition delay and rich oxygen circumstance from dioxane in the mixture. However, the NOx emission at higher blends slightly decreases as the exhaust gas temperature decreases at higher blends [16].

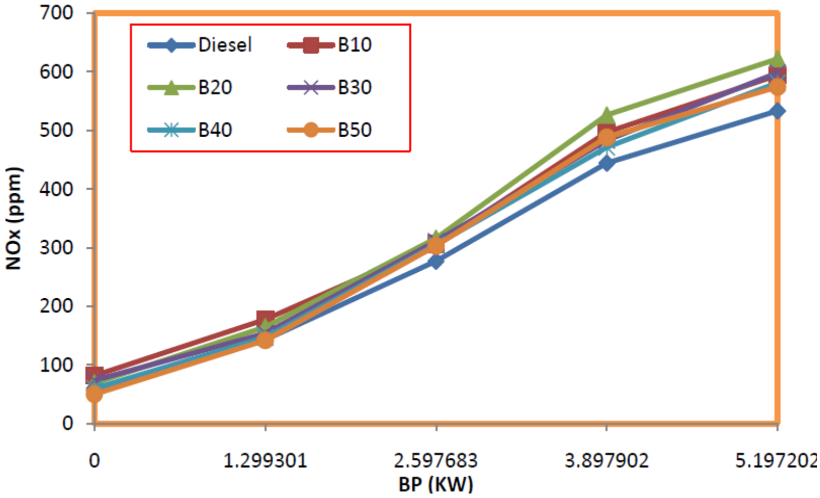

Fig. 6. NOx vs. BP for different blends.

4.3. Combustion parameters

Dioxane contains two oxygen molecules that increase the spray optimization and evaporation. Hence it improves the combustion process of the engine. Figure 7 illustrate cylinder pressure traces of dioxane blended diesel fuels. It is found that at the same engine speed and maximum load, the cylinder pressure shows greater differences for sole fuel and oxygenated fuel. The peak pressure is 75 bar for B50 blends and is 70 bar for sole fuel. An increase of 1bar peak pressure is observed for every 10% addition of dioxane.

Figure 8 illustrates heat release rate for oxygenated fuel blends and sole fuel for different crank angle. Heat release rate curves of the oxygenated fuel blends and sole fuel shows similar curve pattern although the rate of heat release for the B50 blends shows higher heat release than sole fuel. The reason is the rate of diffusion combustion of the oxygenated fuel increasing the heat release rate– consequently oxygenated fuel has controlled rate of pre-mixed combustion [17].

From the above results, it was concluded that 10% of 1,4 dioxane can be blended with diesel to improve performance of a diesel engine without any engine modifications. Higher proportions of 1,4 dioxane with diesel decreases the thermal efficiency with decrease in smoke and increase in NOx. 10% dioxane with diesel performs better than diesel in all aspects and was taken as optimum blend.

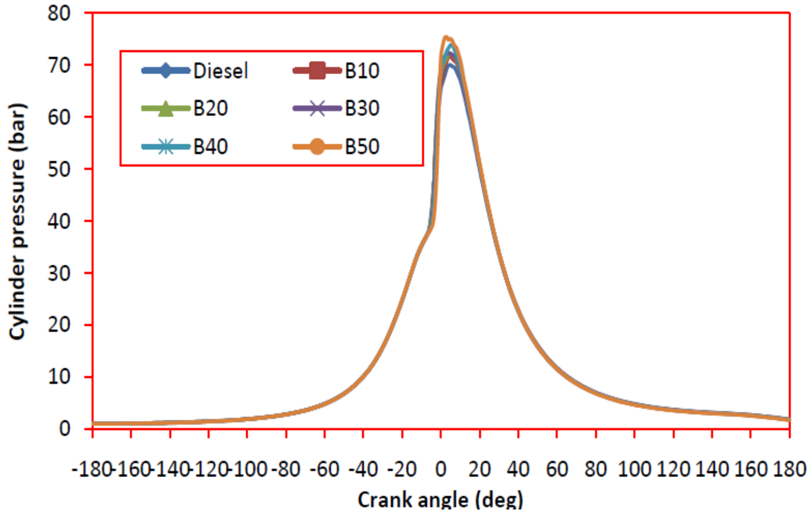

Fig. 7. Cylinder pressure vs. BP for different blends.

