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Research Article

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A Study on Engine Performance and Emission Characteristics of Ethanol Fuel in Diesel Engine

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Abstract Alcohol fuel is in the spotlight as an alternative fuel. It is not difficult to mix alcohol fuel with gasoline engines, and it is used in many countries including North America. However, adding alcohol fuel to diesel engines is not easy to put into practical use in automobile engines due to problems such as viscosity, lubricity, and low cetane number of added fuel. This study was carried out to add ethanol to compression ignition engines using diesel fuel. There are two ways to add ethanol to diesel fuel. The first method is to add a surfactant to mix the diesel fuel with the ethanol fuel. The second method is the fumigation method to supply the diesel fuel and the ethanol fuel separately in the combustion chamber. By adding ethanol to the diesel engine in two ways, the engine performance and the characteristics of CO, HC, NOx, and Smoke emissions were examined.

Keywords Compression Ignition Engine, Diesel, Methanol, Smoke Emission

Introduction

Over the last several years, the number of cars has been rapidly increasing, and the social interest has a number of problems. The issue of depletion of fossil fuels is not a problem yesterday, and there are various problems, ranging from the stable supply and demand of energy sources and environmental issues. There are studies that fossil fuels disappear, but fossil fuels or alternative fuels corresponding to them are still being discovered in unexpected places. Researches that can replace fossil fuels have been continuously studied. The fear of fossil fuels is that exhaust gases from fuels can further aggravate the quality of life [1-3].

Research has been conducted to solve the pollution problem of exhaust gas emitted from automobiles. In addition, one of the best ways to easily use the vehicle without significantly changing the structure of the vehicle is to use alcohol fuel. These alcohol fuels, which can be substituted for the depletion of fossil fuels, are also important fuels in the category of biofuels and renewable energy. This is because alcohol fuels are renewable fuels that can be produced from sugarcane, fermentation materials, natural gas, and biomass, a renewable energy material [4-5].

In the United States, gasoline fuel is usedby mixing less than 10% of ethanol with gasoline engine. By using the gasohol fuel, it was possible to reduce the exhaust gas. However, it is not easy to mix ethanol or methanol with a compression ignition engine. In the compression ignition engine, high-pressure fuel is supplied through the injection nozzle in a state where the atmosphere in the combustion chamber is high temperature and high pressure by compression, and self-ignition is performed. Typically, the cetane number used in a diesel vehicle engine should be about 50 ± 10. However, the cetane number of alcohol fuels is less than 10. Due to the low cetane number of the alcohol fuels, combustion with alcohol is almost impossible in the compression ignition engine, and the low viscosity of the alcohol fuel causes the problem of lubrication of the fuel injection pump, so that the high pressure fuel cannot be supplied to the combustion chamber [6-8].

Especially, it is expected that the exhaust gas generated from diesel vehicles will have the effect of alternative energy effect and reduction of exhaust gas when alcohol fuel is added or mixed [9-11].

In this study, a compression ignition engine using diesel fuel was used. An engine experiment was conducted by mixing a diesel fuel with ethanol in a compression ignition engine and adding a phase separation inhibitor, a surfactant. It is believed that the addition of surfactant and ethanol to the diesel fuel can significantly reduce the emissions from the diesel engine. In addition, if the fuel is supplied in a fumigation state in which diesel fuel and ethanol are supplied separately, it is possible to expect a combustion behavior approaching the homogeneous charge compression ignition engine. As a result, mixing of ethanol with pure diesel fuel is expected to be effective in various exhaust gases (CO, HC, NOx, Smoke) although the torque will decrease slightly

Experimental apparatus and Procedure

Table 1 shows the engine specifications used in this study. The engine used in this study was a 4-cycle single cylinder diesel engine. The cooling method is water-cooled. The compression ratio is 21, and it is designed with a high compression ratio which enables self-ignition in compression ignition engines.

