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EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF DIETHYL ETHER-DIESEL FUEL BLENDS ON ENGINE PARAMETERS IN A LOW POWER DIESEL ENGINE

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ABSTRACT
In many countries, emission values are limited on low-power engines. Catalytic converter and smoke filter are not used in these engines and NO_x and smoke emission values are high in this type of engines. In this study, the effects of using the blends of diesel - diethyl ether (DEE) as an alternative fuel on engine performance and emissions was investigated. Test fuel blends were prepared as2.5%, 5%, 7.5% and 10% (by vol.) DEE in defined amount of diesel fuel. In present experiments, brake thermal efficiency (BTE), specific fuel consumption (SFC), exhaust gas temperature (EGT) and gas emissions such as nitrogen oxides (NO_x), carbon monoxide (CO), unburned hydrocarbons (HC) and smoke emissions were measured. Experimental results showed that increasing amount of DEE in blends, BTE and SFC increased whereas, NO_x, smoke, CO and HC decreased. Also, EGT reduced with rising the rate of DEE. Maximum increase in BTE was achieved 8% with DEE7.5. At the same time, the maximum increase in SFC was achieved with DEE10 at 10%.Furthermore, as long as addition of DEE was proceeded, NO_x and smoke emissions become lower. Maximum reduction of NO_x emission was obtained by using DEE10 with 56%, nonetheless by the same fuel blend also CO emissions declined about 45%. The smoke and HC were decreased about 31% and 28% respectively with DEE7.5.

Keywords: Diethyl Ether Blends, Diesel Engine, Alternative Fuels, Engine Performance, Emissions.

I. INTRODUCTION
Population growing over the last years has led to enormous growth in fossil energy request[1]. The Energy Organizations anticipated that traditional fuels will be decreasing in the near future. So, the decline of the petroleum oil utilization is a significant aim for many countries [2].After the fuel crisis in 1970, the studies made on the alternative fuels gained speed [3].Diesel engines have begun to be used more widespread in recent years due to their lower hydrocarbon (HC) and carbon monoxide (CO) emissions, high efficiency and high moment compared to petrol engines. However, diesel engines are important resource of many air pollutants, including nitrogenoxides (NO_x), particulate matter (PM), hydrocarbons (HC), carbonmonoxide (CO) and other toxic types [4].To fulfill the legal regulations and their requirements for exhaust emissions, alternative fuels and additives and emission control methods are being studied [5-8].Oxygenated fuels are used directly in an engine as a neat fuel, or they can be mixture with fossil fuel [9]. Oxygen-containing fuels can be applied without the need for significant structural changes in engine design and because of the presence of oxygen-containing fuels, it can be used as an additive to the engine and can be applied to increase the engine performance by improving the combustion [8-10].Even though alcohols are used as an alternative fuel for the spark-ignition engines because of their high octane number, they are also used as fuel additives for the diesel engines[11]. The major alcohol types which used as an oxygenate additives are ethanol and but anol [12].Therefore, the diethyl ether (DEE) has a highercetanenumberfromdieselfuelandhighercalorificvaluecomparedtobothbutanolandethanol [13].DEE, that is also acknowledged as ethoxyethane, simply ether, sulfuricetherorethyletheris an organic combination in the category of ether with formula $(C_2H_5)_2O$. It is an uncolored and highly volatile combustible liquid [14]. DEE, which is usually used to help diesel engines operate in cold weather, is also being used as a fuel and fue ladditive. It can be generated from ethanol, which is produced of biomass [15]. For this reason, DEE is considered to be renewable biofuels.DEE has several positive features for diesel engines; high oxygen content and cetane number, wide flammability limits, low auto ignition temperature and high mixing ability with

diesel fuel [14]. In addition, since it is in the liquid phase under normal atmospheric conditions, it can easily participate in diesel fuel by desired rate [6].

Low power diesel engines are used in lawnmowers, water engines, wood cutting machines, motorcycles, generators and laboratories for testing purposes. In these engines, the catalytic converter is not used due to the low price. It can be said that there is the potency of emission reduction and performance development in the low power engines without using any exhaust control system which increase cost of engine and fuel injection system.

The use of DEE as an additive into diesel engine fuel has recently begun to be of interest. Some researchers worked on this subject extensively. In the literature, many studies were made about DEE as an alternative fuel and additive fuel [13-32]. In this study, effects of DEE-diesel blends on engine performance and exhaust emissions of a direct-injection single-cylinder diesel engine were investigated. For this purpose, the results obtained by comparing different ratios of DEE-diesel mixtures and the data obtained with diesel fuel were evaluated. The uncertainty analysis was applied in the study to show the reliability of the results obtained.

II. EXPERIMENTAL SETUP

The experimental setup consisting of the test engine, measuring devices and control panel is shown in Figure 1. The properties oftest engine are shown in Table 1.The test engine loading was made with a generator system consisting of a digital tachometer and a loading unit consisting of 150, 300, 500 and 1000watt lamps. Emissions in the experiments were measured using an exhaust gas analyzer, EGT was measured using a digital thermometer and fuel consumption (FC) were measured using a scale cap and chronometer. The measurement principles of exhaust gas analyzer are shown in Table 2.

