

Research on Basic Fuel Properties and Emission Characteristics of E-Diesel Fuel Blend

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Abstract: An additive compound consists of alkyl alcohol, ether, macromolecule polymer and alkyl nitrate is proposed to resolve the phase separation and low cetane number of E-diesel. The experimental results show that, blending with 1-2% this additive compound, the solubility of E-diesel is increased and the cold starting performance of diesel engine is also improved. The further results also present the variation of THC, CO and NO_x emissions with load and blend ratio of ethanol. Especially, Bosch smoke number reduces greatly at any percentage of ethanol.

Keywords: E-diesel, phase separation, cosolvent, cetane improver, emission characteristic

1. INTRODUCTION

The increase of vehicle amount day by day is now making Chinese petroleum supply and air pollution more and more serious. Therefore, searching new automotive energies becomes an urgent task. In addition to CNG and LPG, as a renewable energy, ethanol has been started to apply extensively on gasoline engine in some north China cities. The corresponding national standard on E-gasoline (the blend ratio of ethanol is below 10%) has also been enacted. Meanwhile, E-diesel, the blend of ethanol and diesel, cannot work well on diesel engine because of its low cetane number and phase separation under low temperature. Therefore, in order to overcome the limitations of E-diesel application, in this study, an additive compound consists of alkyl alcohol, aether, macromolecule polymer and alkyl nitrate is proposed on the base of physical and chemical properties of E-diesel. Blending with this additive at a volume ratio range of 1%-2% can improve evidently the solubility of E-diesel. Furthermore, the results of engine bench test under various blend ratios indicate that the cold starting performance of E-diesel is better than that of diesel; with the increase of blend ratio, the specific fuel consumption also increases, but the Bosch smoke number reduces. The variation of emissions of THC, CO, NO_x at various loads are also investigated.

2. FUEL PROPERTIES OF E-DIESEL AND ADDITIVE COMPOUND

The physical and chemical properties of diesel and five alkanols are listed in Table.1. According to these data, it is obviously that, with the increase of carbon atom number, the fuel properties of alkanols gradually approach diesel. As to ethanol, it has particular characteristics below.

- 1) Oxygen occupies 35% mass fraction. Its heat value is equivalent to 63% of diesel, but its mixture heat value is very close to diesel.
- 2) Its flammability limit is broader than diesel at the lean side, which is of great advantage to the stability of lean burn and reducing emissions.

- 3) Its cetane number is much lower than diesel, but its gasification latent heat is much higher than diesel.

Directly mixing ethanol with diesel, like E-gasoline, is a convenient way to use E-diesel, but it will bring phase separation, even slight amount water is blended, due to hydrogen bond produced by hydroxyl of ethanol combining with water molecule. Another problem is low cetane number of the blend fuel. This number will reduce rapidly with the blend ratio of ethanol increasing^[1]. In addition, there are other problems, high gasification latent heat etc. All these make the cold starting performance and emission performance of the E-diesel different from pure diesel. Therefore, only overcoming the limitations above can extend the application of E-diesel.

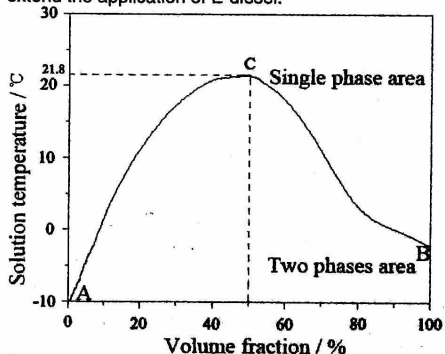


Figure 1: The binary phase diagram of diesel and ethanol

2.1 Solubility

The solubility of E-diesel is also related to the blend ratio of ethanol and the temperature of the solution besides the water ratio in ethanol and the aromatic hydrocarbon ratio in diesel. Fig.1 is the binary phase diagram of diesel and ethanol, in which the part above the curve is single phase area and the below is two phases area. In Fig.1, curve AC presents the variation of ethanol concentration in diesel phase