Table 1: Specifications of the test engine

Items	Specifications
Cooling system	Water-Cooled
Displacement	632 cc
Bore × stoke	92 × 95 mm
Compression ratio	21.0
Cylinder number	Single
Combustion chamber	w type
Nozzle hole diameter	0.4mm
Number of nozzle holes	4

Table 2 shows the characteristics of diesel and ethanol used.

Table 2: Comparison of properties of diesel and ethanol fuel

Property	Diesel	Ethanol
Chemical formula	$C_{16}H_{34}$	C_2H_5OH
Specific gravity	0.82~0.85	0.79
Lower heating value (MJ/kg)	42.6	26.8
Cetane number	45~60	8
Boiling point (℃)	210~325	78.5
Viscosity (cSt) at 25℃	2.79	1.1
Latent heat of vaporization (kJ/kg)	310	854
Theoretical air-fuel ratio (by volume)	14.7	9.0

Figure 1 shows the schematic of the experimental setup. Various experiments were conducted, control and measurement were performed, and a DC dynamometer was connected to the flywheel to control the engine speed and load. In order to evaluate various engine performance, the temperature and pressure on the intake side and the exhaust side were measured, and a thermocouple was inserted to measure the temperature of necessary parts such as cooling water and engine oil.

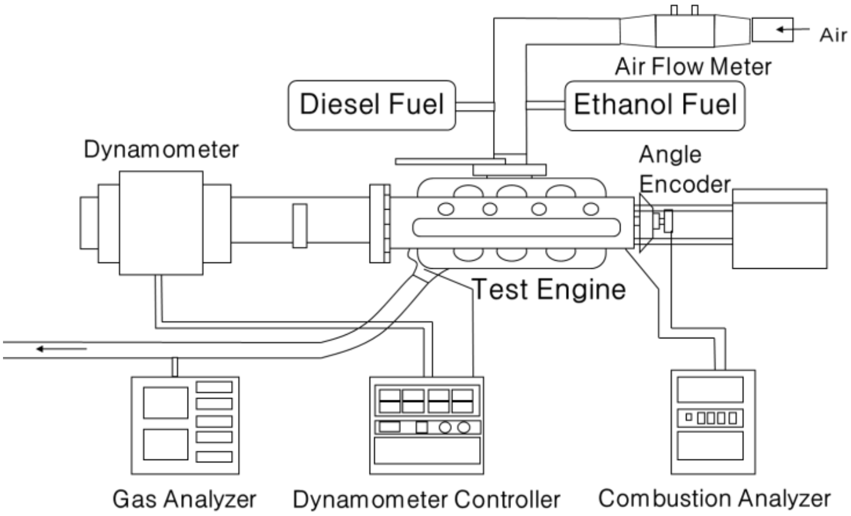

Figure 1: The schematic diagram of the experimental set-up

Various sensors were attached to the engine to measure the combustion chamber head temperature, oil temperature, coolant temperature, exhaust gas temperature, boost pressure, and back pressure. An exhaust analyzer was also used to determine the exhaust characteristics of the engine. The exhaust gas analyzer measures CO, HC, NOx, and smoke.

In order to obtain the indicated diagram for the combustion analysis, a pressure sensor was used for pressure measurement. The crank angle was measured using an encoder. 100 cycles were taken and various combustion analyzes were performed based on the average pressure value. The pressure sensor was inserted into the combustion chamber head through a hole, and various pressure, pressure rise rate, pressure-volume, rate of heat release, and mass burned rate diagrams were obtained.

The engine speed was set at 800rpm and the engine speed was increased stepwise by 200rpm, and the experiment was performed up to 2000rpm. The engine experiments were conducted in two major ways. The first experiment is a blending concept in which ethanol is mixed with diesel fuel and a surfactant is mixed so that phase-separation does not occur. The second experiment is a dual system approach, not a blending of fuel. That is, ethanol is supplied in the form of fumigation using carburetor. In addition, the experimental engine is the engine with the highest torque at 1600rpm, so the amount of ethanol at 1600rpm was blended and fumigation up to 5%, 10%, 15%, and 20%.

