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Effects of Oxygenated Additives with Diesel on the Performance of D I Diesel Engine

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Authors' contributions

This work was carried out in collaboration by all authors. Author PVR designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SR and SAK managed the analyses of the study. Author SAK managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The primary objective of this work is to reduce the particulate matter (PM) or smoke emission and oxides of nitrogen (NOx emissions) the two important harmful emissions and to increase the performance of diesel engine by using oxygenated additives with diesel as blend fuel. Formulation of available diesel fuel with additives is an advantage than considering of engine modification for improvement of higher output. From the available additives, three oxygenates are selected for experimentation by considering many aspects like cost, content of oxygen, flashpoint, solubility, seal etc. The selected oxygenates are Ethyl Aceto Acetate (EAA), Diethyl Carbonate (DEC), Diethylene Glycol (DEG). These oxygenates are blended with diesel fuel in proportions of 2.5%, 5% and 7.5% by volume and experiments were conducted on a single cylinder naturally aspirated direct injection diesel engine. From the results the conclusion are higher brake power and lower *BSFC* obtained for DEC blends at 7.5% of additive as compared to EAA, DEG and diesel at full load. In case of DEC blends the smoke emission is lower, whereas NOx emissions are very low in case of EAA additive blend fuels. The DEC can be considered is the best oxygenating additive to be blend with diesel in a proportion of 7.5% by volume.

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1. INTRODUCTION

To meet the ever increased demand and stringent emissions regulations requires both engine modification and fuel reformulation with some additives. The changes in engine design impact the interaction of fuels and emissions. Emission of diesel engine vehicles has been steadily reduced in recent years by a great deal of research and development in fuel formulation rather than modification in the engine. In this regard, effort has been focused on reducing particularly particulate and nitrogen oxide emissions. One of the promising approaches to reduce these emissions involves the addition of excess oxygen to the fuel [1]. By adding a little amount of oxygenated additive to the conventional diesel fuel emissions can be decreased with higher output from the engine. Although a great deal of research has been done on oxygenated compounds, it is still unclear what causes them to be effective for particulate reduction and how to choose or predict which oxygenates might be more effective.

The 20% Mahua Oil Methyl Ester (MOME20) and Mahua oil Ethyl Ester (MOEE20) and standard diesel fuel separately produces 13.2% less power at 3.22% more specific fuel consumption than diesel fuel at maximum load with slight reduction of hydrocarbon, carbon monoxide and smoke emissions but moderate increase in carbon dioxide emission [2]. The observation of B20 blend with diethylene glycol dimethyl ether on volume basis (0.2 to 0.6%), brake thermal efficiency, fuel consumption and the exhaust emission including smoke density, Carbon Monoxide (CO), Hydro Carbon (HC), Carbon dioxide (CO_2), and Nitrogen Oxides (NOx) were improved when compared with mineral diesel [3]. The performance and combustion characteristics of B20 Palm Oil Methyl Ester with 10% Dimethoxymethane (DMM) was found that the blends could substitute for diesel and used as an alternate source for the future generation. The addition of additive is able to decrease the carbon monoxide emission and opacity but oxides of nitrogen increases due to the biodiesel blends is marginally reduced and with better brake thermal efficiency [4].

In the experiments of titanium dioxide and calcium carbonate nanoparticles as fuel additive in B20 methyl ester of pongamia pinnata oil enhanced performance and emission characteristics by titanium dioxide nanoparticles in comparison to plain fuel and calcium carbonate nanofuel samples. The brake thermal efficiency of the engine was improved by 2% with the usage of TiO_2 nanoparticles in B20 blend and 6% reduction in BSFC value is with TiO_2 nanofuel in comparison to plain oil [5]. Ethanol-biodiesels have lower cloud points for all blends compared to cloud points obtained for diesel fuel alone [6]. Many researchers investigated that without doing modification in the standard engine, the fuel properties such as the high temperature and low temperature properties of biodiesel can be enhanced by using different fuel additives such as oxygenated additives, metal based additives, antioxidant additives, cold flow properties improver, lubricity improver additives and cetane number improver additives [7,8].

