Study on Emission of Dimethyl Ether Engine by Avl-fire

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Abstract: The combustion characteristics of WD615 diesel engine fuelled with dimethyl ether content of 0%, 5%, 15% and 25% were numerically simulated and analysed by AVL-FIRE software. The simulation results show that with the increase of DME content, the emission of NOx and HC in the engine exhaust is declining, while the CO is increasing. The simulation results show that when the crankshaft turning angle for 500 °C A and 25% dimethyl ether added, NOx decreases by 93.7%, HC decreases by 25.3%. While the CO increases a little, but it is still within the scope of the national standard. The simulation also shows that the NOx emission decreased by 49.2% when the EGR rate increased from 0 to 27.5% under n=2200r/min and Pme=0.3MPa conditions. CO increased by 70.7%; HC emissions increased by 159.7%. However, when the n=2200r/min and Pme =0.6 MPa conditions, NOx emissions decreased more obvious, CO and HC increased more obvious, but also within the scope of the national standard. Therefore, it is helpful to choose a reasonable proportion of EGR in the actual engine control.

Key words: dimethyl ether; diesel engine; blended; EGR rate; emission characteristics.

1. Introduction

Until the end of 2017, the automobile industry still serves as the develop engine and pillar of China's industry and economic. But in China, with the increase amount of car ownership and international political and economic forms of crude oil supply, for the stability of the crude oil import in China and the double pressure of environmental protection contradiction is especially prominent. Therefore, the search for an alternative fuel is more political and economic.

At present, domestic and foreign research institutions and scholars have carried out research on the special physical and chemical properties of dimethyl ether [1], which proves the characteristics of high efficiency and low pollution combustion of the engine. Wang wenlong of Qingdao university in shandong province found that the combustion speed of mixed fuel increased with the addition of dimethyl ether. Jun-hua wu, Shanghai jiaotong university, research in supercharged diesel engine EGR influence on engine combustion and emissions, EGR have a great influence on NOx emission. But with the increase of EGR rate, the amplitude of engine NOx emissions, high load falling even faster [2]. Austria AVL company in diesel engine was carried on the gasification of dimethyl ether experiment found that the dimethyl ether to realize ultra-low emissions and soft burning, smoke carbon emissions
is almost zero [3], low combustion noise characteristics. Table 1 shows the main physicochemical properties and chemical properties of dimethyl ether and diesel.

This article uses FIRE software to research the dimethyl ether in a diesel blending ratio of different emission characteristics and control EGR rate to implement of dimethyl ether engine exhaust gas.

Table 1. Comparison of main physical and chemical properties of methyl ether and diesel engine

| characteristic                  | DME    | diesel |
|---------------------------------|--------|--------|
| chemical formula                | CH$_3$-O-CH$_3$ | CxHy   |
| boiling point                   | -24.9  | 180-360|
| molecular weight                | 46.07  | 190-220|
| liquid density/g/cm$^3$         | 0.668  | 0.84   |
| saturated vapor pressure/MPa   | 0.51   | ----   |
| Low heating value (MJ/kg)       | 28.4   | 42.5   |
| cetane number                   | 55-66  | 40-55  |
| oxygen(\% weight)              | 34.8   | 0      |
| A/F                             | 9.0    | 14.6   |

2. Build the simulation model of wd615 diesel engine

2.1. Establishment of Combustion Chamber Simulation Model

Combustion chamber geometry precision of the engine number of finite element numerical simulation is more important, but in the combustion chamber geometry model process is influenced by various factors [5], and if all according to the shape of combustion chamber will have larger geometric error modeling and influence the finite element computation efficiency. Therefore, in order to reduce the influence in the modeling process, we usually ignore the gap between the cylinder wall and the piston to improve the calculation accuracy. Table 2 shows the parameters of the eccentric combustion chamber of WD615 diesel engine used in this paper [6]. The 3D model of the engine can be divided by the HyperMesh after the PROE is drawn. As shown in FIG. 1-1, the finite element grid diagram of the engine at a certain crankshaft Angle.

![Fig.1 Finite element mesh diagram of a certain axle corner](image)

Table 2. The specifications of WD615 diesel engine

| model                          | WD615                           |
|--------------------------------|---------------------------------|
| form                           | four-stroke, Six cylinder, supercharge, intercooling |
| Cylinder diameter              | 110mm                           |
| piston stroke                  | 130mm                           |
| Vst                            | 7.98                            |
| compression ratio              | 18:1                            |
| Maximum torque/speed           | 980N.m/1450r/min                |
| Maximum power/speed            | 178KW/2000r/min                 |
2.2. Parameter Setting

2.2.1. Calculate the Time Step. Studying the characteristics of dimethyl ether engine emissions can be through the establishment of the corresponding model, so we focus on researching two stroke which are work and discharge, the corresponding crank Angle is 348 ° CA To 708 ° CA [4]. The engine oil supply Angle is 348 ° CA, internal combustion engine soon after oil supply, so we will be 348 ° CA - 378 ° CA calculation step length is set to 0.05, 378 ° CA - 708 ° CA is set to 0.1 [7].