Table 2 shows the basic characteristics of diesel fuel and ethanol. In Table 2, the air-fuel ratio is 14.7 for diesel and 9 for ethanol. This is due to the lower heating value of ethanol, which will increase the fuel consumption rate, but if a small amount of ethanol is mixed, it will not be an economically significant problem.To prevent phase-separation of diesel and alcohol fuels, it is advisable to use dodecanol for methanol and unleaded gasoline for ethanol. In this study, unleaded gasoline was used to suppress phase-separation of diesel fuel and ethanol fuel and mix well.

Results and Discussions

The mixture of ethanol fuel was labeled EB and fumigation with carburetor was labeled EF. B05, EB10, EB15, and EB20 indicate the mixing of 5%, 10%, 15%, and 20% ethanol in diesel fuel. EF05, EF10, EF15, and EF20 were also used to fumigate 5%, 10%, 15%, and 20% ethanol with diesel fuel.

Figure 2 shows the results of the torque test for changes in engine speed. As shown in Table 2, the torque value depends on the value of the lower heating value. That is, 100% of the diesel fuel has the highest torque value for engine speed change. The next largest torque values for diesel fuel are EB05, EB10, EB15, EB20, EF05, EF10, EF15, and EF20. Overall, the blending of diesel fuel with ethanol has a higher torque than fumigation.

Figure 3 shows the blending and fumigation method for the ethanol volume rate at the engine torque of 1600 rpm, which is the optimum torque. The blending method is generally higher than the fumigation method.

Figures 4, 5 and 6 show experimental results showing the ignition delay period, cylinder head temperature, and exhaust gas temperature of experimental fuels with varying ethanol volume rates at engine speed 1600 rpm.

In Figure 5, the value of cylinder head temperature blending is larger than that of fumigation. Therefore, it is considered that the blending torque is largerthanthe fumigation torque.

In Figure 6, it can be seen that the value of the exhaust gas temperature is higher for the blending case than for the fumigation case.

Figure 7 shows the experimental results of the CO emissions for the engine speed increase.

CO generation is increasing with increasing engine speed, and CO emissions are gradually decreasing with increasing ethanol loading. Generally, it is known that CO emissions are caused when the mixture of air and fuel is not homogeneous, or when the supply of air is insufficient compared with the fuel, incomplete combustion occurs.Compression ignition engines, however, can operate at higher air-fuel ratios than spark ignition engines. Compression ignition engines using diesel fuel generate relatively low CO emissions compared to spark ignition engines that use gasoline. As shown in Figure 7, as the proportion of ethanol added to the diesel engine gradually increases, the intake of oxygen becomes sufficient due to the oxygen-containing (oxygenated) ethanol, and as the ethanol mixture increases, the generation of CO decreases.

Figure 8 shows the diesel-ethanol blended fuel and fumigation method for the ethanol volumerate at engine speed 1600 rpm, which is the optimal torque. Overall, the fumigation method has lower CO emissions than the blending method.

Figure 9 shows the results of the experiment showing the HC emission amount to the engine speed change. Generally, HC refers to unconverted hydrocarbons generated in incomplete combustion. HC is also a generic term for unburned gas or partially combustible hydrocarbons. HC emissions increase in areas where the air-fuel ratio is rich and emissions tend to increase even in areas of high load or unstable air-fuel ratio.

As the engine speed of the test engine increases, the HC emissions increase. However, it can be seen that as the mixing ratio of ethanol to the diesel fuel increases, the HC emission amount sharply decreases. This gasoline or diesel fuel already contains HC as a hydrocarbon-based paraffin series. However, ethanol is familiar with water and has a structure that already contains oxygen, so it is considered that HC is less generated than diesel fuel.

Figure 10 shows diesel-ethanol blended fuel and fumigation method for ethanol volume rate at engine speed 1600 rpm, which shows optimal torque. Overall blending method shows lower HC emission than fumigation method.

