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Effect of Some Oxygenates on the Opacity Level of a DI Diesel Engine with and without DPF

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Abstract

Toyota car fitted with smoke meter to measure the opacity in the exhaust was used. Five different types of oxygenates were used with the concentration of each one varied between 5 to 20% by volume at an increment of 5%.

The results show a significant reduction in the opacity of the exhaust products. A maximum of 70% reduction was achieved when 15% ethanol was added at 3000 RPM, and 62% reduction when 20% methanol was added at same speed. As for Dimethoxy Ethane (DMET), a maximum reduction of 30% was achieved at 3000 RPM and that of Tri-propylene glycol methyl ether (TPGME) was 27.3% at same speed. Diethylene glycol monoethyl ether (DGME) did not show encouraging results as a maximum reduction of 10.3% was achieved at 2000 RPM with 5% of DGME. Further, it was found that the reduction in the opacity level was less significant when the filter was used. This, perhaps, is due to the nature of the DPF used.

Keyword: diesel engine, diesel-alcohol blends, opacity, diesel emission

1. Introduction

Diesel engines are widely used as power source for in-sea and on-land transportation vehicles due to their simple operation, excellent performance, easy maintenance, low fuel oil cost, low fuel consumption rate, high compression ratio, high power/weight ratio, high fuel oil density, high thermal efficiency and durability.

In the last two decades of the 20th century, major advances in engine technology have occurred, leading to greater fuel economy in vehicles. The reduction of emissions from engines has become a major factor in the development of new engines and manufacturers are spending considerable energy and resources in order to meet the international emissions standards.

New technologies are used to reduce the emission from the diesel fuel such as diesel particulate traps, diesel catalytic converters, and oxygenated fuel additives. Diesel traps, which are primarily diesel particulate filter (DPF), control diesel particulate matter emissions by physically trapping the particulates. Diesel catalysts control emissions by promoting chemical changes in the exhaust gas. These oxygenated fuel additives improve combustion efficiency, increase cetane number (CN), and reduce the formation of fuel deposits like particulate matter which consists of about 60-80% of the emission of diesel fuel combustion.

This study investigates the variation of the PM level in the exhaust (indirectly through measuring the opacity of the diesel engine smoke) of a 4-stroke, water cooled, multi-cylinder C.I. engine, using the Jordanian high sulfur content diesel fuel with/without certain oxygenates as fuel additives. Further, with each additive in turn, the exhaust system was used with/without the installation of the diesel particulate filter.

The authors realize the weak correlation between the PM level and opacity of the exhaust as stated in (Jarrett, 2000), however, as an initial step; the opacity level was used to indicate the PM level change. For more accurate analysis, PM measuring devices are recommended to be used.

2. Experimental Approach

In order to investigate the effect of fuel additives on the opacity level of the exhaust gasses, two sets of experiments were performed. In the first stage, pure diesel was used to set the baseline for comparison. In the second stage, additives were used such as: Ethanol (EOH) C2H5OH, Methanol (MOH) CH3OH, Dimethoxy Ethane (DMET)

C4Hl0O2, Tri-propylene glycol methyl ether (TPGME) C10H22O4, and, Diethylene glycol monoethyl ether (DGEME): C6Hl4O3.

The respective physical properties of the above additives are listed as in Table (1) below. They are compared with what is available for the Jordanian diesel fuel. The fuel and additives properties are available in (Hansen et al., 2005; Bayrakter 2008, Ren Et al., 2008; Nylund et al., 2005; Song et al., 2007; Rakopoulos et al., 2007; Ying et al., 2006).

Table (1). The respective properties of the oxygenates used.

	Diesel	Ethanol	Methanol	DMET	TPGME	DGEME
Chemical Formula	NA	C_2H_5OH	CH_3OH	$C_4H_{10}O_2$	$C_{10}H_{22}O_4$	$C_6H_{14}O_3$
Molecular Weight (kg/kmol)	NA	46	32.042	90	206	134.2
Density (kg/m^3)	840	788	790	870	965	940
Cetane Number	46-50	5-8	3-5	90-98	75.5	126
Ignition Temperature (ºC)	NA	420	470	205	277	204
Lower Heating Value (MJ/kg)	42.74	26.8	20.27	27.96	28.1	24.5
Viscosity at 298.15 K (mPa s)	5.2	0.9456	0.59	1.1	6.1	4.5
Stoichiometric F/A ratio	NA	0.1111	0.15393	0.1192	0.1111	0.1220

Referring to the above table it is noticed that the heating value of all the used oxygenates is lower than that for diesel fuel. This means that when used as mono-fuel or dual-fuel, the amount of energy that will be admitted to the engine will be reduced. Hence, more fuel would be needed to obtain the same performance of that of pure diesel powered engine.

