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Exhaust emissions of a single cylinder diesel engine with addition of ethanol

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ABSTRACT

The effects of ethanol addition to the intake air manifold (ethanol fumigation) with percentage 10% and 20% on CO, HC, smoke and soot emissions of a single cylinder diesel engine have been investigated experimentally and compared with each other and with the original diesel engine (100 % diesel fuel). The results show that the optimum percentage for ethanol fumigation is 20%. This percentage produces an increase in CO emissions, HC emissions and reduction in engine smoke and soot mass concentration.

Introduction

It is apparent from the increasing popularity of light-duty diesel engines that alternative fuels, such as alcohols (ethanol), must be applicable to diesel combustion if they are to contribute significantly as substitutes for petroleum-based fuels. However, in the past, little attention has been given to the utilization of alcohol fuels in compression ignition engines [1]. This is due to the difficulties encountered while attempting to use alcohols in diesel engines, such as, large percentages of alcohol do not mix with diesel fuel; alcohols have extremely low cetane numbers, whereas the diesel engine is known to prefer high cetane number fuels (45-55) which auto-ignite easily and give small ignition delay [3]; diesel fuels serve as lubricants for diesel engine. Alcohol fuels do not have the same lubricating qualities [2]; the poor auto-ignition capability of alcohols is responsible for severe knock due to rapid burning of vaporized alcohol and combustion quenching caused by high latent heat of vaporization and subsequent charge cooling [2]. Although replacing diesel fuel entirely by alcohols is very difficult, an increased interest has emerged for the use of alcohols, and particularly lower alcohols (methanol and ethanol) with different amounts and different techniques in diesel engines as a dual fuel operation during recent years.

There are several techniques involving alcohol-diesel dual fuel operation. The ignition of alcohol in dual fuel operation is ensured by the high self-ignition diesel fuel. The most common methods for achieving dual fuel operation are [4]: Alcohol fumigation - the addition of alcohols to the intake air charge, displacing up to50% of diesel fuel demand; Dual injection - separate injection systems for each fuel, displacing up to 90% of diesel fuel demand; Alcohol-diesel fuel blend - mixture of the fuels just prior to injection, displacing up to 25% of diesel fuel demand; Alcohol-diesel fuel emulsion - using an emulsifier to mix the fuels to prevent separation, displacing up to 25% diesel fuel demand. The technique I was concerned with in this study is alcohol fumigation. Fumigation is a method by which alcohol is introduced into the engine by carbureting, vaporizing or injecting the alcohol into the intake air stream. This requires the addition of a carburetor, vaporizer or injector, along with a separate fuel tank, lines and controls. Fumigation has some following advantages: It requires a minimum of modification to the engine, since alcohol injector is placed at the take air manifold. Also, flow control of the fuel can be managed by a simplified device and fuel supply system; the alcohol fuel system is separate from the diesel system. This flexibility enables diesel engines, equipped with the fumigation system, to be operated with diesel fuel only. The engine can switch from dual fuel to diesel fuel operation and vice-versa by disconnection and connection of the alcohol source to the injector; if an engine is limited in power output due to smoke emissions, fumigated ethanol could increase the power output because alcohol tends to reduce smoke. This is because of good mixing of the injected charge with alcohol.

An advantage of ethanol-diesel fuel solutions is that few major component changes are required for their use. Small adjustments to the injection timing and fuel delivery may be necessary to restore full power. The adjustments depend on the ethanol concentration and the combustion effects of ethanol [5]. In this study, no modification on the engine was made for blends, since the amounts used were within the permitted range. Weidmann and Menard [6] used a standard Volkswagen 4-cylinder, swirl-chamber diesel engine to test the performance of alcohol-diesel fuel blends. The alcohols involved were ethanol and methanol. Their object was to report on the development of an engine/fuel concept designed for alcohol-diesel fuel blends. They reported that HC and CO emissions were increased and NOx emissions decreased compared to diesel fuel. Also, alcohol-diesel fuel blends emit more aldehydes and less polycyclic aromatic hydrocarbons (PAH). Czerwinski [7] tested a 4-cylinder, heavy duty, direct injection diesel engine in which30% ethanol and 15% rape oil mixtures were used.

He found that the addition of 30% ethanol to the diesel fuel causes longer ignition delay. The combustion temperatures were lower. At full load, all emissions were lower. At lower loads and speeds, CO and HC emissions were increased. It was possible to obtain emissions similar to diesel fuel, but with reduced power output up to 12.5%.