2.2.2. Boundary Conditions. The effective area calculated by this model is the combustion chamber of the engine, while the combustion chamber is a closed system which is consisting of three boundary surfaces consisting of the cylinder head surface, the piston top surface and the cylinder wall surface. In this system of temperature boundary can be identified at the top of the cylinder head bottom and cylinder wall and piston temperature boundary are the three surfaces as the constant value, thus we can refer to the constant value experience in the following formula [8]:

\[ T_{w1} = 120 + 30p_e + 273 \]  
\[ T_{w2} = 100 + 7p_e + 273 \]  
\[ T_{w3} = 100 + 4p_e + 273 \]

In the formula, \( p_e \) represents average effective pressure (bar). According to the above empirical formula, the final cylinder temperature of the wall surface is 470K, the top of piston and cylinder head temperature is 570K. The boundary data obtained from the calculation is entered into the boundary conditions of FIRE2013[9].

2.2.3. Initial Condition Setting. The setting of boundary conditions and initial conditions has great influence on the final simulation result for the high-speed combustion hybrid fuel engine. Assumption in the initial phase calculation, the initial temperature and pressure of the gas in the cylinder is uniform, pressure value by the experiment of the related equipment to measure, the initial temperature can be calculated according to the empirical formula:

\[ T = 316 + 0.86(T_0 - 273) \]  

In the formula, \( T_0 \) represents the temperature of the inlet. The turbulence kinetic energy TKE at the initial time can be calculated according to the following formula [10]:

\[ TKE = \frac{3}{2} \times u'^2 \]  
\[ u' = 0.7 \times C_m \]  
\[ C_m = 2 \times h \times \left( \frac{n}{60} \right) \]

Where, \( u' \) is the velocity of turbulence pulsation, and the unit is m/s; The average velocity of the piston is m/s. H is the stroke of the piston, the unit is m; N is the engine speed, the unit is r/min. According to equation 5, the size of TLS (turbulent length) can be calculated [11]:

3
\[ TLS = \frac{h_v}{2} \]  

(8)

Where, the \( h_v \) unit is m, which represents the maximum valve lift.

The calculation equation of the fuel injection amount of the engine is:

\[ V_o = \frac{h_v P_i \tau}{120 n \rho_i} \times 10^3 \]  

(9)

Among them, \( P_e \) is the power of the calibration power point, and the density of the dimethyl ether is the density of \( l \), and \( I \) is the number of cylinders of diesel engine, the number of strokes of the diesel engine, and the fuel consumption rate of the calibration power point [12].

2.3. Calculation Model Selection

| name[13]                                      | Choose the model name in FIRE             |
|-----------------------------------------------|------------------------------------------|
| Engine combustion chamber model               | turbulence model k-\( \xi \)-f model      |
| Fuel spray model                              | WAVE discrete model                      |
| Evaporation model of mixed fuel               | Multi-component model                     |
| combustion model                              | ECFM-3Z flame model                       |
| NOx generation model                          | Zeldov-ich model                          |
| Carbon smoke formation and oxidation model    | Lund Flamelet Model                       |

3. Simulation of emission characteristics and analysis

Liang Chen, of Beijing University of Technology, found that when the quality score of dimethyl ether was more than 25% [14], the dynamic performance of the engine decreases greatly at high speed and heavy load, resulting in a serious increase in NOx emissions. Therefore, the proportion of diesel mixed with dimethyl ether can’t be more than 25% [15]. In order to further demonstrate the advantages of the combustion of dimethyl ether engine, this section selects four kinds of mixed fuels with a mixture ratio of 0%, 5%, 15% and 25% to study and analyze the emission characteristics.

3.1. The Effect of Dimethyl Ether on Diesel Engine Emissions.

By AVL FIRE software simulation output graphics can see clearly in the mixing dimethyl ether in diesel combustion emissions in the instantaneous change rule. In this paper, we selected the engine speed \( n = 1400 \) r/min, BMEP = 0.5 MPa, NOx, and found HC and CO in the engine exhaust gas with dimethyl ether in diesel blending proportion change of emission characteristics [16].

