Preparation and emission characteristics of ethanol-diesel fuel blends

ZHANG Run-duo¹, HE Hong¹,², SHI Xiao-yan¹, ZHANG Chang-bin, HE Bang-quan², WANG Jian-xin²
(1. Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China E-mail: honghe@msl.reees.ac.cn; 2. State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, China)

Abstract: The preparation of ethanol-diesel fuel blends and their emission characteristics were investigated. Results showed the absolute ethanol can dissolve in diesel fuel at an arbitrary ratio and a small quantity of water (0.2%) addition can lead to the phase separation of blends. An organic additive was synthesized and it can develop the ability of resistance to water and maintain the stability of ethanol-diesel-trace amounts of water system. The emission characteristics of 10%, 20%, and 30% ethanol-diesel-fuel blends, with or without additives, were compared with those of diesel fuel in a direct injection (DI) diesel engine. The experimental results indicated that the blend of ethanol with diesel fuel significantly reduced the concentrations of smoke, hydrocarbon (HC), and carbon monoxide (CO) in exhaust gas. Using 20% ethanol-diesel fuel blend with the additive of 2% of the total volume, the optimum mixing ratio was achieved, at which the bench diesel engine testing showed a significant decrease in exhaust gas. Bosch smoke number was reduced by 55%, HC emission by 70%, and CO emission by 45%, at 13 kW/1540 r/min. However, ethanol-diesel-fuel blends produced a few ppm acetaldehyde and more ethanol in exhaust gas.

Keywords: ethanol-diesel fuel blends; preparation; emission; acetaldehyde; ethanol

Introduction

Motor vehicles have an important impact on air quality, which affects both human health and the environment. Therefore, legislations were introduced to limit the emission of CO, HC, nitrogen oxides (NOx), and smoke from vehicles (Ertl, 1999). The diesel engine has the advantage of lower consumption of fuel and lower emission of CO, carbon dioxide (CO₂) and HC than usual gasoline engine. However, diesel engine emits a large amount of smoke and NOx compared to the gasoline engine equipped with a three-way catalyst. It is a suitable way to solve this problem by partially replacing diesel fuel by ethanol (Abu-Qudsia, 2000; Ajay, 1998; 1999; 2000; Wang, 2002; Noguchi, 1996; Ahmed, 2001; Satge de Caro, 1997; 2001; Zervas, 2001; 2002; Reddy, 1999). Because replacing diesel fuel entirely by ethanol is rather difficult, researchers focus on particular substitute for diesel fuel which consist of diesel fuel, ethanol and certain additives.

The most common methods for achieving ethanol alternative fuel are ethanol fermentation (Abu-Qudsia, 2000; Ajay, 1998), dual injection (Wang, 2002; Noguchi, 1996), ethanol-diesel fuel blend (Abu-Qudsia, 2000; Ajay, 1999; 2000; Ahmed, 2001), and ethanol-diesel fuel emulsion (Satge de Caro, 1997; 2001). An advantage of ethanol-diesel fuel blending is that no major component changes are required for its use. Small adjustments to the injection timing and fuel delivery may be necessary to restore full power (Eugene, 1984). M. Abu-Qudsia et al. (Abu-Qudsia, 2000) studied the impact of ethanol-diesel fuel blending on the performance and emissions of a single cylinder diesel engine. He pointed out that the optimum ethanol percentage for ethanol-diesel fuel blends was 15%, this produced a reduction of 32% in smoke level. Ajay et al. (Ajay, 1999) also found that the CO emission was reduced by 36.8%, 56.5%, 58.8%, and 62.5% by the use of 5%, 10%, 15%, and 20% ethanol-diesel blends, respectively, as compared to using diesel fuel alone. In previous work (Ajay, 1998; 1999; 2000; Noguchi, 1996; Ahmed, 2001; Satge de Caro, 1997; 2001), the correlation between ethanol-diesel blends and exhaust emissions from diesel engine had been researched for the case of regulated pollutants (smoke, HC, NOx, CO). However, exhaust gas contains other specific pollutants such as acetaldehyde and ethanol that have not been thoroughly investigated so far. New analytical methods should be set up to determine the amounts of acetaldehyde and ethanol in exhaust gas. Moreover, ethanol is a substance with polar molecules with properties similar to water and far away from diesel fuel. It is necessary to introduce additive into ethanol-diesel blends to stabilize the mixture in the presence of water and ensure the homogeneity and compatibility of blends under all conditions. The influences of newly introduced additives on the emission characteristics of ethanol-diesel fuel blends have not been well established. A study was, therefore, undertaken with the objective of finding out the optimum method to partially replace diesel by ethanol with or without additive and comparing the emissions of various pollutants from diesel engine using ethanol-diesel fuel blends with or without additive and diesel fuel alone. Considering the new organic compound pollutants brought by blending ethanol with diesel fuel, the emissions of acetaldehyde and unburned ethanol, besides the emissions of regular pollutants (NOx, HC, CO, and smoke) were also investigated.