Further noticed is the lower viscosity of most of the oxygenates compared with the diesel fuel. This means that they can be easily injected, atomized and mixed with the air. However, this will affect the lubricity of the fuel and may cause harm to the fuel system components. Hence lubricant additive should be added to the fuel to improve its lubrication effect. On the other hand, using the oxygenates with the highly viscous diesel fuels will moderate this property and hence improves the injection characteristics of the mixture.

As for the cetane number (CN), EtOH and MeOH have very low CN compared with pure diesel. This poses great problem in starting and easy ignition of the fuel hence results in greater ignition delay when used alone. On the other hand, the rest of the oxygenates have very high CN value. This means that the fuel will very easily ignite as soon as it enters the combustion chamber. Both extremes are not quite needed. Little delay is required to allow for relatively large quantity of fuel to ignite suddenly (at almost constant volume) and thus achieving more work.

This wide range variation of fuel properties makes it of interest to study their effect on the engine behavior (though this study was restricted mainly to studying the opacity level of the exhaust).

As for the vehicle used, and the setup arrangement, this is presented in Figure (1). It shows a schematic diagram of the setup used while table (2) describes some of the vehicle specifications.

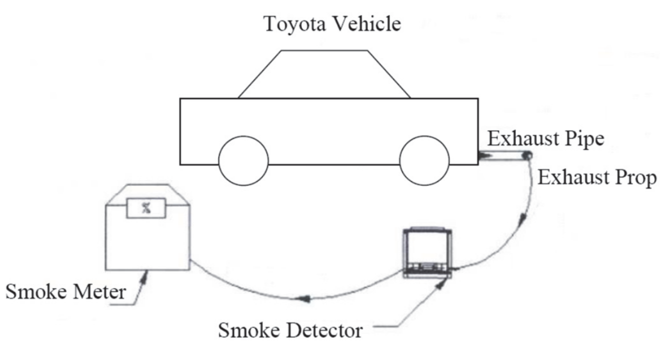

Figure (1). Schematic diagram for experimental setup

Table (2). Details for the vehicle engine

Engine Configuration	Turbocharged-Direct Injection (1997)
Engine Type	Toyota-Diesel Engine Vehicle
Compression Ratio	21:1
Max. Power (BHP)	72
No. of Cylinders	4
Cylinder Capacity	2446 cc

3. Experimental Procedure

Initially, the engine was allowed to run for certain period of time with pure diesel. After it reaches the steady condition, sampling process starts. This was carried out at engine speeds of 1000, 2000 and 3000 RPM. The additives were then individually introduced and mixed with diesel in four different quantities (5, 10, 15 and 20 % Vol.) into the fuel tank and the values of the opacity were recorded. This was done without the use of the DPF.

Finally, a locally available diesel particulate filter was installed in the exhaust manifold to measure its capability to trap the emitted PM (by reducing the opacity of the exhaust emissions) and hence reducing the amount of PM emitted to the atmosphere.

4. Results and Discussions

This section is divided into two parts, in the first part; the results without using the DPF will be presented and discussed, while the second part presents those when the DPF was used.

4.1 Without DPF

Figure (2) shows the variation of smoke opacity level of the exhaust gasses at 1000 RPM. As shown in the figure, there is general trend of the oxygenate additives to reduce the smoke opacity of the exhaust. The maximum reduction in all oxygenate percentages was achieved with the TPGME. This is expected to be as a result of the higher oxygen content as well as moderate cetane number compared with other oxygenates. This effect continues till an optimum of 15% by volume is reached. It is believed that beyond this level, due to the reduction in energy input to the cylinder and increased fuel viscosity and density with higher ignition temperature the combustion process is adversely affected. On the other hand, it is noticed that the addition of DGEME reached optimum early (at 5% by volume) while other additives continuously reduces the smoke opacity levels for all the percentages studied. DGME has very high CN, density and lowest ignition temperature amongst the oxygenates used. Therefore, beyond 5% it is thought that the adverse effect of the high CN and lower ignition temperature reduces the ignition delay period to such an extent that ignition process occurs before most of the fuel is injected. Further, due to the high oxygen content of the fuel, the ignition delay is further reduced which may have resulted in the increased smoke opacity with DEGME.