Biodiesel is an alkyl monoester available from vegetable oils, animal fats or waste cooking oils. It will be produced by transesterification process in presence of methanol as a catalyst to remove fats from oil. Renewability of bioenergy and its carbon–neutral structure, the bioenergy utilization can contribute to reduce carbon dioxide emissions. When ethanol was added to palm oil methyl esters-diesel blends B50 has shown significant difference in low temperature performance, with a maximum decrease in pour point temperature [9]. The results of B20 with alcohols flash point decrease drastically at 5% alcohol and increases at higher percentages. Increase in flash point as blend concentration increase may be considered better with respect to safety in fuel handling. In case of viscosity and density, cetane number and acid values decrease as the percentage of alcohol increases. Alcohols lower the flash point slightly and reduces the viscosity and density of blend fuel marginally, thus fuel ignition can start at lower temperature and able to burn completely. The combustion rate of fuel is increased due to more oxygen availability in alcohol that results in reducing the levels of pollutants in the exhaust gases [10].

The performance characteristics were evaluated with WFME (Groundnut Oil) biodiesel and its blends with diesel on diesel engine. The properties and combustion characteristics of the blend fuel were found similar to diesel. A minor decrease in thermal efficiency, with significant improvement in reduction of particulates, carbon monoxide and unburnt hydrocarbon, was observed as compared to diesel fuel [11]. Addition of the 20 vol% of ethanol to diesel fuel decreased cetane number and that leads to the longer autoignition delay, increased cyclic irregularity and augmented CO and HC emissions [12]. To avoid phase separation between two fractions fuels the rapeseed oil methyl ester from 5 vol% to 10 vol% can be added to ethanol–diesel fuel blends to take complete combustion [13]. The engine performance with the biodiesel of Thevetia puruviana was comparable to that of diesel. CO, HC emissions were less but NOx and smoke are slightly higher than that of diesel [14]. The result with 5% DEE-Diesel blend is the most effective combination based on performance and emission characteristics [15].

From the experiments conducted with 5 % DEE found lower CO, THC and smoke emissions while a slight improvement in thermal efficiency was observed [16]. It was investigated the effect of fourteen different oxygenated fuels on diesel emissions, especially on the effect PM and NOx emissions [17]. Simultaneous reduction of oxides of nitrogen (NOx) and smoke emissions achieved by using 10 to 30% DEE by volume along with 5 to 15% EGR through an experimental investigation on a diesel engine. They found that 5% EGR operated with 20 vol.% of DEE–diesel blend to be favorable. Diethyl ether (DEE), which can be easily converted through ethanol, has high cetane number (approximates to 125) and could be used as a cetane improver. DEE is in liquid form at ambient condition, which makes it well to handle [18]. The results of diesel–biodiesel mixture with methanol as an additive in blends reduce the exhaust gas temperature due to the higher oxygen content and increase heat of evaporation of the blended fuel, hence reduces the HC, NO_x emission and soot compared to diesel fuel [19]. The results sorted that 10% Triacetin additive with COME blended biodiesel fuel yielded better results than the conventional diesel and biodiesel especially in the aspect of tail pipe emissions [20]. In this paper experiments were conducted to reformulate the diesel fuel using three high oxygen containing additives such as Ethyl Aceto Acetate (EAA), Diethyl Carbonate (DEC) and Diethylene Glycol (DEG) in diesel engines substantially reduce PM and NOx emissions from the engine diesel fuel.

2. PROPERTIES AND STRUCTURE OF OXYGENATED ADDITIVES

The Table 1 summarizes some of the important properties of three selected oxygenated additives. It shows that, the comparison of boiling point, distillation range of all selected additives are within the distillation range of the base diesel fuel. The major properties that affect performance of the engine like vapour density, Cetane number; oxygen content and density are compared among these three additives in Fig. 1. High cetane number improves the cylinder pressure by decreasing and completing total combustion of fuel in shorter period. This is possible only with oxygenate additives due to higher quantity of oxygen availability that helps in proper mixing of fuel in the process of combustion. Addition of these additives also lowers the viscosity improves vaporization of diesel fuel that decreases delay in ignition.