The engine was operated at different engine loads (500, 800, 1000, 1300, 1500 and 1650 watt) at the original injection pressure, with diesel and volumetric proportions of diesel-diethyl ether mixture (DEE0, DEE2.5, DEE5, DEE7.5, DEE10). Each experiment was repeated three times and the averages of the results were obtained. In this experimental study, DEE with a purity level of 99.5% and diesel fuel by mixing DEE and diesel fuel with 2.5%, 5%, 7.5% and 10% by volume were used. Due to irregular operation of engine at higher rates of DEE, the fuel mixture does not exceed 10%. The properties of DEE and diesel fuel used are given in Table 3.The primary fuel properties were measured in the laboratory according to the IS 1448 standard test method and the results are shown in Table 4.

EGT, CO, HC, NO_x and smoke emissions were recorded, and FC, BTE and SFC were measured and calculated at each operation state after engine was stabilized.

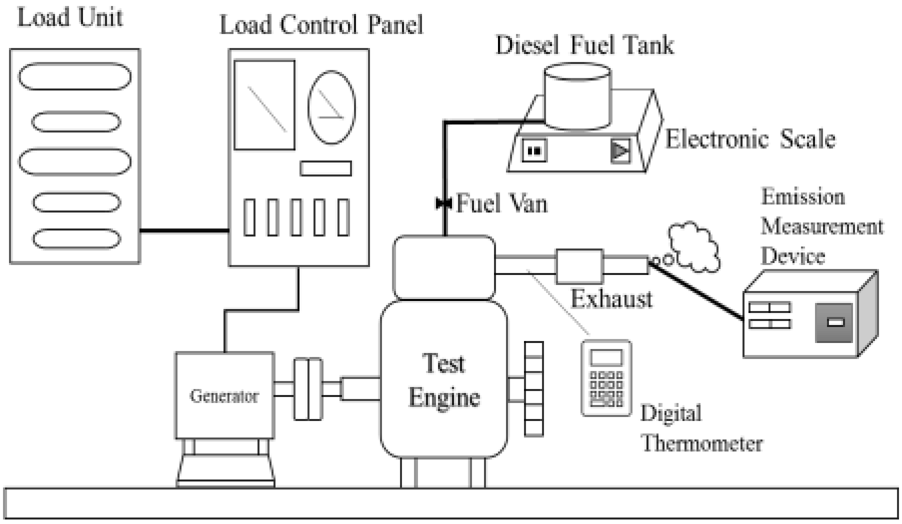

Figure 1. Schematic diagram of experimental setup

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Table 1. Properties of test engine

Properties	
Diameter x Stroke (mm)	78 x 62
Maximum engine speed (rev/min)	3000
Cylinder volume (cm^3)	296
Compressions ratio	18/1
Maximum output power (kW)	5
Cooling system	Air cooled
Type	4-stroke, single cylinder, diesel engine

Table 2. Specifications of the exhaust gas analyzer

Variables	**Measurement Ranges**	**Accuracy**
Oxygen (%)	0-25	± 0,1
Carbon monoxide (%)	0-15	± 0,01
Carbon dioxide (%)	0-20	± 0,01
Hydrocarbon (ppm)	0-20000	± 12
Nitrogen oxide (ppm)	0-4000	± 5
Smoke Causality (%)	0-99	± 2

Table 3. Properties of FuelUsed

Properties	**Diesel Fuel**	**DEE**
Chemical formula	$C_{12}H_{23}$	$C_4H_{10}O$
Molecular weight	190-220	74
Density (at 15 °C) (kg/m^3)	820-845	713
Oxygen content (% weight)	0	21.6
Viscosity (mm^2/s)	2-4.5 (at 40 °C)	0.23 (at 20 °C)
Boiling point (°C)	160-370	34.6
Ignition temperature (°C)	315	160
Stoichiometric air-fuel ratio $(A/F)_s$	≈ 15	11.2
Evaporation latent heat (kJ/kg)	260	360
Lower calorific value (MJ/kg)	43	33.9
Cetane number	>51	125

Table4. Properties of FuelBlends

Fuel Blend	Viscosity at 40 °C (mm^2/s)	Density at 15 °C (kg/m^3)	calorific value (MJ/kg)	Cetane number
DEE2.5	-	832	42.90	53.5
DEE5	2.10	829	42.59	55.65
DEE7.5	1.95	827	42.29	57.5
DEE10	1.80	823	41.92	59.3

III. CALCULATIONS AND UNCERTAINTY ANALYSIS

The data obtained during the experiments are calculated from the physical quantities measured in the experiments. During the measurement of these physical quantities, some uncertainties arise due to the ambient conditions, the quality of the measurement process and the inadequacy of measuring instruments. Therefore, it was necessary to conduct an uncertainty analysis to show the reliability of the test results [33]. The uncertainty analysis for the brake power, brake thermal efficiency and fuel consumption from the measured experimental data are shown at the below. The uncertainties of some parameters are shown in Table 5.At below a sample calculation and uncertainty analysis for the brake power, fuel consumption, fuel power and brake thermal efficiency from the experimental datas. The measuring equipments were chosen to keep the experimental uncertainties as low as possible.