Table 1: The physical and chemical properties of diesel and five alkanols

Properties	Methanol	Ethanol	Propanol	Butanol	Pentanol	Diesel (-10 [#])
Molecular formula	CH ₃ OH	C ₂ H ₅ OH	C ₃ H ₇ OH	C ₄ H ₉ OH	C ₅ H ₁₁ OH	C ₁₆ ~C ₂₃
Molecular weight	32	46	60	74	88	180~220
Oxygen content (%)	50	34.8	26.7	21.6	18.2	0.4~0
Specific weight	0.791	0.787	0.804	0.81	0.817	0.81~0.84
Boiling point (°C)	64.7	78.3	97.2	117.7	138	200~270
Freezing point (°C)	-97.8	-114	-126	-90	-79	-10~-14
Flashing point (°C)	11	13	15	28	33	65
Autoignition temperature (°C)	465	426	430	441	327	270~350
Ignition limit (vol%)	6.7~36	4.3~19	2.6~13.5	1.45~11.25	1.2~10.5	1.5~8.2
Cetane number	3	8				40~45
Low heat value (MJ/kg)	20.1	27.1	30.9	33.4	35.1	43.8
Mixture heat value (MJ/kg)	2.708	2.708	2.713	2.73	2.738	2.73
Reid vapor pressure (mmHg)	232.4	130	48	19	8	69
Latent heat of vaporization (MJ/kg)	1.1	0.86	0.69	0.594	0.427	0.25~0.27
Solubility (g/100gH ₂ O)	∞	∞	∞	8	2.3	~0

with temperature of the solution; curve BC presents the change of diesel concentration in ethanol phase. It can be seen, when the temperature is 21.8 °C, that the curve AC and the curve BC intersect at C, the critical point. Experiments show that the critical point of E-diesel composed of ethanol and -10[#] diesel locates at the place where the ethanol blend ratio is about 50%.

The allowable limit of water in E-diesel is so small^[2] that it make the E-diesel containing 10%-90% diesel can not be used in most of a year even stringently control temperature difference between day and night and the water ratio during transportation and storage. Therefore, it is necessary to find out a cosolvent to promote the solubility of ethanol in diesel at lower temperature. Fig.2 shows the cosolvent effect of some substances^[3], the horizontal axis indicates the type of cosolvent and the vertical axis indicates the drop value of critical temperature after blending 1% cosolvent in volume fraction. It is obviously that the more this value drops the better the cosolvent effect is. As shown in Fig.2, there are several medium alcohols, high alcohols and ether are suitable for being as cosolvents, while the gasoline is not suitable due to its poor cosolvent effect and low cetane number of 12^[4].

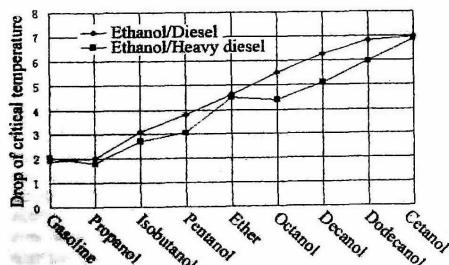


Figure 2: Effects of some cosolvents

Moreover, it needs to take the production cost and the universality of production materials into account to determine a cosolvent, so it is appropriate, in this

study, to adopt the mixture of isobutyl alcohol, amyl alcohol and low ethers as the cosolvent.

2.2 Flammability

The cetane number of ethanol is only 8. Adding 10%-15% ethanol into diesel will make the cetane number of the blend fuel drops 6-9^[1], which hence extend the ignition delay period, increase the rate of pressure rise and make the cold starting difficult. So it is necessary to blend cetane improver with E-diesel to improve the flammability of the blended fuel.

The cetane improvers now used use for diesel are mainly alkyl nitrates and organic peroxides^[5]. Ethers are also good cetane improvers^[6], the cetane number of ethyl ether is 126 and butyl ether is 100.