Figure 11 shows the experimental results showing the NOx emission from engine speed change. Generally, it is known that the higher the combustion temperature in an automobile engine, the higher the NOx emission amount, and the lower the combustion temperature, the less the NOx is generated. Ethanol fuel has less latent heat of vaporization than gasoline, so it has the effect of lowering the combustion temperature in the engine. Therefore, mixing the ethanol with the diesel fuel would lower the combustion temperature, so that the effect of reducing NOx is considered to be large. The result of reducing the flue gas temperature due to the addition of alcohol fuels is to lower the temperature of the combustion chamber head (see Figure 5) and lower the exhaust gas temperature (see Figure 6).

Figure 12 shows the diesel-ethanol blended fuel and fumigation method for the ethanol volume rate at the optimum engine speed of 1600 rpm.

Figure 6. Exhaust gas temperature of test fuels with varying ethanol volume rate at 1600 rpm.When ethanol is supplied by diesel-alcohol blended fuel or fumigation method, NOx reduction effect is large. However, it can be seen that the overall fumigation method has a larger decrease in NOx emissions than the blending method.

Figure 13 shows the experimental results showing the smoke emission from the engine speed change.Generally, there is a tendency that, when the compression ignition engine becomes nonhomogeneous in the air excess ratio, or when the fuel supplied from the old injection pump is unevenly mixed with air, smoke is generated. Even if air is left as a result of such uneven combustion, smoke is generated. In particular, the supplied fuel, diesel ($C_{16}H_{34}$), generates a dehydrogenation reaction in the presence of hot oxygen deficiency and creates smoke when liberated carbon is released.As the engine speed increases, the smoke concentration increases. In addition, the latent heat of vaporization of ethanol (C_2H_5OH) is 2.78 times higher than that of diesel, so that hydrogen atoms in the fuel molecules weaken the binding force with oxygen, and the amount of unburned carbon decreases as the mixing ratio of ethanol increases. Therefore, ethanol fuel is thought to reduce smoke compared to diesel fuel operation.

Figure 14 shows the diesel-ethanol blended fuel and fumigation method for the ethanol volume rate at engine speed of 1600rpm, which is the optimal torque. Overall, the fumigation method has lower smoke emission than the blending method.

As the mixing ratio of ethanol increases, the generation of NOx is less in CO, HC, NOx, and smoke than in pure diesel engines.