Calculation of brake power

$$Brake\ Power\ (BP) = \frac{2\,\pi\,N\,T}{60} = \frac{2\,\pi\,N\,W\,R}{60}\ (kW) \quad (1)$$

Calculation of fuel consumption

$$Fuel\ Consumption\ (FC) = \frac{V}{t}\ x\ \frac{Specific\ gravity\ of\ fuel}{Density\ of\ water}\ x\ 3600\ (kg/h) \tag{2}$$

Calculation of fuel power

$$Fuel\ Power\ (FP) = \frac{FC\ x\ Calorific\ Value}{3600}\ (kW) \tag{3}$$

Calculation of brake thermal efficiency

$$Brake\ Thermal\ Efficiency\ (BTE) = \frac{BP}{FP}\ x\ 100\ (\%) \tag{4}$$

Calculation of uncertainty in brake power

$$\frac{\Delta BP}{BP} = \sqrt{\left[\frac{\Delta W}{w}\right]^2 + \left[\frac{\Delta N}{N}\right]^2 + \left[\frac{\Delta R}{R}\right]^2} \tag{5}$$

Calculation of uncertainty in fuel consumption

$$\frac{\Delta FC}{FC} = \sqrt{\left[\frac{\Delta V}{V}\right]^2 + \left[\frac{\Delta t}{t}\right]^2} \tag{6}$$

Calculation of uncertainty in BTE

$$\frac{\Delta BTE}{BTE} = \sqrt{\left[\frac{\Delta BP}{BP}\right]^2 + \left[\frac{\Delta FC}{FC}\right]^2} \tag{7}$$

Wherethepossibleerrors in thechronometer is Δt, speedometer is ΔN, graduatedglastube is ΔV,loadcell is ΔW andmeasuringscale is ΔR.

Table5. Uncertainties of someparameters

Parameter	Uncertainty
BTE	±1.2
SFC	±1.5
NO_x	±0.3
CO	±0.05
HC	±0.2
Smoke opacity	±0.5

IV. RESULTS AND DISCUSSION

BTE is the indication of how much of the fuel is converted into useful work by the combustion of the fuel. It is known that a large part of energy released in combustion is removed from the engine by lubrication, cooling and exhaust gases. As a result, remaining energy can be transformed into power in engines. The variation of the BTE according to changing of engine load and the DEE ratio is given in Fig. 2 and Fig. 3, respectively.1300 watt reference value was selected when examining the effects of DEE changes. As shown in Figure 3, BTE increased to 7.5% DEE and it started to decrease after this point.

The maximum increase with DEE7.5 fuel was 8%.Depending on the DEE ratio, these changes in the BTE can be explained as follows;the impoverishment effect of DEE and the oxygen in its contents helped to create a more homogeneous fuel-air mixture within the combustion chamber, thereby improving combustion and increasing efficiency. However, when DEE is increased by a certain amount, irregularities are observed in operation of the engine.

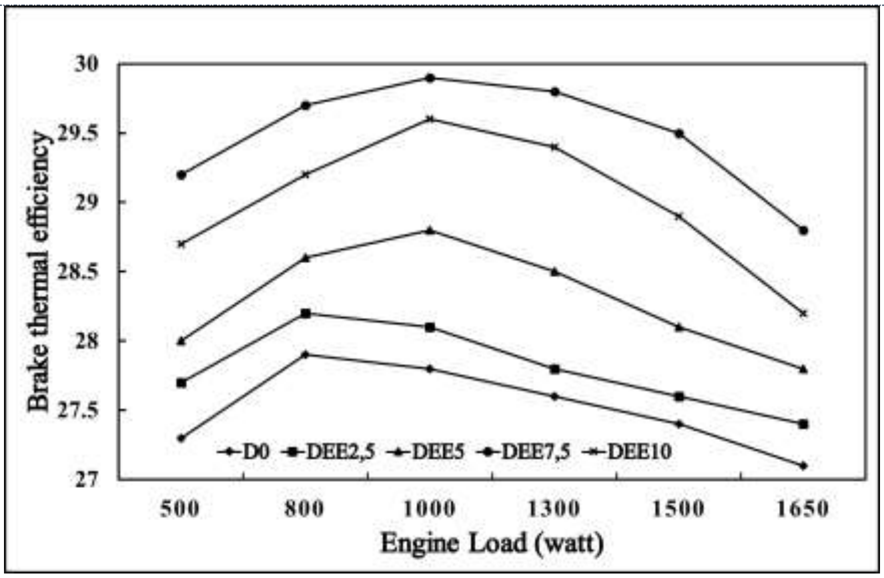

Figure 2. Variation of the brake thermal efficiency to engine load

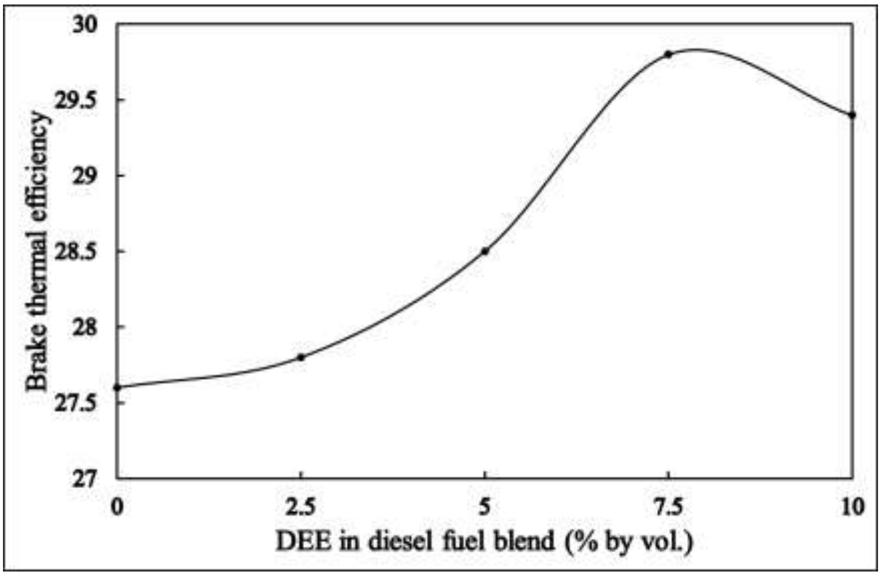

Figure 3. Variation of the brake thermal efficiency to DEE ratio

The effect of diethyl ether addition into neat diesel fuel, depending on engine load and DEE ratio on SFC is shown in Figure 4 and Figure 5.It is clear that as the amount of diethyl ether added to neat diesel fuel increases, SFC also increases.With the use of DEE10 fuel, SFC increased by 10%. Since the lower thermal value of DEE is lower than diesel fuel, the thermal value of the fuel mixture decreases as DEE is added to the diesel fuel, which causes the increase of ÖYT.In addition, the densities of diesel-DEE blends are lower than the densities of standard diesel fuel. As a result, the injected fuel mass in the cylinder must be increased so that the engine can deliver the same output power.