It can be seen from the literature survey reviewed earlier that there is no detailed information about the effects of alcohols on diesel engine smoke or particulate matter emissions, and this will be the main object from this study.

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Experimental apparatus

The engine used for this study was a single cylinder, four stroke, direct injection, variable compression ratio, diesel engine with a swept volume of 582 cm3. The engine is naturally aspirated and water cooled. The engine was coupled to an electrical generator through which load was applied by increasing the field voltage. A fixed 20o injection timing and 18 compression ratio were used throughout the experiments. Indicators on the test bed show the following quantities which are measured electrically: engine speed, brake power and various temperatures.

Test procedures

Fig. 1 shows a schematic of the ethanol fumigation system. Ethanol was fumigated into the intake air charge and introduced in the engine as a vapor or mist, dependent on the degree of vaporization which occurred. A simple fumigation system was used, consisting of a single hole, direct opening configuration spraying nozzle. It was selected to achieve ethanol delivery at relatively low pressure. The nozzle has a diameter of about 0.25 mm. Since the obtained nozzle flow rate was relatively high, the produced ethanol jet was allowed to hit a partition in order to get ethanol mist which is directly mixed with air before entering the engine. An electrically driven air compressor was used to supply ethanol to the nozzle. The nozzle was positioned approximately 50 cm ahead of the inlet manifold. This allowed the ethanol to be mixed with the intake air for a sufficient period, providing uniform mixing. The intake manifold was provided with a transparent window for optical inspection of the ethanol-air mixture.

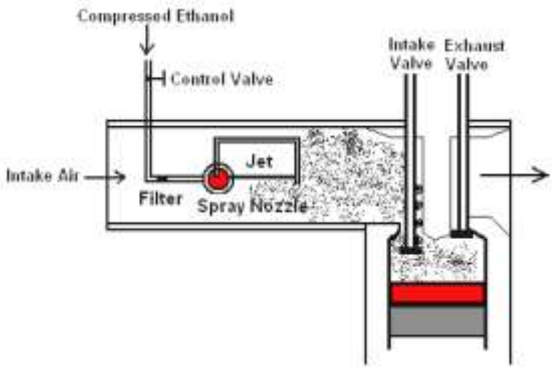

Figure 1. Schematic diagram of ethanol fumigation system

Results and discussion

Effect of ethanol substitution on CO emission

Fig. 2 shows the effect of ethanol substitution on CO production. The maximum increase in CO emissions was at 20% ethanol fumigation as shown in Fig. 3. The increase in the CO levels with increasing ethanol substitution from 10% to 20% is a result of incomplete combustion of the ethanol-air mixture. Factors causing combustion deterioration (such as high latent heats of vaporization) could be responsible for the increased CO production. Combustion temperatures may have had a significant effect. A thickened quench layer created by the cooling effect of vaporizing alcohol could have played a major role in the increased CO production.

For 20% ethanol fumigation, the increase in CO emissions was in the range of 21-55% at the speed range used.

Another reason for the increasing CO production is the increase in ignition delay. This could lead to a lower temperature throughout the cycle. This results in combustion of a proportion of the fuel in the expansion stroke, which lowers temperatures and reduces the CO oxidation reaction rate.

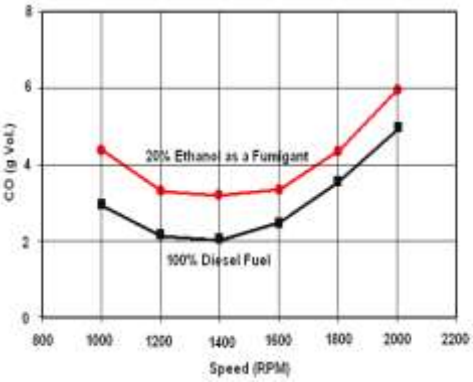

Figure 2 CO emissions versus speed for 20% ethanol fumigation and for 100% diesel fuel