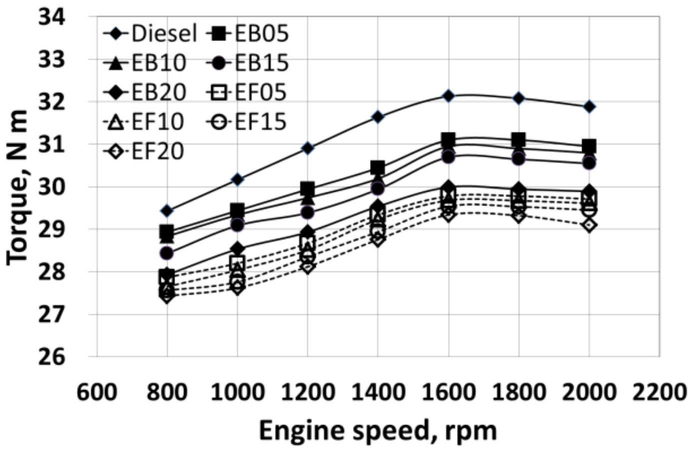

Figure 2: Engine torque of test fuels with varying engine speeds

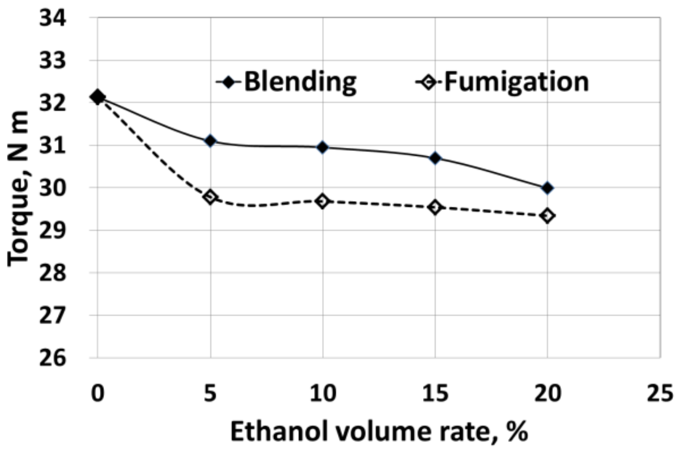

Figure 3: Engine torque of test fuels with varying engine speeds at 1600 rpm

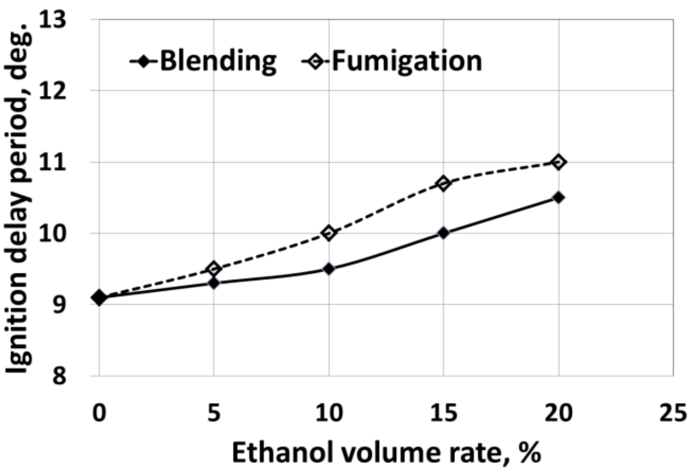

Figure 4: Ignition delay period of test fuels with varying ethanol volume rates at 1600 rpm

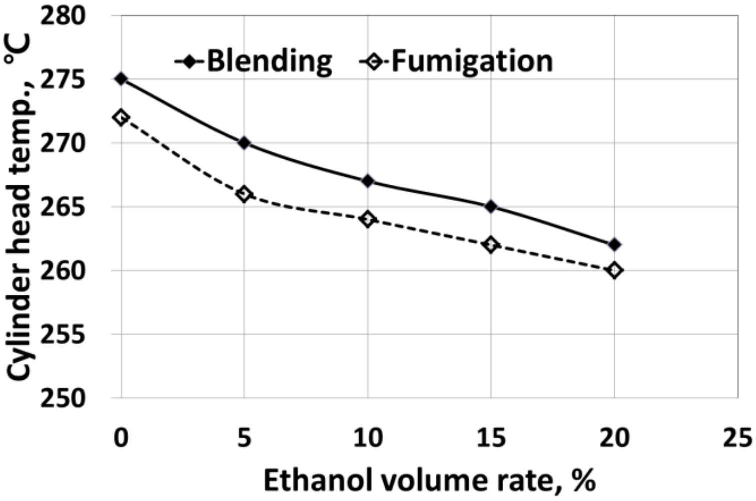

Figure 5: Cylinder head temperature of test fuels with varying ethanol volume rates at 1600 rpm

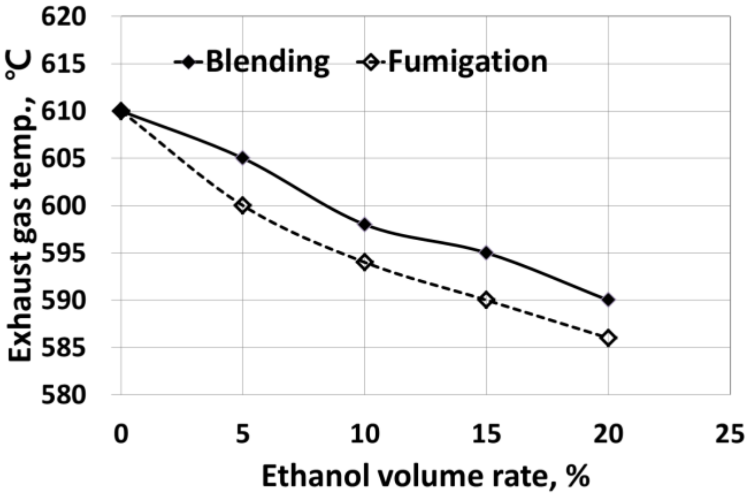

Figure 6: Exhaust gas temperature of test fuels with varying ethanol volume rate at 1600 rpm