3.1.1. Effect of Dimethyl Ether in Diesel on NOx Emission

![Fig. 2 Effect of different content of dimethyl ether on NOx](image-url)
Figure 2 the effect of dimethyl ether on The NOx emission of diesel engines in different proportions. As can be seen from figure 2, the NOx emission of the engine decreases successively with the increase of the content of dimethyl ether in fuel. In the pure diesel engine, 5% of dimethyl ether was added, while the NOx content decreased obviously, while the content of NOx in the exhaust gas was greatly reduced after the addition of 25% of the mixed dimethyl ether-diesel. This is because the NOx produced is the result of the high temperature under the condition of combustion, and with the increasing content of dimethyl ether and dimethyl ether spray effect is better than diesel, low temperature than in cylinder diesel engine combustion chamber, the dimethyl ether to higher value of the latent heat of vaporization, these factors will make mixing dimethyl ether engine combustion chamber temperature to relatively lower compared with pure diesel engine, thus NOx emissions down.

Fig. 3 Effect of different content of dimethyl ether on HC

3.1.2. The Effect of Dimethyl Ether in Diesel on HC Emission. Figure 3 is the effect of dimethyl ether content on HC emission of diesel engine. As can be seen from figure 3, with the increasing proportion of dimethyl ether in fuel, the HC emission of the engine decreased successively. Diesel engine mixed with dimethyl ether production is the main reason for the HC because too much carbon or lubricating oil film, as a result, adsorption and release of dimethyl ether and containing dimethyl ether engine atomization is better than pure diesel engine, can better distribution in the combustion chamber, coupled with dimethyl ether low boiling point than diesel, so in the combustion process of unexploded corresponding to reduce HC.

Fig. 4 Effect of different content of dimethyl ether on CO

3.1.3. The Effect of Dimethyl in Diesel Ether on CO Emission.
FIG. 4 shows the influence of dimethyl ether content on diesel engine CO emission. As can be seen from figure 4, the content of dimethyl ether increases in fuel, the CO emission of the engine increased successively. This is mainly because CO is produced by incomplete combustion or incomplete oxidation of carbon. And dimethyl ether engine or mixed fuel of dimethyl ether engine under the same conditions than pure diesel engine combustion chamber combustion temperature is low. Therefore, the probability of CO oxidation to CO$_2$ is also reduced, that is, the basic reason for the higher CO content with the higher content of dimethyl ether mixed.

3.2. The Effect of EGR on The Emission of Dimethyl Ether Engine.

Liao shuirong of Chongqing jiaotong University and professor wu junhua of Nanjing Forestry University carried out the combustion test study of EGR on dimethyl ether engine. It was pointed out that the engine has a best EGR rate at all operating conditions, and with the increasing of EGR rate, the corresponding ignition advance Angle of the engine is also advanced [17]. In this section, the effect of EGR on NO$_x$, CO and HC emissions of pure dimethyl ether engine was studied by using AVL-FIRE software advanced simulation function. Because dimethyl ether has a higher oxygen content and no c-c bond, the combustion of dimethyl ether engine will not produce carbon smoke. This section does not describe the effect of EGR rate on carbon smoke. Due to the significant change in the emission of all operating conditions of the engine, two typical working conditions were selected for the study: when the engine speed was 2200r/min, P$_{me}$=0.3Mpa and P$_{me}$=0.61Mpa.

3.2.1. Effect of EGR rate on NO$_x$ emission

![Fig. 5 The effect of EGR on NO$_x$ emission from DME engine](image)