1 Materials and methods
1.1 Additive
Additive is mainly produced from oleic acid, polyvinyl
alcohol and lecithin. Oleic acid, polyvinyl alcohol, xylene and tetrabutyl phthalate were mixed together in the ratio of 15:5:3:1. After stirring completely, this mixture was poured into a rotary evaporator and evaporated at 70°C for 10 h under vacuum condition. 2% lecithin in the volume of prepared mixture was added and mixed continuously, and then a yellow and viscous liquid additive was prepared.

1.2 Ethanol-diesel blend fuel

Absolute ethanol (Beijing Chemical Engineering Factory, A.R.) and commercial diesel fuel (commercial diesel, 0°, Chinese Petrochemical Co.) were mixed together to get ethanol-diesel mixture (ethanol + diesel). 2% additive of the total volume was introduced into this mixture. After stirring, ultrasonic vibration and filtering, an ethanol-diesel fuel blend was obtained (ethanol + diesel + additive).

1.3 Operational condition of diesel engine

The emission characteristics of ethanol-diesel fuel blends were carried out in a DI diesel engine rig. The test engine is a two-cylinder unit, Model 29STA with a compression ratio of 17:1 and a displacement of 2000 cm³. The engine rated power is 20 kW at a speed of 2200 r/min. Engine speed and load were detected and controlled by tachometer and electric eddy dynamometer. The engine speed was fixed at 1540 r/min and the range of engine load was from 20 Nm to 80 Nm during the experimental process.

1.4 Analytical methods of exhaust gas

Exhaust gas was divided into two parts. One part went through gas analysis system (AVL GEM-110, AVL Company, Austria) to check the concentration of NOx, HC, and CO. Bosch smoke number was detected by a FBY-1 smoke analyzer. Another part was collected by plastic sampling bag coated with aluminum film. The concentrations of acetaldehyde and unburned ethanol were quantitatively analyzed by gas chromatograph (GC)/mass spectrometry (MS) (Agilent Company, America) with a PLOT-Q capillary column.

This study of ethanol-diesel fuel focuses on its effects on the environment, so more attention has to be paid to the production and exhaust of new pollutants such as acetaldehyde and unburned ethanol after ethanol blending. The authors developed a quantitative method to determine the amounts of exhaust acetaldehyde and unburned ethanol by GC/MS. Fig. 1 shows the result of the combustion of 20% ethanol-diesel fuel blend at the power of 3.4 kW. SIM model was selected for the quantitative analysis. The m/z of main fragment ion of acetaldehyde and ethanol are 29, 44, 43 and 31, 45, 27 respectively. As shown in Fig. 1 acetaldehyde and ethanol were separated completely to ensure the accurate quantitative analysis.

2 Results and discussion

2.1 Ethanol-diesel fuel blends

Ethanol is a hydrophilic organic compound containing hydroxyl functional group and can dissolve in water. Diesel fuel is a sort of product of petroleum. The detailed composition of diesel fuel is depended on its original area and process. In general, diesel fuel is mainly composed of C6-C18 saturated hydrocarbon, olefin, and arenene. Because of the different polarity between ethanol and diesel fuel, it is necessary to introduce some material to decrease the tension between ethanol and diesel fuel to obtain an even, stable ethanol-diesel fuel blend. The stability of ethanol-diesel fuel blend is affected by diesel fuel composition, contained water, density, temperature and additive amount. In addition, because diesel fuels also serve as lubricants for diesel engine (Abu-Qudais, 2000), with this regards the properties of additive should not have an obvious distinction from those of diesel fuel in order to avoid the problem in the practical use in diesel engine. Low cost and easy obtaining of fuel blends are also the factors that should be considered in practice.