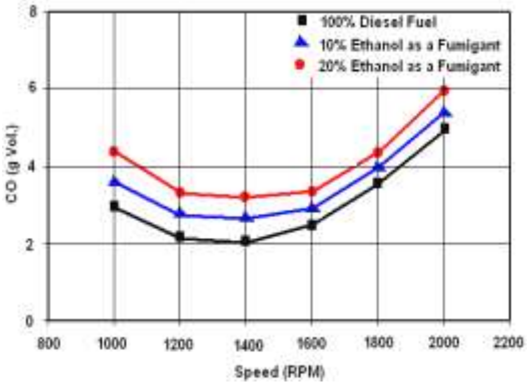

Figure 3. CO emissions versus speed for 10%, 20% ethanol fumigation and for 100% diesel fuel

Effect of ethanol substitution on HC emission

Fig. 4 shows the effect of ethanol substitution on HC emissions. The maximum increase in HC emissions was at 20% ethanol fumigation as shown in Fig. 5. IT is noticed that there is a resemblance in the results concerning CO and HC emissions production. The HC emissions tend to increase because of the quench layer of unburned fumigated ethanol present during fumigation. There is no quench layer with diesel fuel injection alone because the combustion is droplet-diffusion-controlled and completely surrounded by air. Also, the high latent heat of vaporization can produce slow vaporization and mixing of fuel and air. These factors result in high HC levels.

For 20% ethanol fumigation, the increases in HC emissions were between 20 and 36%.

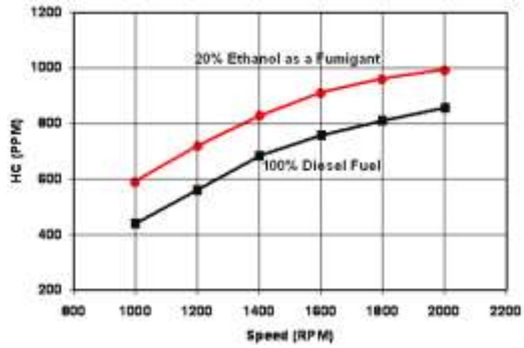

Figure 4. HC emissions versus speed for 20% ethanol fumigation and for 100% diesel fuel

Effect of ethanol fumigation on engine smoke

Figure 6 shows the effect of ethanol fumigation on engine smoke. The smoke measurements were plotted as a smoke absorption coefficient, K. This is a number which gives an indication about the exhaust emissions density. The maximum decrease in smoke coefficient was at 20% ethanol fumigation as shown in Fig. 7.

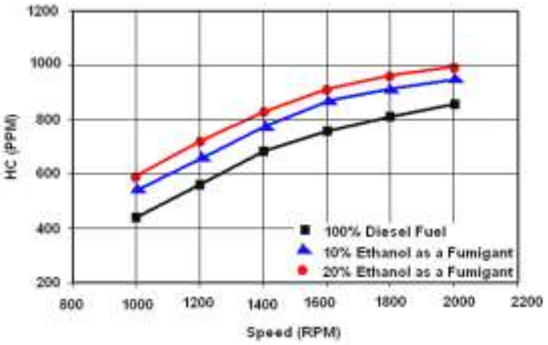

Figure 5. HC emissions versus speed for 10%, 20% ethanol fumigation and for 100% diesel fuel

The recognized drastic reduction in smoke coefficient, as more amount of ethanol was used, is attributed to several reasons. Here, the charge cooling increases ignition delay and, thus, enhances the mixing of diesel fuel with the ethanol-air mixture which, in turn, makes for better air utilization and less smoke. Also, diesel fuel has a high tendency to soot formation due to its low H/C ratio and the nature of its combustion process. Using ethanol as a fumigant in a diesel engine increases the hydrogen content in the mixture and eventually reduces the engine smoke and leads to a soot free combustion of ethanol under normal diesel engine operating conditions.

There is a decrease in smoke coefficient of 30-48% for 20% ethanol as a fumigant. This decrease was the maximum over the entire speed range used as shown in Fig. 6 & 7.

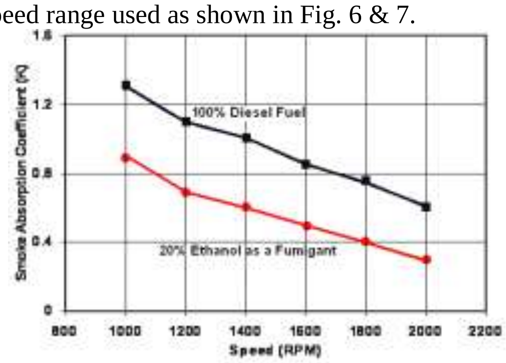

Figure 6. Engine smoke versus speed for 20% ethanol fuel fumigation and for 100% diesel fuel