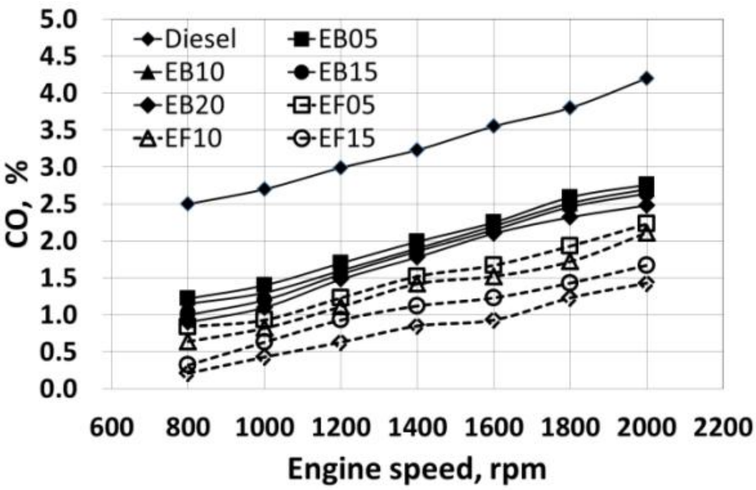

Figure 7: Variation of CO emissions with engine speed, for different fuels

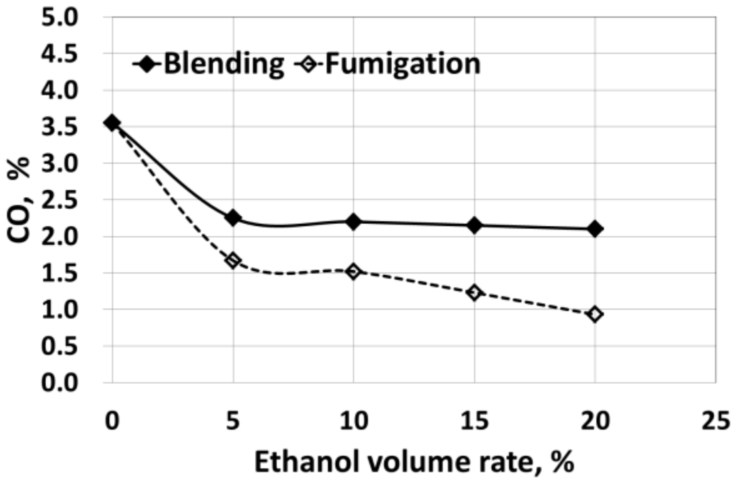

Figure 8: Variation of CO emissions with ethanol volume rate, for different fuel supplies