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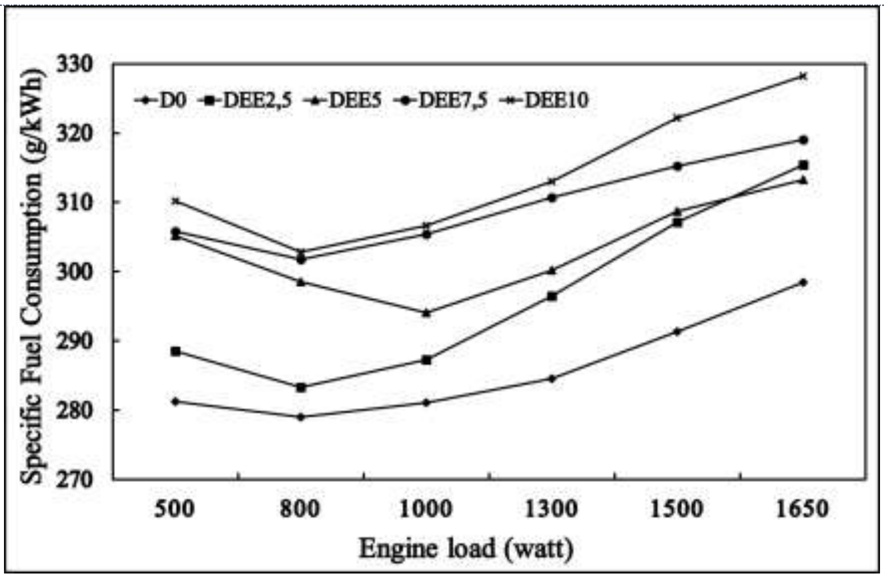

Figure 4. Variation of the specific fuel consumption to engine load

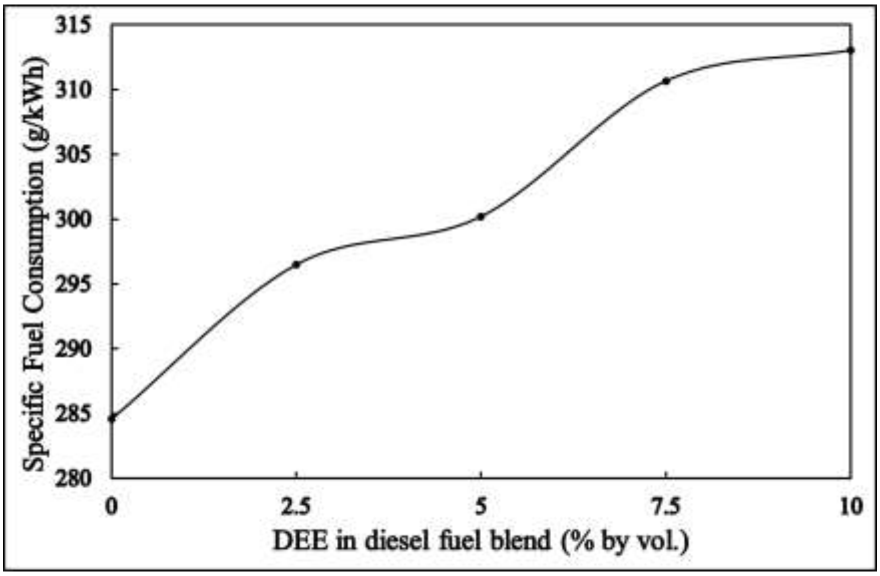

Figure 5. Variation of the specific fuel consumption to DEE ratio

The change of EGT depending on the engine load and the ratio of diethyl ether in the mixture is shown in Figure 6 and Figure 7.EGT increased with increasing engine load. The reason of this, as the amount of load increases, the air / fuel ratio decreases and more fuel enters the cylinder.Thus resulting in more energy input the cylinder. It is observed that EGT decreases with increasing DEE ratio.EGT decreased by 17% with the use of DEE10 fuel. This reduction is due to high latent heat of vaporization and lowercalorific value of DEE compared to diesel fuel.As the amount of DEE in the fuel mixture increases, the combustion temperatures and EGT decrease due to decreasing calorific value.