1. ETHYL ACETO ACETATE (EAA):- (C6H10O3): CH3[C=O] CH2[C=O]OCH2 CH3
2. DIETHYL CARBONATE (DEC):- (C5H10O3):CH3CH2O[C=O]OCH2CH3
3. DIETHYLENE GLYCOL(DEG):- (C4H10O3): HOCH2CH2OCH2 CH2OH

3. EXPERIMENTATION

The Kirloskar make single cylinder, four-stroke, DI diesel engine coupled with eddy current dynamometer is used for the experimental work. The main focus of this work is to compare three high oxygen containing additives such as EAA, DEC and DEG for the performance and emissions. The oxygenate additives were mixed with diesel at 2.5, 5, and 7.5% to form oxygenate additive blend fuels as shown in Table 2. With these blend fuels experiments were conducted at constant rated speed 1500 rpm of the engine as shown in Fig. 2 at steady state condition. The parameters like fuel consumption, brake thermal efficiency and brake specific fuel consumption are evaluated at all load conditions of the engine. The emission characteristics are measured at steady state condition of the engine with the help of AVL make smoke meter. The exhaust gas analyzer was used to measure the carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbon emission (HC) and nitrogen oxides (NO_x).The smoke intensity was measured with smoke meter and the final results of smoke and NO_x were shown in the form of graphs and compared with the diesel fuel values.

Table 1. Properties of oxygenated additives considered to test

Sl. No	Additive Names /Property	Ethyl Aceto Acetate (EAA)	Diethyl Carbonate (DEC)	Diethylene Glycol (DEG)
1	Chemical formula	$C_6H_{10}O_3$	$C_5H_{10}O_3$	$C_4H_{10}O_3$
2	State	Clear Liquid	Clear Liquid	Clear Liquid
3	Melting Point	-45°C	-43°C	-10°C
4	Boiling Point	180°C	126°C	245°C
5	Solubility in water	Soluble	None	Soluble
6	Vapour Density	4.48	4.07	3.66
7	Auto Ignition	295°C	445°C	700°C
8	Oxygen (wt%)	36.9	40.6	45.2
9	Flash Point (°C)	70°C	25°C	143°C
10	Density (gm/cc)	1.021	0.98	1.1184
11	Cetane Number	46	58	46