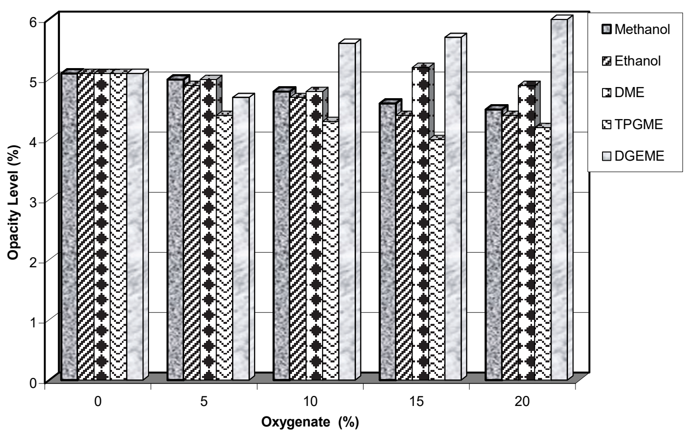

Figure (2). Variation of Opacity level with Oxygenates' percentage at 1000 rpm

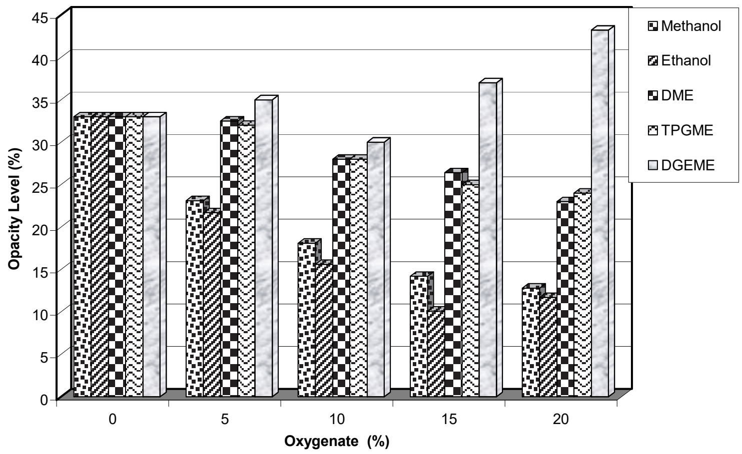

Figure (3). Variation of Opacity level with Oxygenates' percentage at 2000 rpm

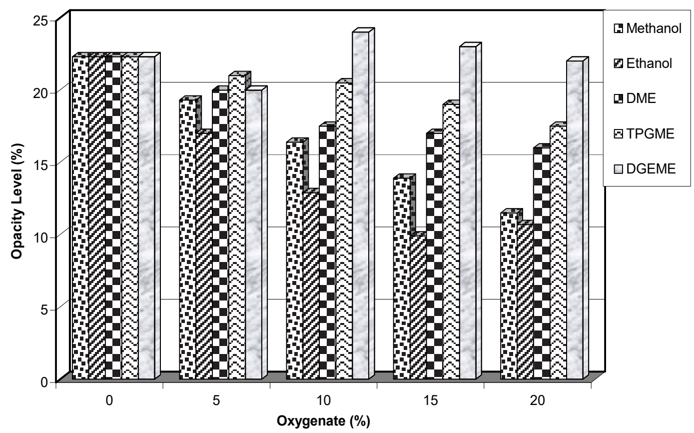

Figure (4). Variation of Opacity level with Oxygenates' percentage at 3000 rpm

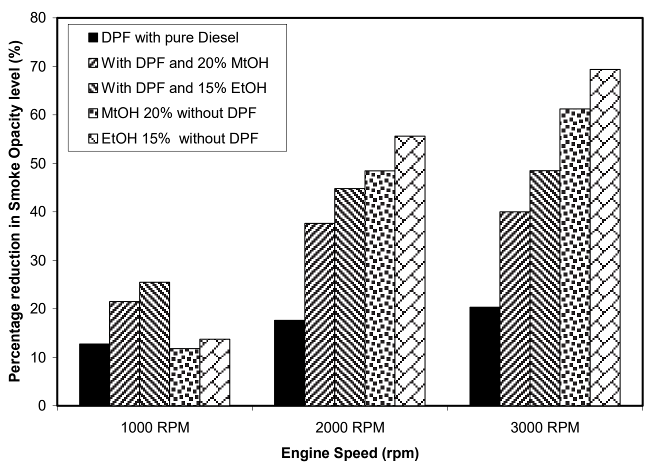

Figure (5). Percentage reduction in smoke level with and without DPF at different engine speeds