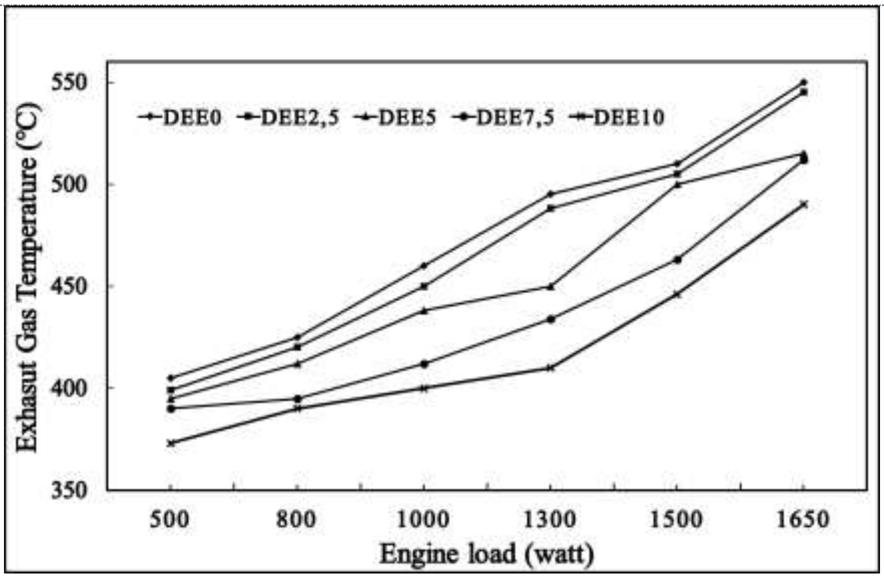

Figure 6. Variation of the exhaust gas temperature to engine load

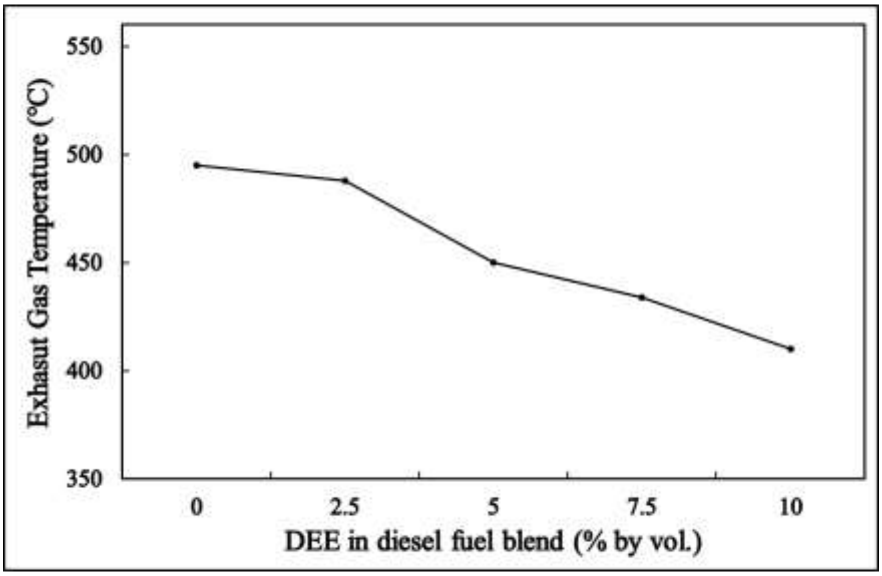

Figure 7. Variation of the exhaust gas temperature to DEE ratio

In Figure 8, because of increasing end of combustion temperatures, NOx emissions are rising with the increasing engine load. The main reason for the formation of NO_x emissions in diesel engines is increasing combustion end temperatures.At high temperatures (above 1600 ° C) in the combustion process, nitrogen oxides in the air react with oxygen to form the nitrogen oxides. It is understood that nitrogen oxide formation is affected by the in-cylinder temperatures to a great extent and NO_x emissions are increasing rapidly with increasing temperature.Figure 9 shows that as the DEE ratio in the mixture increases, the NO_x valuesdecreaseand maximum reduction was 56% with DEE10 fuel.Oxygen-rich fuel mixtures with low energy content often cause end-of-combustion temperatures to drop. The DEE placed in the diesel fuel has a direct effect on the end-of-combustion temperatures in the cylinder because the thermal energy and density are lowerthan the standard diesel fuel.