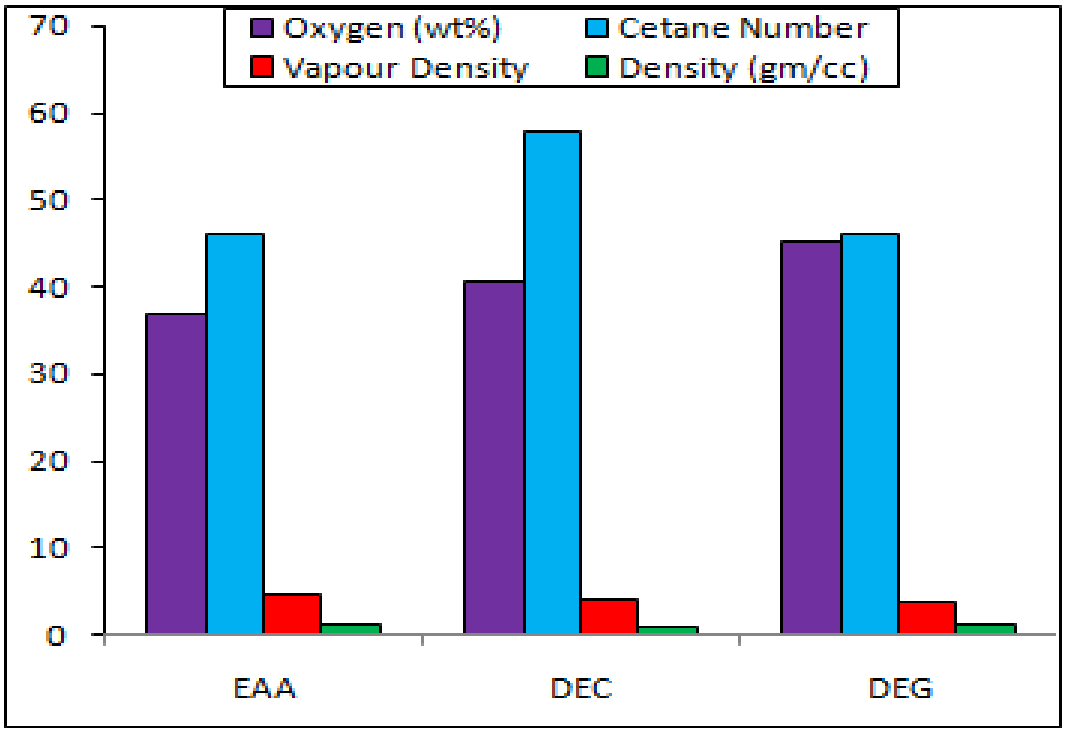

Fig. 1. Comparison of selected additives main properties

Table 2. Test fuels with additives

Sl. no	Fuel used	Percentage
1	D100	100% Diesel (D)
2	EAA2.5	2.5% EAA+ 97.5%D
3	DCE2.5	2.5% DEC+ 97.5%D
4	DEG2.5	2.5% DEG+ 97.5%D
5	EAA5	5% EAA+ 95%D
6	DCE5	5% DEC+ 95%D
7	DEG5	5% DEG+ 95%D
8	EAA7.5	7.5% EAA+ 92.5%D
9	DCE7.5	7.5% DEC+ 92.5%D
10	DEG7.5	7.5% DEG+ 92.5%D

Fig. 2. Experimental setup

4. RESULTS AND DISCUSSION

The properties and performance with respect Brake thermal efficiency and *BSFC* of C I engine are *analyze*d and the results are compared among three additive-diesel blends with diesel at 2.5, 5, and 7.5% percentages.

4.1 Performance Analysis

4.1.1 Brake thermal efficiency

Fig. 3 shows the variation of brake thermal efficiency with load in percentage. It is observed that, thermal efficiency increases in all the three cases as the percentage of additives increase. In case of DEC and DEG the percentage increase is more at 75% and full load condition on the engine as compared to EAA additive due higher rate of oxygen availability in blend fuel and complete combustion. The efficiency increases is 24.4% and 8.4% at full load and 8.6% and 4.7% at 50% load on the engine as compared to diesel in case of DEC and DEG respectively. In case EAA the efficiency decreases to less than diesel fuel by 6.4% and 17.6% at full and half load condition on the engine due to less oxygen availability and low heat release rate of the additive. At full load conditions, thermal efficiency of the diesel engine is high in case of 7.5% of DEC additive with 24.4% because the quantity of oxygen available with additive is more among the selected additives that helps in completion of combustion within the prescribed time of fuel burning period. Among the three additives tested DEC performed well with high efficiency and low fuel consumption with low emissions due to more oxygen content in the additive.

4.1.2 Brake specific fuel consumption

The Fig. 4 shows that as the load increases the *BSFC* reduces for all biodiesel blends with three additives. At maximum load, the *BSFC* values are 0.32 kg/kWh, for EAA, 0.27 kg/kWh for DEC and 0.3 kg/kWh DEG for diesel with additive blends compared to 0.22 kg/kWh for diesel fuel. As the percentage of additive increase in diesel, the blends the value of BSFC is decreasing due to increase in total oxygen quantity in the fuel which promotes fuel properties that helps in complete combustion to release total heat content from the fuel used.