Alkyl nitrates are more easily decomposable than diesel. When they decompose at lower activation energy, it will produce free alkoxyl radical (R) which can sequentially decompose into new free radicals and aldehydes during the ignition delay period. This process will accelerate the preflame reaction of diesel and shorten the ignition delay period.

According to Thompson^[7], the improved cetane number after adding the alkyl nitrates and organic peroxides into diesel can be evaluated by the empirical formula below.

$$CNI = A \times CN^{0.36} \times G^{0.57} \times C^{0.032} \times \ln(1 + 17.5 \times C) \quad (1)$$

Where CNI is improved cetane number,

CN is original cetane number of diesel,

A is the component constant. For alkyl nitrates, A=0.16; for organic peroxides, A=0.119^[7],

G is the API gravity of diesel. G=40~50^[7],

C is the volume fraction of the added materials.

Generally, the cetane number of -10[#] diesel is 40~45. If 0.3% (in volume) alkyl nitrates is added into, the CNI of E-diesel composed of 10% ethanol + 90% diesel and 15% ethanol + 85% diesel are 9.21 and 8.95, respectively. So it can be derived that, for the E-diesel in which the ethanol blend ratio is less than 15%, the cetane number can reach the pure diesel level after blending a very small quantity of alkyl nitrates.

2.3 A New additive compound

An excellent additive must have high cosolvent effect and good flammability, in addition to a certain viscosity to keep the lubricity of diesel. Besides, its combustion product can not contain residues which will block injector orifice hole.

In this study, an amount of titration experiments were done to investigate the cosolvent effect of alcohols and ethers. The results show that the more the nonpolar group of one substance is similar to diesel, the better the ethanol disperses in diesel and the less the dosage of this substance. Because the medium and high alcohols have low cetane number and bad flammability, and because the low ethers have significant effect on stability of E-diesel due to their too easy volatilization although they can promote the combustion, the blend of an isomer of a medium alcohol and a low ether is used to act the role of cosolvent in the new additive compound on the ground of low cost and extensive resource of the product materials. As to this new additive compound, the carbon atoms number of the medium alcohol is same to that of the low ether, so the alcohol molecules will associate with ether to restrain the ether molecules from escaping. Moreover, it can adjust the ratio of alcohol to ether to satisfy the required volatility in different seasons.

There are many types of alkyl nitrates and each one has different effect on improving cetane number. In this study, isooctyl nitrate is determined as the cetane improver according to engine bench tests.

The additive also contains the component of high polymer because of its emulsification to avoid the phase separation when water is mixed into. For another reason, the high polymer has high molecular weight and high viscosity, so it can form a viscous film around the separate phases to improve the lubricity of E-diesel.

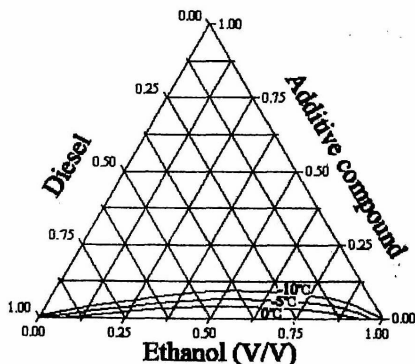


Figure 3: Ternary phase diagram of diesel, ethanol and additive

To sum up the above, the new additive compound consists of isobutyl alcohol, low ether, high polymer and isooctyl nitrate, and the corresponding volume fraction ratio is 1:3:1:1. The ternary phase diagram of diesel, ethanol and additive is shown in Fig.3, in

which three isotherms at -10 °C, 0 °C and 5 °C, respectively, are illustrated. As the Fig.3 shows,

- 1) Adding a little of the additive compound can notably improve the cosolvency between diesel and ethanol. For instance, to dissolve 15% ethanol at 0 °C, only need to add 1% additive. Even at -10 °C, not more than 2%.
- 2) With the temperature of fuel increases, the dosage of the additive gradually reduces, and the maximum value always appears at the critical point C, which is in well accord with the conclusion of binary phase diagram.