FIG. 5 shows the effect of P$_{me}$=0.3Mpa and P$_{me}$=0.61Mpa on NO$_x$ emission of dimethyl ether engine when the engine is converted to 2200r/min. It can be seen from figure 5 that, with the increase of EGR, NO$_x$ emission in the exhaust emissions under both conditions has significantly decreased. Under the condition of n=2200r/min and P$_{me}$=0.3Mpa, the EGR increased from 0 to 27.5%, and NO$_x$ emission decreased from $124 \times 10^{-6}$ to $63 \times 10^{-6}$, and decreased by 49.2%. When n=2200r/min and P$_{me}$=0.6Mpa, NO$_x$ emission decreased from $228 \times 10^{-6}$ to $87 \times 10^{-6}$, and decreased by 61.8%. It is indicated that with the increase of EGR in high load, NO$_x$ emission of engine decreases rapidly. Because the three elements of NO$_x$ generation are high temperature, oxygen enrichment and retention time at high temperature, under high load with the increase of EGR rate, when the amount of waste gas entering the cylinder increases, lead to the enter fresh air to reduce, thereby inhibiting the combustion reaction, reduced the maximum temperature in the combustion chamber, finally the NO$_x$ emission reduced [18]. Therefore, the increase ratio of EGR can significantly affect the decrease of NO$_x$ emission in dimethyl ether engine.
3.2.2. **Effect of EGR rate on CO emission.** Figure 6 shows the engine speed was 2200 r/min, Pme = 0.3 Mpa and Pme = 0.61 Mpa of EGR rate on the influence of dimethyl ether engine CO emissions. Figure 6 illustrates the, although CO emissions increased with the increase of EGR rate on the rise, but no more than 20% when the rise in the EGR rate is not obvious [19]. When the engine speed is n = 2200 r/min, Pme = 0.3 Mpa, the EGR rate increased from 0 to 20%, CO emissions up from 140 × 10^{-6} to 239 × 10^{-6}, increased by 70.7%. When the engine speed is n = 2200 r/min, Pme = 0.61 Mpa, the EGR rate increased from 0 to 20%, CO emissions, up from 140 × 10^{-6} to 589 ×10^{-6}, increased by 320.7%. when the EGR rate continue increases to 35%, the engine emission of CO increased dramatically. As is known to all, the mechanism of CO is due to carbon burning oxygen is not sufficient, and at the time of the EGR rate increased, increasing the amount of waste gas into the engine combustion chamber, the fresh oxygen is declining, especially the engine combustion chamber during high load coefficient of excess air in the cylinder is relatively low, the waste gas of combustion is larger, the influence of EGR rate under high load control can significantly inhibit CO emissions increased dramatically[2].

![Image: Effect of EGR on CO emission of DME engine](image)

**Fig. 6** Effect of EGR on CO emission of DME engine

3.2.3. **The Effect of EGR Rate on HC Emission.** Figure 7 shows the effect of EGR rate on HC emission of dimethyl ether engine when the engine speed was 2200 r/min, Pme=0.3mpa and Pme= 0.61mpa. It can be seen from figure 7 that HC emissions tend to increase with the increase of EGR rate, and the higher the load, the more obvious the increase. When the engine speed was n=2200r/min and Pme=0.3mpa, when the EGR rate rises from 0 to 30%, HC emission increases from 62 x10^{-6} to 161× 10^{-6}, which increases by 159.7%. When the engine speed was n=2200r/min and Pme=0.61Mpa, when the EGR rate rises from 0 to 30%, HC emission increases from 40×10^{-6} to 62×10^{-6}, increasing by 305%. According to the formation mechanism of HC, with the gradual increase of EGR rate, the oxygen content in the combustion chamber decreases, which led to the worse combustion condition in the cylinder, thus led to the increase of HC emission in engine exhaust. At higher load conditions, the influence of exhaust gas on combustion is greater because the excess air coefficient in engine cylinder is relatively low. Therefore, similar to CO, it was not recommended to use large EGR rate.
Fig. 7 The effect of EGR on HC emission of dimethyl ether engine

4. Conclusion

1) Using AVL- FIRE software of dimethyl ether and diesel fuel mix was simulated analysis, explored the dimethyl ether content on the emission characteristics of mixed fuel, in turn the crankshaft Angle of 50 °C when adding 25% dimethyl ether, the NOx is reduced by 93.7%, HC fell by 25.3%, and CO have risen, but still within the scope of the national standard.

2) In the dimethyl ether engine, this paper analyzed the EGR rate influence on engine emissions of NOx. The higher the EGR rate, the greater the reduction of NOx and the more obvious decrease in the high load. Under the condition of n=2200/r/min and Pme= 0.3mpa, the rate of EGR increased from 0 to 27.5%, and NOx emission decreased by 49.2%. When n=2200/r/min and Pme= 0.6mpa, NOx emission reduction is more obvious.

3) In dimethyl ether engines, the EGR rate also had a significant impact on the emission of CO and HC, but in contrast to the NOx effect. With the increase of EGR rate, the content of CO and HC also increased, and in high load and high EGR rate, it increased dramatically. When engine speed n=2200/r/min, Pme= 0.3mpa and EGR rate increased from 0 to 20%, CO increased by 70.7%. CO emission was more obvious when engine speed n=2200/r/min, Pme= 0.61mpa and EGR rate increased from 0 to 20%. HC emissions increased by 159.7% when engine speed n=2200/r/min, Pme= 0.3mpa and EGR rate increased from 0 to 30%. HC emission was more significant when engine speed n=2200/r/min, Pme= 0.61mpa and EGR rate increased from 0 to 30%.

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