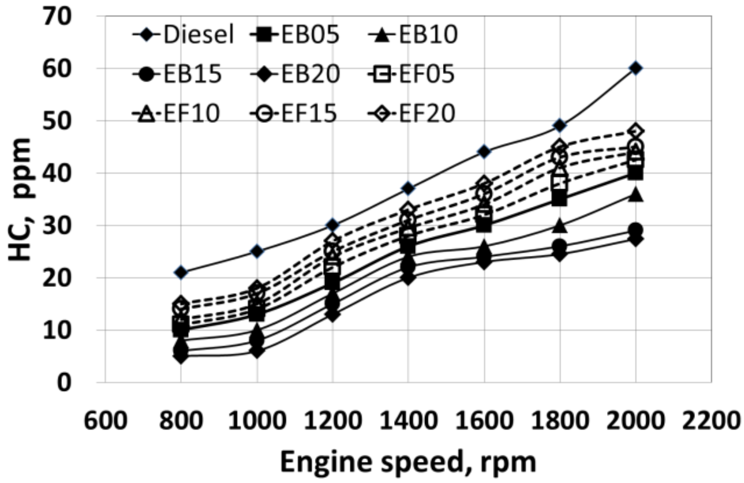

Figure 9: Variation of HC emissions with engine speed, or different fuels

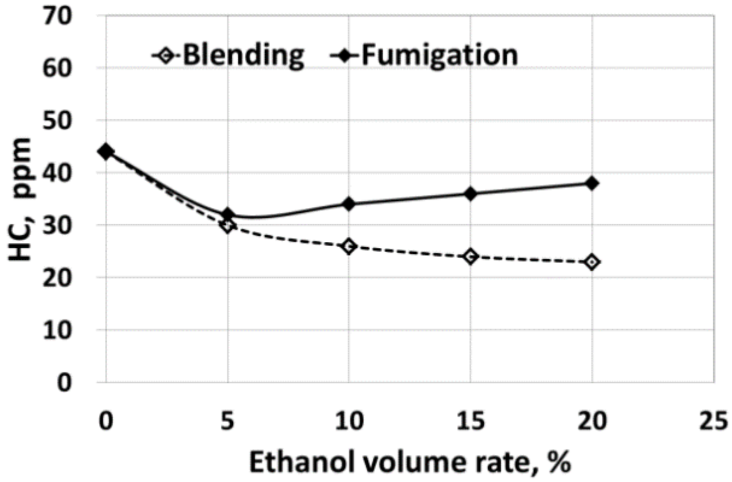

Figure 10: Variation of HC emissions with ethanol volume rate, for different fuel supplies