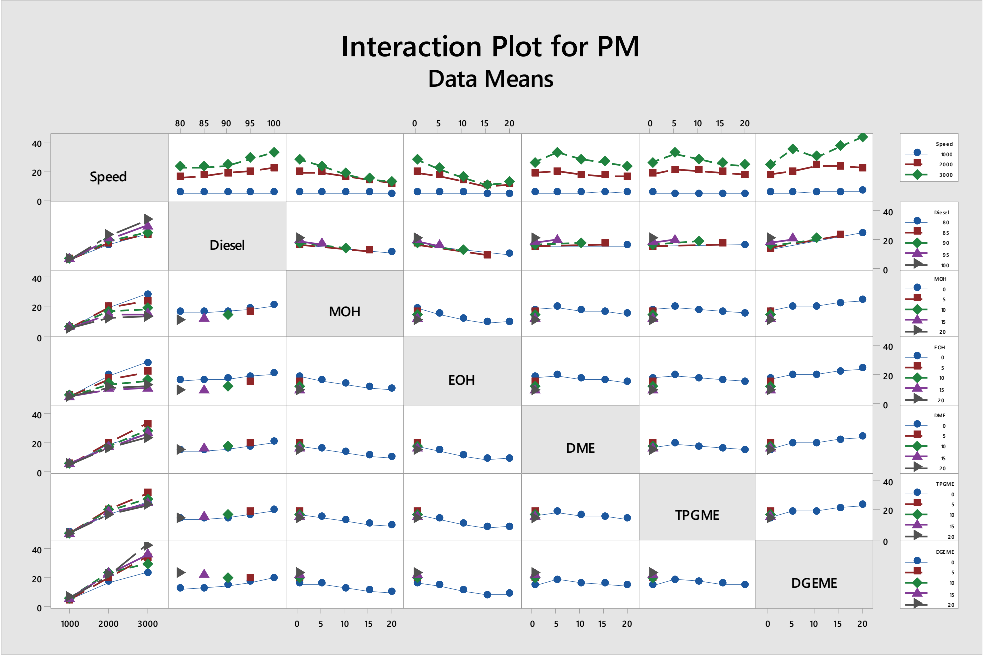

Figure (6). Main interaction plot between factors

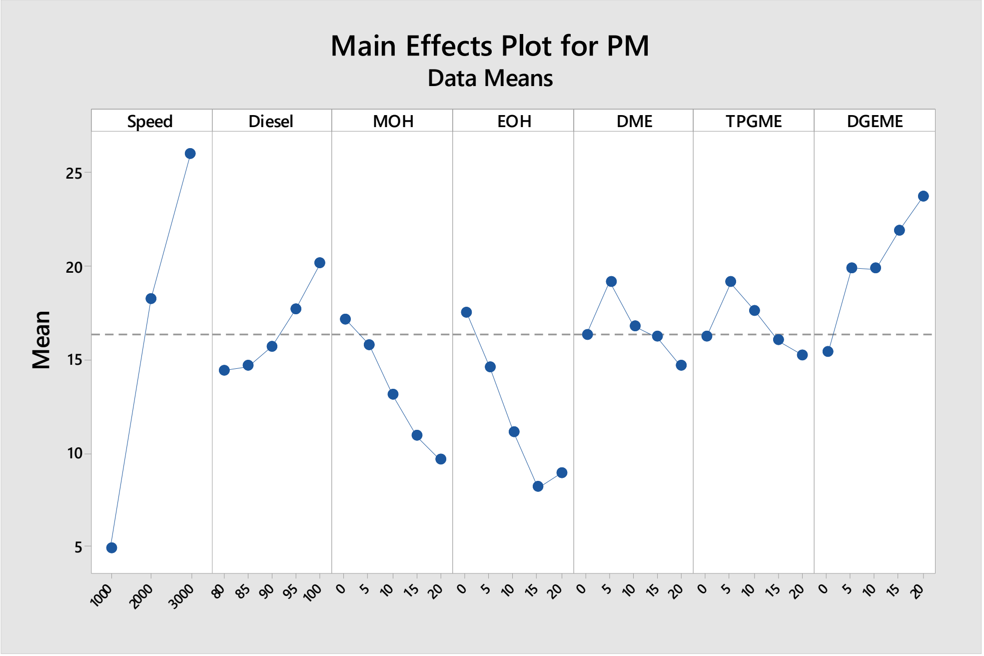

Figure (7). Main effect plot between the factors

This scenario is altered when studying the behavior of these additives at lower (2000 RPM) and higher speeds (3000 RPM) represented by Figures (3) and Figure (4) respectively. DEGME retains almost the same characteristics for all engine speeds (within the engine speed range and DEGME percentage studied). MtOH and Etoh shows consistent behavior all throughout the engine speeds studied. In spite of their lower CN, high latent heat of evaporation and low oxygen content, all of which prolongs the ignition delay period, however, when mixed with diesel fuel, they produce moderate fuel properties that may have slightly better combustion qualities.

Further noticed that, within the concentrations studied, an optimum of 15% EtOH and 20% MtOH gives the best (lowest) smoke opacity level for all the speed range covered. DME also has favorable effect on smoke opacity for all speed range and concentration studied. However, at medium to high engine speeds, the percentage reduction in exhaust smoke level is greater for the case of EtOH and MtOH than the others.

4.2 With DPF

In this section, two additives were selected based on their performance. The additives selected were Ethanol 15% and 20% Methanol. The study was conducted with the use of DPF with pure diesel, and with Diesel-alcohol blends, all were done under different engine speeds. The summery of the results are shown in Figure (5). Keeping in mind that the DPF used in this study was a locally available, old and used DPF. This was (as mentioned earlier) due to the inability of the researchers to procure new one due to the high sulphur content (around 0.9-1.2%).

As shown in the figure. The percentage reduction when using the DPF is not satisfactory perhaps due to the nature of the DPF used. This reduction capacity increases significantly when an oxygenate is added. It is also noticed that the use of EtOH at medium and higher engine speeds produced the best (highest) reduction level of the smoke opacity compared with MtOH. This might be due to the relatively higher CN, fuel calorific value and viscosity. All of which are favorable to the combustion process.