Like E-gasoline, it is easily to be accepted to blend 10%-15% ethanol with diesel^[9]. Take the E-diesel composed of 13.5% ethanol, 85% diesel and 1.5% this additive compound as an example, there is 0.3% isooctyl nitrate in it, and ether is also a prominent cetane improver, so according to Equa.1, the cetane number of this E-diesel is slightly more than the pure diesel.

3. BENCH TESTS

To verify the cold starting performance and the emissions performance, engine bench tests were implemented using pure diesel (-10th), noted as A0; 8.5% ethanol + 90% diesel + 1.5% additive, noted as A10; 18% ethanol + 80% diesel + 2% additive, noted as A20; 27.5% ethanol + 70% diesel + 2.5% additive, noted as A30, respectively. The schematic diagram of the test bench is shown in Fig.4. A single cylinder, four stroke direct injection 1105 diesel engine is employed. Its compression ratio is 17.1 and nominal horsepower is 12.1KW/2000r min⁻¹. The ambient temperature in laboratory was -5 °C-0 °C.

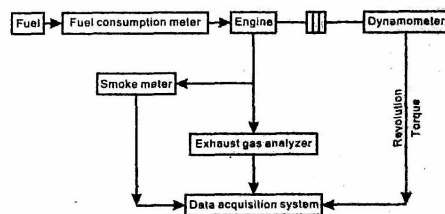


Figure 4: Experiment apparatus

3.1 Cold starting performance

Firstly, adjust the MBT, and then start the engine for 10 seconds at low temperature of -5 °C-0 °C. If the engine can run more than a minute after ignition, it can be thought the cold starting is successful. The experimental results show that when the engine was fuelled with the E-diesel composed of 20% ethanol, 80% diesel and cosolvent, the consecutive three times of cold starting were all failed, while fuelled with A0, A10, and A20 were all successful after only one start. The A10 and A20 started more easily and smoothly than A0. It is evident that the low ether and the isooctyl nitrate can promote the flammability of E-diesel.

3.2 Load characteristics

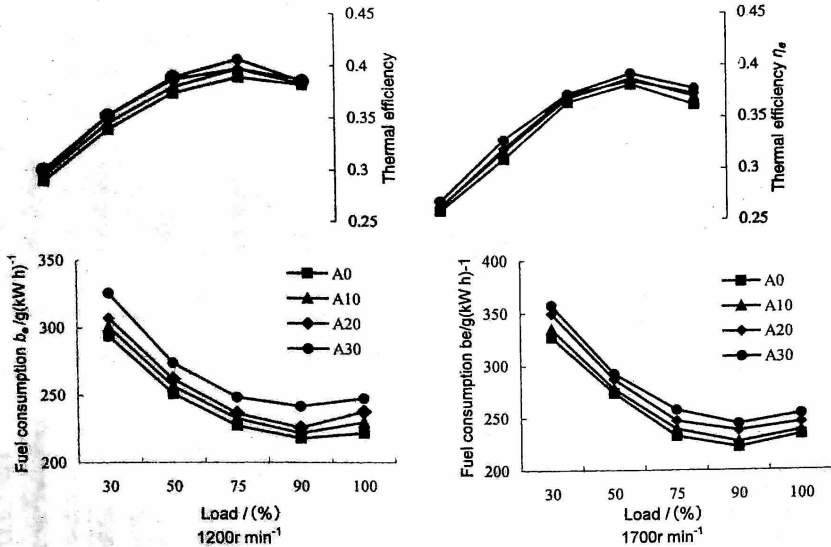


Figure 5: Effect of E-diesel on brake specific fuel consumption and brake thermal efficiency