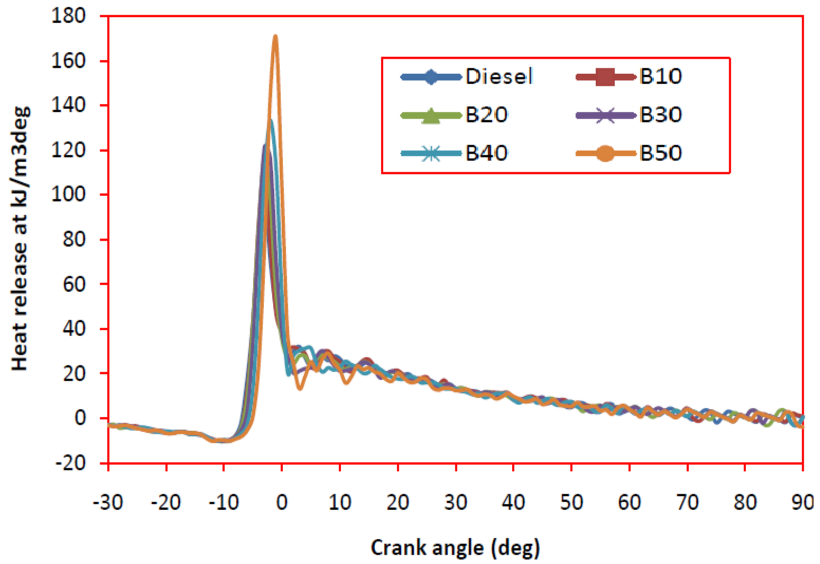

Fig. 8. Heat release rate vs. BP for different blends.

The increase of BSFC for higher blends indicates that there are no cavitations in the injector nozzle and choking of flow with respect to the addition of dioxane. The 1-4 dioxane are procured in the open market at Rs. 60/-($1.0) per litre respectively when compared to Diesel at Rs.54/- ($0.9) per litre. The cost of operation per hour is highest for 10 % 1-4 dioxane as the basic cost per litre is high. Though at present the cost of 1-4 dioxane are marginally higher than the cost of diesel which may be a temporary phenomenon on account of the current policy of the oil-producing nations, it is likely to go up even this policy of higher petroleum charges leading to unforeseen escalation on the price of crude oil. A study is under way to investigate facilitated transport enabled in situ chemical oxidation to treat 1,4-dioxane-contamined source zones effectively. The technical approach consists of the co-injection of strong oxidants (such as ozone) with chemical agents that facilitate the transport of the oxidant

5. Conclusions

Tests were carried out on the diesel engine with different blends of 1,4 dioxane and diesel without any modifications in the fuel injection system. The following conclusions are made based on the test results.

- 10% dioxane blends improves the brake thermal efficiency and reduces BSFC of the diesel engine.
- In diesel engine, up to 30%, dioxane can be substituted for diesel fuel without any modification in the fuel injection system.
- The increase of BSFC for higher blends indicates that there is no cavitation in the injector nozzle and choking of flow with respect to the addition of dioxane.
- Smoke levels were reduced for all blends.
- Increase in NOx was observed.
- Maximum cylinder pressure and heat release rate for blends were found to be increased

overall, it is concluded that 1,4 dioxane can be used as a blended fuel with diesel to replace 30% of diesel in a compression ignition engine with significant reduction in exhaust emissions as compared to neat diesel without any engine modifications. Modifications like thermal barrier coating and exhaust gas recirculation may be incorporated for significant improvements in efficiency to use higher blends.

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