4.3 Design of Experiment

The effect of all the above factors can be studied together on the percentage opacity of the exhaust gases using both interaction and main effect plots shown below in Figures (6 and 7).

With reference to the figures, it can be clear that the addition of methanol and ethanol has the greatest effect in opacity reduction compared with other additives. This effect id predominant at all speeds.

Further, the last additive i.e. DGEME has adverse effect on opacity level for all speeds and concentrations studied. It caused the pollutant level to increase.

DME and TPGME has almost similar effect on opacity level for all speeds and concentrations studied. They first increase the opacity level then decreases it. The rate of reduction is more for the DME than the TPGME.

5. Conclusions

This work was carried out to study the effect of some oxygenated fuel additives on the smoke opacity level of the exhaust gasses. The following may be concluded:

1. Oxygenates can help in reducing the smoke opacity level of the exhaust.
2. Within the range of concentration studied, ethanol is considered the best oxygenate fuel additive to reduce the smoke level. It reduced the smoke opacity level by 70.0% when 15% of ethanol was added to the diesel fuel at 3000 RPM.
3. Methanol reduces particulate matter by 62.0% when 20% was added to the diesel fuel at 3000 RPM.
4. 20% of Dimethoxy Ethane (DMET) and Tri-propylene glycol methyl ether (TPGME) addition to diesel fuel reduced the emitted PM by 28% at 3000 RPM and hence they have same reduction effect.
5. The addition of Diethylene Glycol monoethyl ether increase the emitted of PM at all engine speed values.
6. Using diesel particulate filter with 20% of methanol will reduce the particulate matter by 40.0% at 3000 RPM engine speed. Whereas 15% of ethanol will reduce the particulate matter by 50.0% at 3000 RPM engine speed.
7. DEGME gave the worst performance amongst all the oxygenates studied.
8. The age and nature of the DPF also adversely affects the smoke reduction ability.
9. Based on the above results, pre-combustion treatment of the fuel can produce better reduction results that post combustion.

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