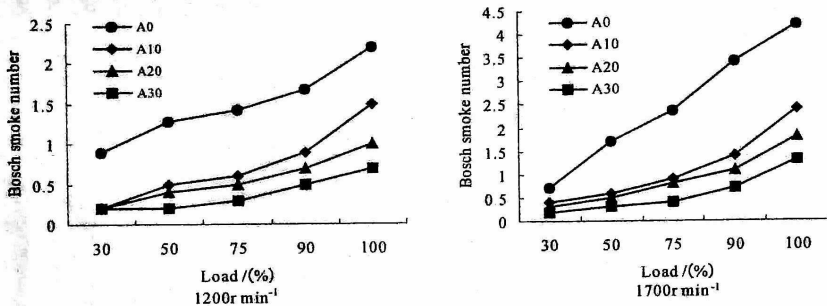


Figure 6: Effect of E-diesel on smoke intensity

Fig.5 shows the load characteristics of A0, A10, A20, and A30 under the operation conditions of 1200r/min and 1700r/min. Because the heat value of ethanol is only equivalent to 63% of that of diesel, the specific fuel consumption of each type of E-diesel is higher than that of diesel in specific weight. The consumption of A10, A20 and A30 are 2.3%, 5.3% and 9.5% higher than that of A0, respectively; the corresponding higher values of brake thermal efficiency are 0.55%, 0.94% and 1.06%, respectively. It is clear that the combustion of ethanol needs less oxygen than that of diesel. This has a positive effect on accelerating the homogeneous blend of fuel and air in diffusion combustion stage, especially under the high load operation conditions.

3.3 Smoke intensity

In this study, the smoke intensities under several operation conditions were tested by using AVL Dismoke 4000 smoke meter. Fig.6 shows the effects of different E-diesels on smoke intensities. It can be seen from Fig.6 that under high load conditions, even as to A10, the smoke intensity is only equivalent to half that of A0; for low load conditions, the ratio is less. With increase of ethanol blend ratio, comparing to A10, the smoke intensities of A20 and A30 become less and less. This can be interpreted by the following, the viscosity of E-diesel is less than that of pure diesel and thus the former atomizes better; the high latent heat of vaporization of ethanol will depress the flame temperature at preliminary combustion stage^[6]; the oxygen contained in ethanol will accelerate the combustion at later stage.