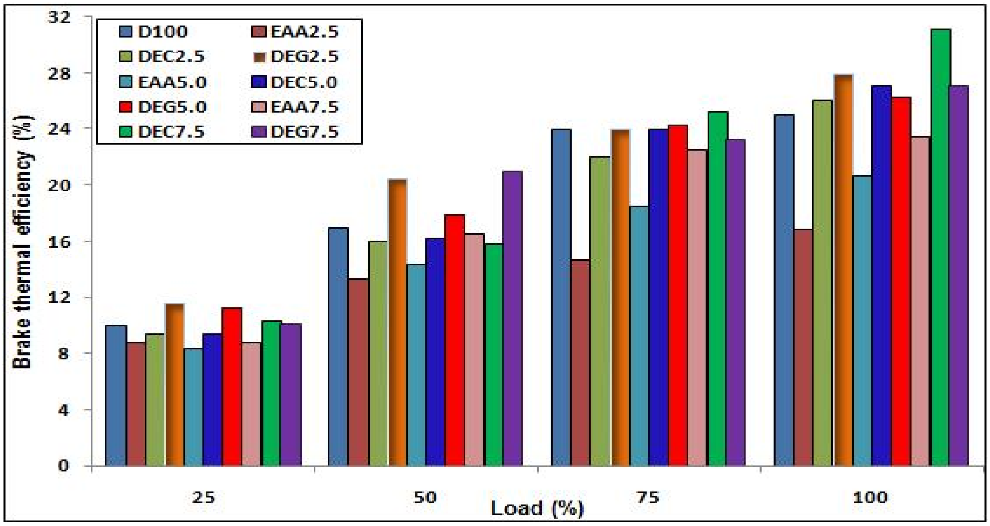

Fig. 3. Thermal efficiency variation of blend fuels with load

4.2 Emissions Analysis

4.2.1 Smoke emission

Fig. 5 shows the variation of smoke with load in percentage. The smoke emissions are increased as the load and percentage of additive increases. At maximum load, the smoke intensity for blend fuels decreases by 63.4%, 82.16% EAA, DEC, DEG at 7.5% of additive as compared with diesel fuel. For other blend fuels the smoke percentage is too lower as compared to diesel at the same load. In case of DEC among all three additives the smoke emissions are very less and higher with DEG additive. Low density and viscosity blend fuel may be the reason that causes to vaporize easily for less smoke emissions as compared to neat diesel. Availability more oxygen in DEC at 7.5% additive in diesel is able to complete combustion for lower emission of smoke when compared to diesel and other blend fuels with the selected additives.

4.2.2 NOx emission

The Fig. 6 shows that nitrogen oxides (NO_x) increases by increasing the load on engine for all blend additive fuels. From the results, NO_x emission is higher for diesel followed by DEG, DEC and EAA additive blends with diesel fuel. However the NO_x emission by EAA and DEC additive blend fuels lower by 31.2% and 42.5% compared to diesel fuel.