In this investigation, ethanol was mixed with diesel fuel at the ratio of 1:9, 3:7, 1:1, 7:3, and 9:1, respectively. It was found that absolute ethanol was highly soluble in diesel fuel. A homogenous ethanol-diesel mixture was obtained without any separation in the absence of water. It is a different condition in the presence of water because the hydrogen bond is formed between water and ethanol. The effect of water on ethanol-diesel mixture can not be ignored. Water will be brought into diesel fuel during the process of store and transportation, so the ability of resistance to water effect must be enhanced for ethanol-diesel blends.

Gradually adding water into 30% ethanol-diesel blend, we observed cloudiness in the mixture followed by separation when water addition amount reached 0.2% of the total volume. Additive for ethanol-diesel fuel was prepared by suitable method as described in the experimental section. Adding 2% additive into the mixture of 30% ethanol + diesel + 0.2% water, we found that the separation disappeared and the mixed solution became clear again. This additive has the surfactant properties to offer the maximum permissible water content with an amphiphilic structure that is aligned between ethanol-water and diesel fuel, thereby reinforcing the structural affinities between the various components of the mixture. The hydrophobic functional group of the additive has a strong affinity with diesel fuel, while the hydrophilic part orient towards the ethanol-water molecules. So the additive could improve the ability of resistance to water and keep the compatibility of ethanol-diesel-water system. Homogenous and stable ethanol-diesel fuel blend was prepared finally.

The viscosity of fuel should also be intensified to ensure adequate lubrication of fuel injection pumps. In this attempt, the absolute viscosity was measured by rotary viscometer as shown in Table 1. Compared with diesel fuel, ethanol-diesel mixture has a low viscosity. This viscosity did not exceed the required minimum (2 Pa·s) of diesel fuel (Sadeghe Caro, 2001). With the addition of additive, the viscosity of
ethanol-diesel blend fuel increased up to 2.3 Pa·s. The introduction of the additive improved the lubrication of diesel engine. At ambient temperature half of the viscosity of diesel fuel that is lost by adding ethanol can be recovered by using the additive. This additive can offer a suitable viscosity to avoid the problem in practical use of ethanol-diesel fuel blends.

Table 1 The viscosity of different fuel at ambient temperature

<table>
<thead>
<tr>
<th>Name</th>
<th>Ethanol</th>
<th>Diesel fuel</th>
<th>30% ethanol-diesel mixture</th>
<th>30% ethanol-diesel fuel blend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity, Pa·s</td>
<td>1.48</td>
<td>3.2</td>
<td>1.66</td>
<td>2.3</td>
</tr>
</tbody>
</table>

In conclusion, absolute ethanol can dissolve in diesel fuel at an arbitrary ratio. 0.2% water addition leads to the appearance of separation. The additive can increase the ability of resistance to water for ethanol-diesel fuel blends and keep the stability of ethanol-diesel-trace amounts of water system.

Fig. 2 The relationship between Bosch smoke numbers and diesel engine loads

**2.2 Trends of smoke level of exhaust gas**

Smoke is one of the major pollutants of diesel exhaust emission and is usually produced under high load condition. Fig. 2 shows the correlation between smoke level and power of diesel engine. Smoke level of the exhaust gas was low at a power level lower than 7 kW. As the power of engine increased, smoke emission became heavier. Bosch smoke number is 3.1 at 13 kW with the use of diesel fuel alone, while Bosch smoke number are 2, 1.4, 1.8 with the use of 10%, 20%, and 30% ethanol-diesel fuel blends, respectively, under the same operating condition. This means that the blend of ethanol can significantly reduce the smoke in exhaust gas of the diesel engine. As an oxygenated compound, ethanol can increase the oxygen-to-fuel ratio in fuel-rich regions and reduce the production of incomplete combustion particulates. The optimum percentage for ethanol-diesel fuel blends is 20%. When the addition of ethanol is 20%, an optimum performance was achieved with up to 55% less smoke.

**2.3 Emission of NOX**

Fig. 3 shows NOx emission of diesel engine for combustion of different fuels at various load conditions. It is clear from the figure that NOx emissions increased with the increase in engine load. NOx emission of 30% ethanol-diesel mixture in the absence of additive was higher than that of diesel fuel. The ethanol-diesel fuel blend was prepared by introducing additive into ethanol-diesel mixture. The experimental results showed that adding additive inhibited the NOx emissions. Due to the additive, the NOx emission levels of ethanol-diesel fuel blends were close to that of diesel fuel. Since NOx is also one of the main pollutants of diesel engine, we have developed Ag/Al2O3 catalyst to remove NOx effectively under excess oxygen condition (Sumiya, 1998).