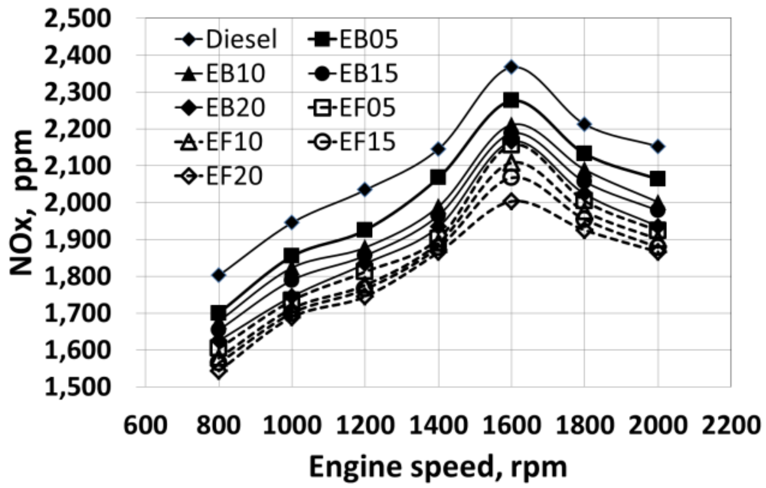

Figure 11: Variation of NOx emissions with engine speed, for different fuels

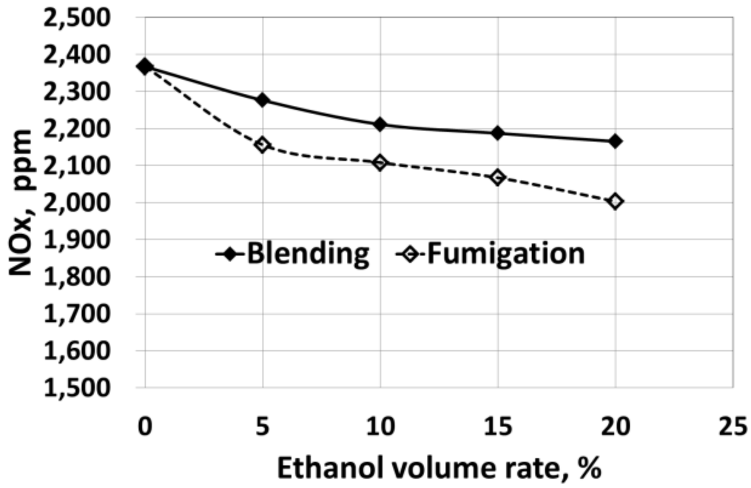

Figure 12: Variation of NOx emissions with ethanol volume rate, for different fuel supplies

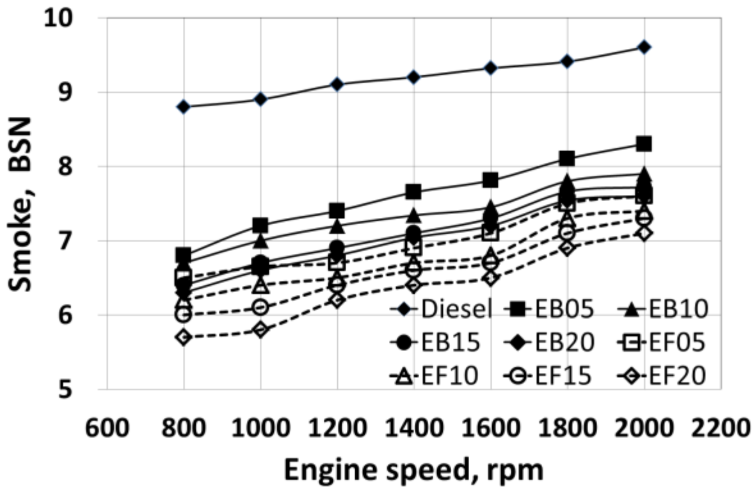

Figure 13: Variation of smoke emissions with engine speed, for different fuels

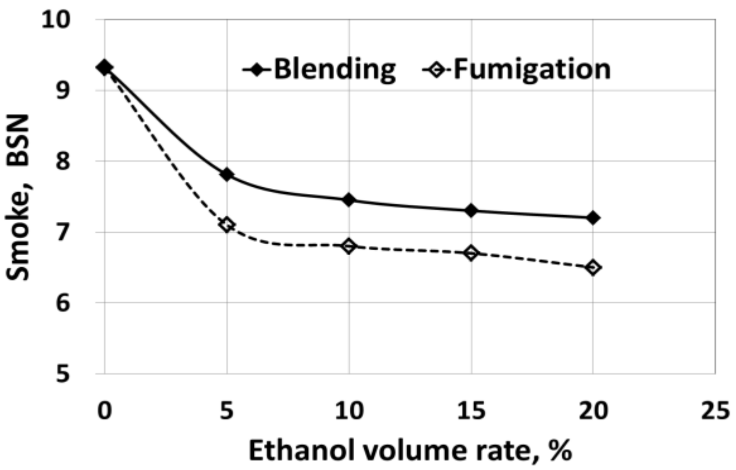

Figure 14: Variation of smoke emissions with ethanol volume rate, for different fuel supplies

Conclusions

Consequently, when alcohol fuel is added, the torque tends to decline as a whole compared to pure diesel fuel. The diesel-alcohol blended fuel system is more effective than the fumigation system.

HC emissions are reduced as alcohol fuel addition increases. In particular, it can be seen that the HC reduction effect has a greater fumigation method than the blending method.

CO, NOx, and smoke emissions decrease as the ethanol fuel addition increases. In particular, it can be seen that the reduction effect of CO, NOx, and smoke emission is larger than the fumigation method.

There is no significant difference in the way of adding ethanol to diesel fuel, but fumigation method is more advantageous in terms of exhaust gas reduction than blending method. Fumigation limit is 85% for diesel fuel and 15% for ethanol. If the aspect of torque is considered to be important, blending method is more advantageous than fumigation method.

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