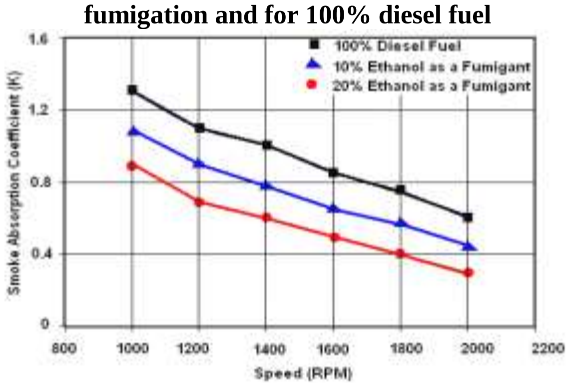

Figure 7. Engine smoke versus speed for 10%, 20% ethanol fuel fumigation and for 100% diesel fuel

Effect of ethanol fumigation on soot mass concentration

Figure 8 shows the effect of ethanol fumigation on soot mass concentrations of the engine. From this figure, it can be seen that there is a matching between smoke and soot measurements, and both methods confirm each other. Soot concentration represents the mass fraction of soot in the exhaust. It is given in milligrams of soot per kilogram of exhaust. The maximum decrease in soot mass concentrations was at 20% ethanol fumigation as shown in Fig. 9.

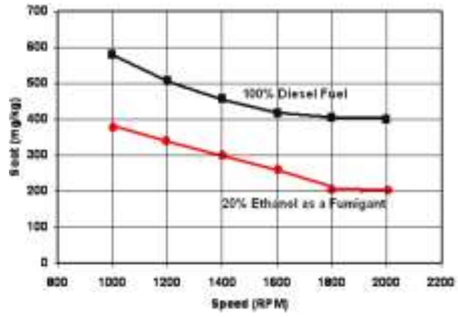

Figure 8. Soot emissions versus speed for 20% ethanol fumigation and for 100% diesel fuel

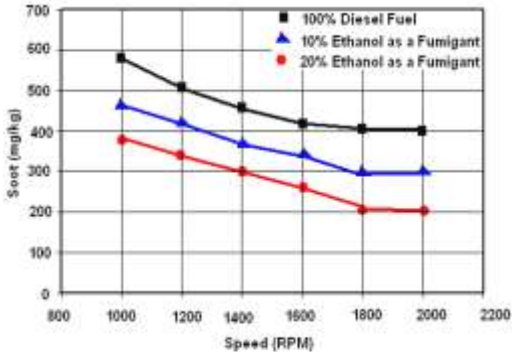

Figure 9. Soot emissions versus speed for 10% and 20% ethanol fumigation and for 100% diesel fuel

From Figures 8 and 9, the maximum decrease (over the entire speed range) in soot concentrations was 33-51% for 20% ethanol fumigation. The decrease in soot formation rate could be attributed to the same reasons responsible for the smoke decrease.

The recognized drastic reduction in soot emissions, as more amount of ethanol was used, is attributed to several reasons. Here, the charge cooling increases ignition delay and, thus, enhances the mixing of diesel fuel with the ethanol-air mixture which, in turn, makes for better air utilization and less soot. Also, diesel fuel has a high tendency to soot formation due to its low H/C ratio and the nature of its combustion process. Using ethanol as a fumigant in a diesel engine increases the hydrogen content in the mixture and eventually reduces the engine smoke and leads to a soot free combustion of ethanol under normal diesel engine operating conditions.

Conclusions

The effects of ethanol addition to the intake air manifold with percentage 10% and 20% on CO, HC, smoke and soot emissions of a single cylinder diesel engine have been investigated experimentally and compared with each other and with the original diesel engine (100 % diesel fuel). This was achieved by using a simple fumigation technique.

The results show that the optimum percentage for ethanol fumigation is 20%. This percentage produces an increase in CO emissions, HC emissions and reduction in engine smoke and soot mass concentration.

The conclusions which may be drawn from this study are as follows:

1. The use of ethanol fumigation technique is effective and gives reasonable results.
2. Based on the above results, the optimum percentage of ethanol appears to be 20% for ethanol fumigation.
3. The use of 20% ethanol as a fumigant can produce an increase of 55% in CO emissions levels and 36% in HC emissions levels. Also, this fumigation percentage produces a decrease of 48% in engine smoke and 51% in soot mass concentration.

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