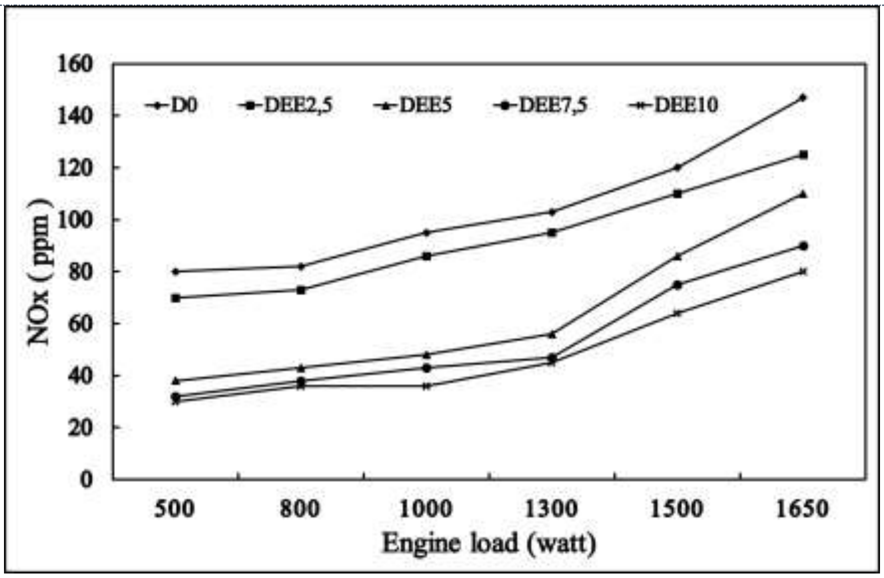

Figure 8. Variation of the NO_x to engine load

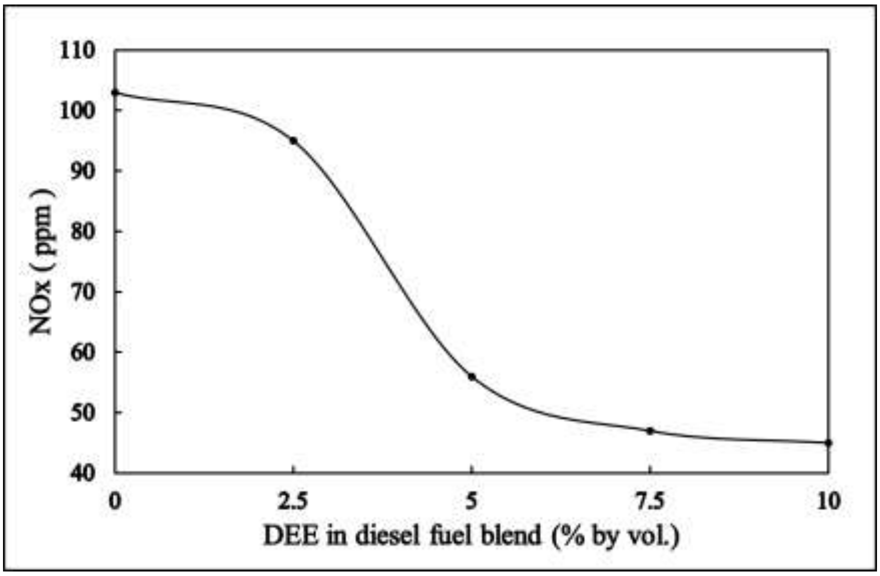

Figure 9. Variation of the NO_x to DEE ratio

Figure 10 and Figure 11 show the effect of variation of engine load and DEE ratio on HC emissions. HC emission is the straight result of uncompleted combustion in the combustion space [33]. HC emissions are a function of the temperature, which in some regions of the cylinder is composed of the fuel molecules that occur due to the formation of the resultant incomplete combustion zone in which the Air/Fuel mixture is very poor or too rich. The increase in HC emissions in diesel engines is due to the fact that the proportion of air in the lean mixture increases and the fuel extinguishes in partial regions within the cylinder. When Figure 11 is examined, as the DEE ratio increases, HC emissions also decrease.HC emissions have been reduced to a certain level due to the impoverishment effect of DEEE. With DEE10 fuel, the mixture becomes extremely poor and HC emissions have increased.

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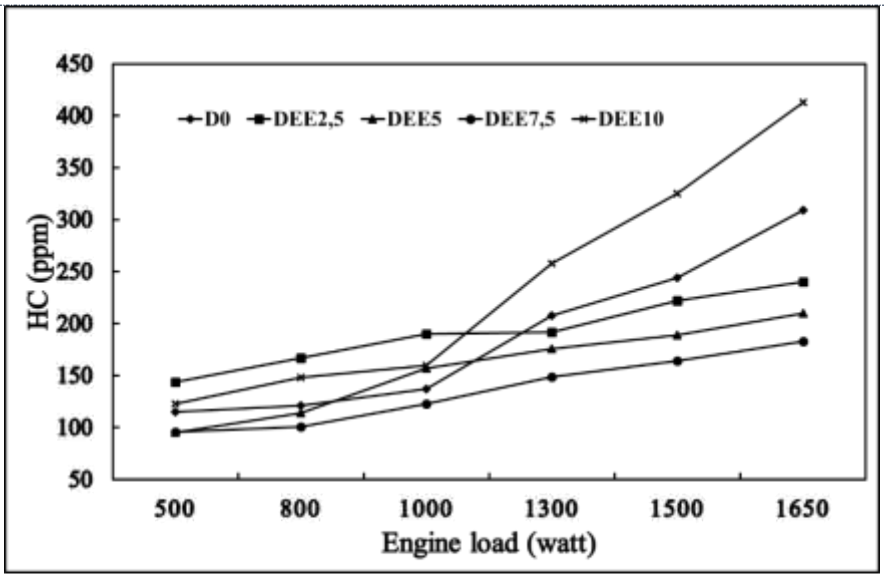

Figure 10. Variation of the HC to engine load

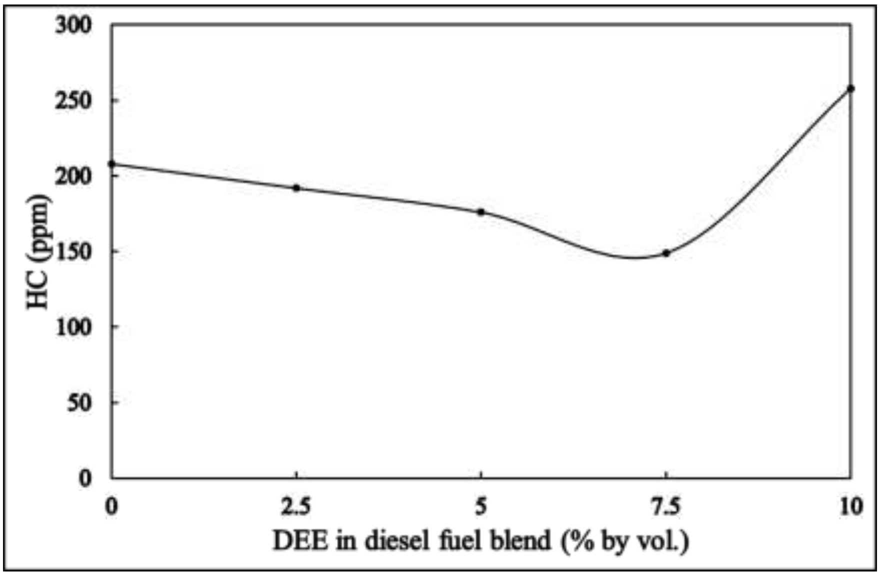

Figure 11. Variation of the HC to DEE ratio

The effect of different fuel mixtures on CO emission at different loads and the effect of changing the ratio of DEE to fuel is given in Figure 12 and Figure 13. The reason for the formation of CO emission is incomplete burning cause of not enough oxygen. CO emissions are reduced as the amount of DEE added to diesel fuel increases.The main reason for the improvement in CO emissions is the presence of oxygen in the DEE structure.