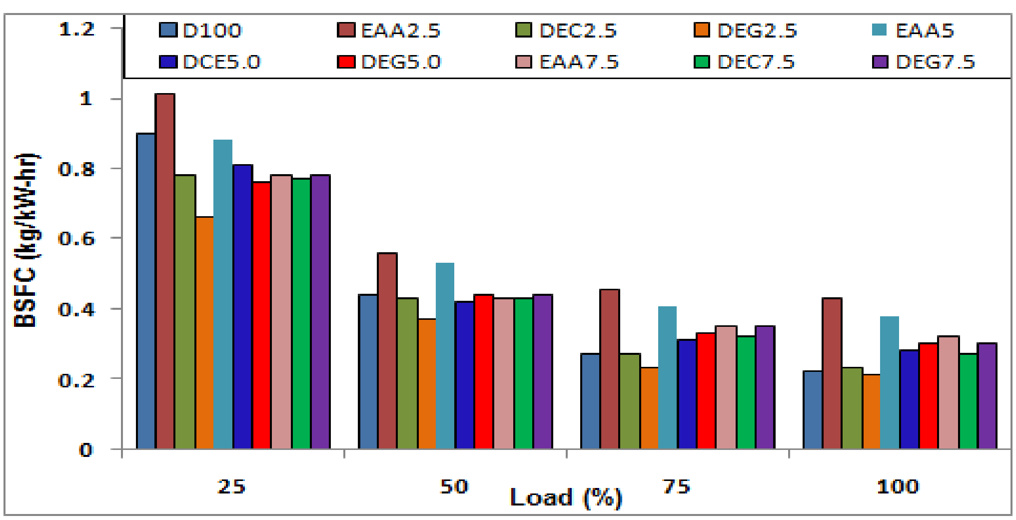

Fig. 4. BSFC variation of blend fuels with load

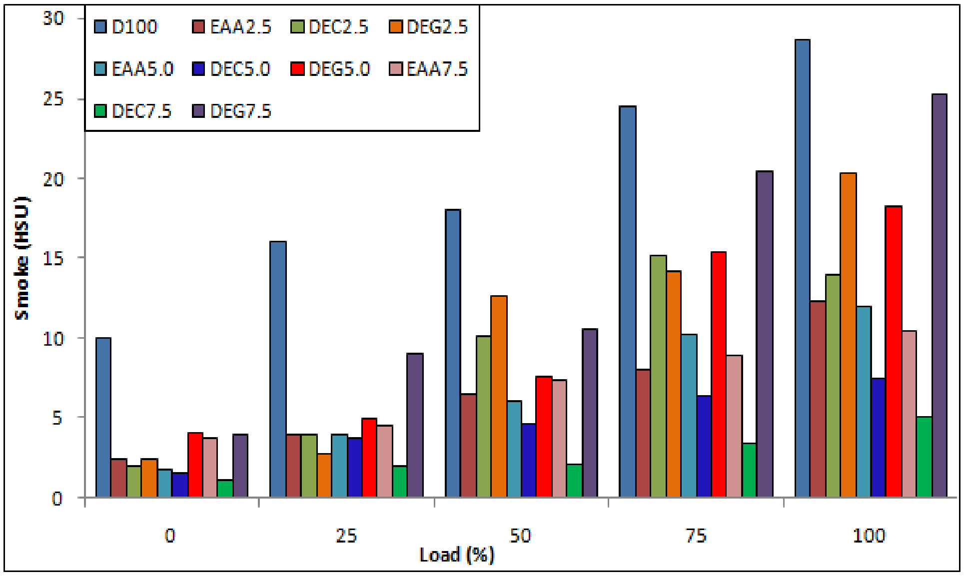

Fig. 5. Smoke variation blend fuels with load

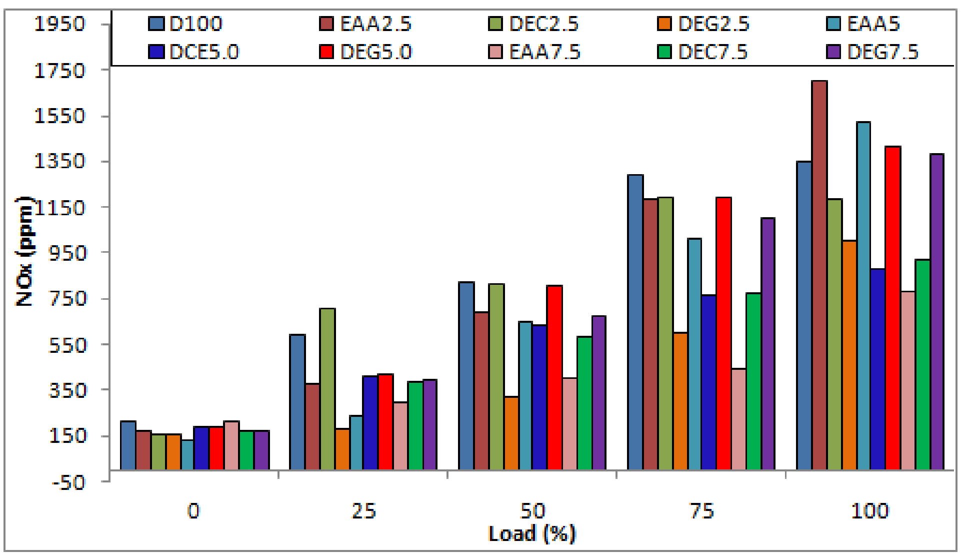

Fig. 6. NO_X variation of blend fuels with load

5. CONCLUSION

- Early combustion is initiated by all three oxygenated additives and effective in reducing the smoke intensity; with respect to NOx, HC and CO the EAA blend fuel is more effective than DCE and DEG.
- The smoke reduction of 81.2, 63.66, and 12.8% in case of DCE, DEG and EAA obtained with 7.5% oxygenated additive blend with diesel as compared to diesel fuel at full load respectively.
- The NO_X found to be reduced 42.2, 31.85% in case of EAA and DEC, whereas slightly increased in DEG as compared to diesel fuel.
- DEC with 7.5% blend delivered high power with less fuel consumption among the three additives considered for testing, hence this is the optimum percentage of additive can be mixed with diesel fuel.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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