Fig. 3 The relationship between NOx concentrations and diesel engine loads

**2.4 Emission of HC**

Emission of HC increased with the increase in engine power as shown in Fig. 4. When the engine power increased to 13 kW, HC concentration in exhaust gas for diesel fuel was 2764 ppm higher than that at low loads. This is due to the fact of rich fuel air ratio at high loads. The HC emission decreased to 1620 ppm with the blend of 30% ethanol in the absence of additive at 13 kW. At high loads, the insufficiency of oxygen supply cannot maintain a good combustion condition for HC. Ethanol is an oxygenated organic compound that can improve the combustion of HC under this condition. With the introduction of the additive, HC emission of ethanol-diesel blend fuel was less than that of ethanol-diesel mixture without using the additive. The additive can improve the distribution of ethanol in diesel fuel, so HC emission of ethanol-diesel fuel blends decreased even more in the presence of additive. The HC emission of 20% ethanol-diesel fuel blend can be inhibited by 70% compared with that of diesel fuel at 13 kW.

Fig. 4 The relationship between HC concentrations and diesel engine loads

**2.5 Emission of CO**

CO is emitted from diesel engine as a product of incomplete combustion of fuel under usual condition. Fig. 5 shows that CO emission was almost constant at low loads. CO emission became higher at high loads because of the increase of the incomplete combustion of fuel.

Fig. 5 also indicates that the blend of ethanol suppressed the CO emission significantly. With 30% ethanol blending, only 479 ppm CO was emitted at 11.9 kW in the absence of additive, in agreement with Ahmed’s result (Ahmed, 2001). CO emissions increased with the introduction of the additive, but they were still lower than that of diesel fuel alone. Exhaust CO concentration of 20% ethanol-diesel blend fuel is 1531 ppm when the power of diesel engine is 13 kW, so its CO level was decreased almost by 45% as compared with the diesel fuel.
2.6 Emission of acetaldehyde

Acetaldehyde is produced from the incomplete combustion of ethanol. Fig. 6 shows the effect of ethanol addition on acetaldehyde emission at various load conditions. It seems that diesel fuel combustion just produced little amounts of acetaldehyde (within 3 ppm). Adding 30% ethanol into diesel fuel, the concentration of exhaust acetaldehyde increased up to 8.6 ppm when engine power was 4.7 kW. The additive served to inhibit the emission of acetaldehyde. After introducing the additive, the acetaldehyde emission of ethanol-diesel fuel blend was similar to that of diesel fuel. In general, the addition of ethanol into fuel will not bring out any new environmental risks.

![Fig. 6 The relationship between acetaldehyde concentrations and diesel engine loads](image)

2.7 Emission of ethanol

The change in ethanol emission in exhaust gas at various load conditions is shown in Fig. 7. It is clear that diesel fuel combustion did not produce any ethanol. More unburned ethanol was emitted with the blend of ethanol. When engine power was 4.7 kW, the unburned ethanol emission of 30% ethanol-diesel mixture was 132 ppm. The increase of unburned ethanol emission is due to an uneven distribution of ethanol, which leads to the incomplete combustion of ethanol. For ethanol-diesel blend fuel, unburned ethanol emissions decreased with the addition of additive. The additive facilitated the blend of ethanol and diesel fuel more evenly to restrain the unburned ethanol emission. In addition, the unburned ethanol can be used as a specific reducing agent for selective catalytic reduction NOx (Sumiya, 1998).

![Fig. 7 The relationship between unburned ethanol concentrations and diesel engine loads](image)

3 Conclusions

The technology of ethanol-diesel fuel blend is an important method to reduce pollutant emissions from diesel engine. An absolute ethanol could dissolve into diesel fuel at arbitrary ratio. Trace amounts of water (e.g., 0.2%) addition led to phase separation. An additive was prepared in order to keep the stability of ethanol-diesel-trace amounts of water system. The ethanol-diesel fuel blends could reduce the particle level of combustion exhaust remarkably. When the diesel engine power was 13 kW, smoke level decreased 54.8% when using 20% ethanol-diesel blend fuel compared with operation on diesel fuel alone. Meanwhile, ethanol (especially ethanol and additive) addition also reduced the HC emission noticeably. Ethanol addition led to the increase of unburned ethanol emission, but the additive used could suppress this emission.

References:


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