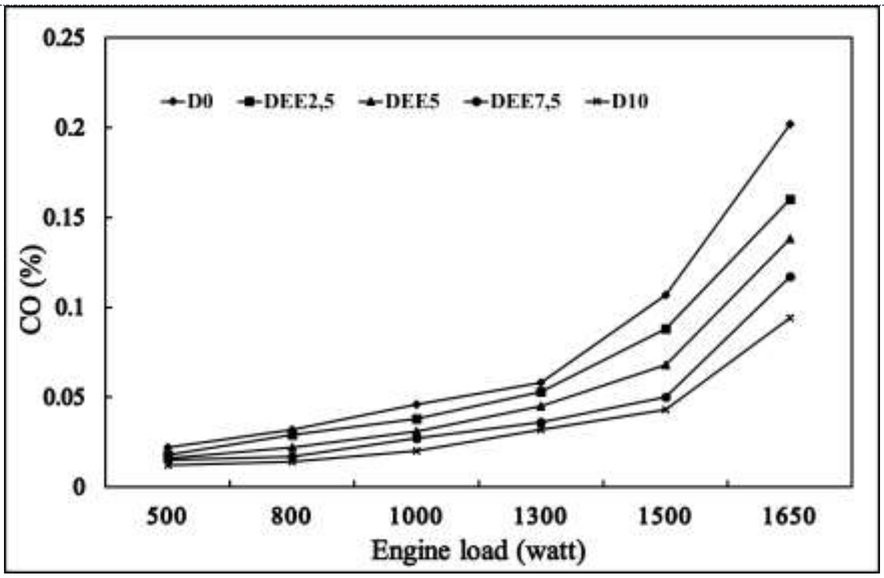

Figure 12. Variation of the CO to engine load

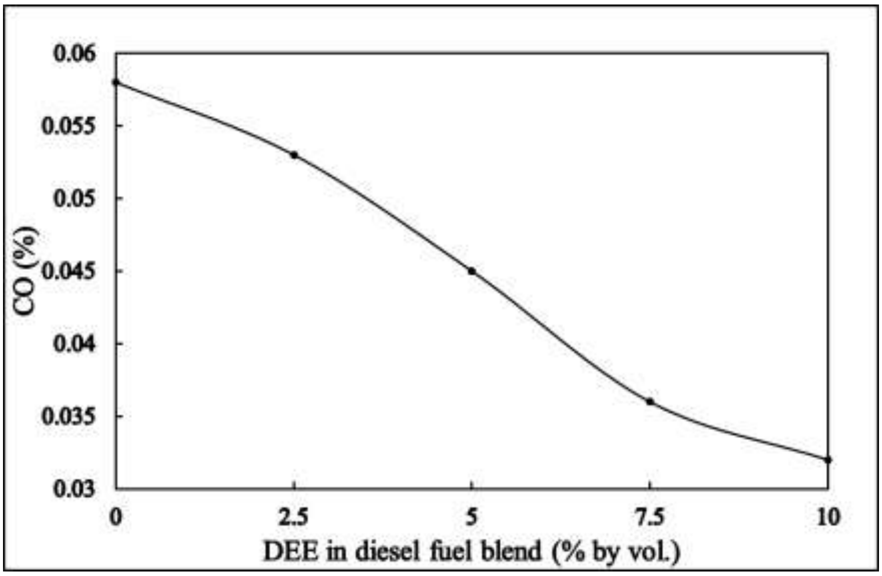

Figure 12. Variation of the CO to DEE ratio

Figure 14 and figure 15 show the impact of DEE addition to diesel fuel on smoke emissions. By the increasing of engine load, the A/F ratio decreases and smoke emissions also increase. As the amount of DEE in the mixture increases, the smoke emission decreases until 7.5% DEE ratio. With DEE7,5 fuel blend, 31% reduction in smoke emissions was achieved. The oxygen in the structure of the DEE is effective in reducing smoke emissions. If the DEE ratio is more than 7.5%, the smoke emission increases again, which suggests a tendency to decrease the break thermal efficiency after 7.5% DEE ratio. In high cetane numbered fuels, ignition delay is very short. As a result, smoke emissions are increasing because the air can't effectively mix with the fuel.