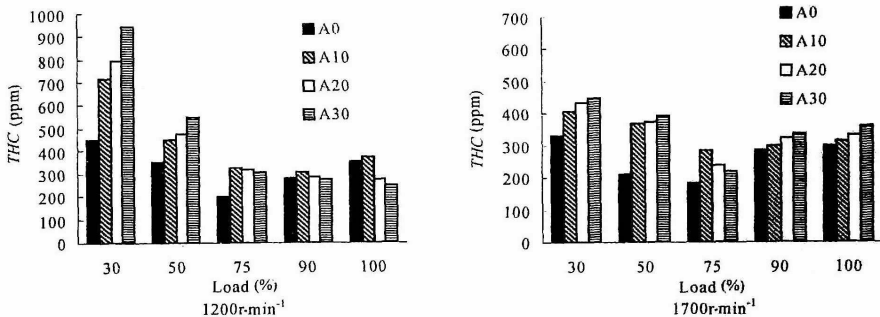


Figure 7: Effect of E-diesel on THC emission

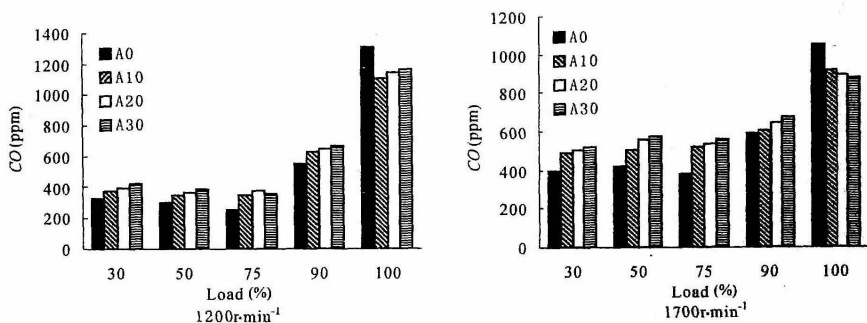


Figure 8: Effect of E-diesel on CO emission

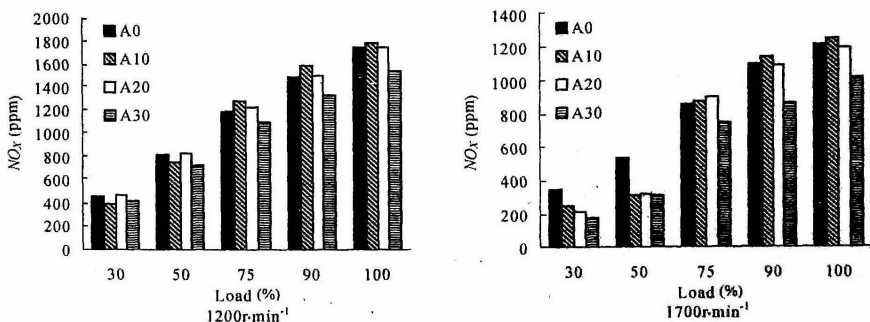


Figure 9: Effect of E-diesel on NO_x emission

3.4 THC, CO and NO_x

Fig.7, Fig.8 and Fig.9 are the emission concentrations of THC, CO and NO_x, respectively, under two operation conditions. The THC emission reduces when the load increases, for both the two revolution conditions, under the same ethanol blend ratios. This is because the THC emission mainly originates from the over thin mixture zone at the outside of the fuel spray, and the addition of ethanol makes the flame temperature drop and the over thin

zone expand. Moreover, the cylinder wall chill zone caused by cooling effect due to the evaporation of ethanol is also a reason why THC emission increases under low load conditions^[9]. However, with the load and the flame temperature rising, the THC emission gradually reduces. For CO emission, it varies a little under partial load conditions but increases rapidly when the load rate is more than 90%. This is considered to have relation with excess air ratio. For NO_x emission, it increases with the increase of load;

this is different from that of the THC and CO emissions. As well known, NO_x is formed under the condition of high temperature, oxygen enrichment and long duration of high temperature, so the rise of flame temperature due to the increase of load and the longer combustion lagging period of ethanol than diesel^[10] makes the ratio of premixing fuel to combusting fuel rise; this furthermore leads to more CO emission.

If the loads under the two revolution conditions are the same, both the THC and CO emissions increase with the rise of ethanol blend ratio. This can be interpreted by that the rise of ethanol blend ratio has reduced the heat released in an operation cycle, prolonged the combustion lagging period and depressed the burning rate, so as to make the flame temperature fall.

Under the partial load conditions, on one hand, the lower flame temperature can reduce the NO_x emission; but on the other hand, the longer combustion lagging period and the oxygen contained in ethanol will promote the NO_x emission, as a result, the synthesis of the two aspects does not have much effect on the NO_x emission. For high load conditions, the higher revolution produces less NO_x emission. It is obviously that the NO_x emission has been suppressed by lower flame temperature for the high latent heat of vaporization of ethanol.

4 CONCLUSIONS

- 1) An additive compound consists of alkyl ethanol, ether, macromolecule polymer and alkyl nitrate is proposed. The ternary phase diagram shows that adding 1%-2% of this additive can evidently improve the solubility of ethanol in diesel. The cold starting experiment also proves the flammability of E-diesel containing additive is equivalent to that of pure diesel.
- 2) With the increase of ethanol blend ratio, the specific fuel consumption of E-diesel in weight is more and more than that of pure diesel. If the ethanol blend ratio is less than 15%, there is not more specific fuel consumption than 5%, but the brake thermal efficiency of E-diesel is slightly more than that of pure diesel.
- 3) With the increase of ethanol blend ratio, the smoke intensity of E-diesel gradually decreases. Even at medium or high loads, it decreases more than 50% than diesel.

- 4) Under the same ethanol blend ratio, with the increase of load, THC emission decreases; CO emission increases rapidly at high loads; NO_x emission increases. On the other hand, under the same load, with the increase of ethanol blend ratio, the THC and CO emissions increase; NO_x emission decreases evidently at high loads.

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