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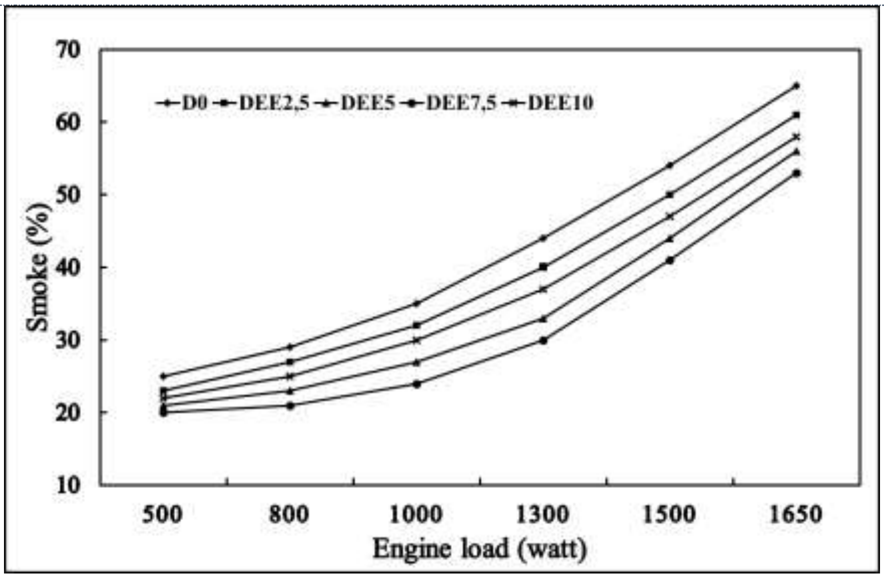

Figure 14. Variation of the Smoke to engine load

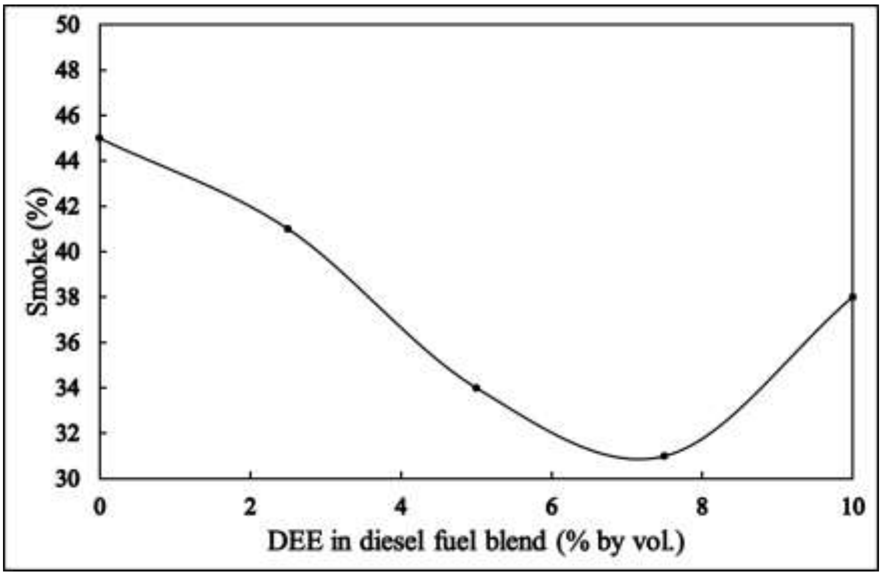

Figure 15. Variation of the Smoke to DEE ratio

V. CONCLUSIONS

In the present study, investigated the effects of using of DEE as an additive to diesel fuel on engine performance and exhaust emissions which is on a single cylinder diesel engine with constant engine speed and different engine loads. BTE increased with the increasing DEE ratio due to the detrimental effect of DEE and the more homogeneous mixture of oxygen in the combustion chamber. However, this increase continued until the 7.5% DEE mixture ratio, the increase in the DEE ratio after this mixture ratio resulted in a significant reduction in engine performance because of engine performance is significantly reduced. The maximum increase was found to be 8% with DEE7.5 fuel.

As the amount of diethyl ether in the mixtures increases, the SFC increases because the fuel mixture has a lower calorific value. Furthermore, densities of diesel-diethyl ether mixtures are lower than standard diesel fuel. As a result, the mass of fuel injected into the cylinder must be increased so that the same output power can be taken from the engine. This is why SFC increases. The highest increase was obtained with the use of DEE10 fuel with 10%.

Mixtures of diethyl ether give lower EGT than a diesel fuel, up to a certain amount. EGT has decreased because DEE has a lower calorific value and higher evaporation latent heat than diesel fuel. EGT decreased by 35% with the use of DEE10 fuel. As the DEE ratio in the fuel mixture increases, the calorific value of the mixture decreases and the combustion temperatures and accordingly the EGT decrease.

Significant reductions in exhaust emissions have been achieved with the addition of DEE into diesel fuel. As the DEE ratio in the mixture increased, NO_x and smoke emissions decreased and while the maximum reduction on NO_x was 56% with DEE10 fuel, lower smoke emissions was achieved with DEE7.5 about %31. This reduction is due to the fact that the DEE is mixed with diesel fuel, the resultant evaporation heat is higher and lower density and thermal value so that the temperature can’t be reached enough to produce NO_x emissions in the cylinder. The reason for the improvement of CO emissions is the presence of oxygen in the fuel, and a 45% improvement is achieved with DEE10. HC emissions also decreased with increasing DEE. A reduction of 28% in HC emissions was achieved with DEE7.5 fuel. Increasing the DEE ratio further tended to increase HC emissions.

Experimental studies show that the data obtained; the addition of DEE fuel containing oxygen to diesel fuel can be used safely with no problem of engine operation. From the results, with low-power engines that do not use a catalytic converter, significant improvements have been achieved in exhaust emissions. This fuel blends reduce NO_x, smoke, CO and HC emissions. Therefore, we can say that DEE fuel is a fuel compatible with nature in terms of exhaust emissions. On the other hand DEE is more expensive fuel than diesel fuel so that using of DEE being an additive for diesel fuel is more efficiency that being an alternative fuel in diesel engine

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