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Influence of Initial Conditions on Combustion Performance of Natural Gas Diesel Engine

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***Abstract* – Natural gas fuel power system technology is becoming one of the main countermeasures for the shipping industry to cope with the increasingly stringent emission regulations and achieve sustainable development. At present, natural gas-diesel dual-fuel engine is the most widely used mode in China's inland shipping industry, and the initial conditions have a crucial influence on the combustion in the engine cylinder. This paper is based on different initial conditions to carry out related research. The research results show that the initial pressure and initial temperature of fuel in cylinder had a greater influence on the flow velocity, fuel burning time with the increase of the initial temperature and pressure of the cylinder in advance, NOx, CO and HC emissions change, according to the engine cylinder combustion and emission characteristic comprehensive analysis, the best operation condition is the initial temperature of 360 k, the initial pressure of 0.19 Mpa.**

***Keywords* – Initial condition, Dual Fuel, Combustion, Emission.**

I. INTRODUCTION

Dual fuel engines composed of natural gas (LNG) and diesel have significant advantages in fuel consumption, NOx, SOx, Soot emissions. Gas/diesel dual fuel engine can reduce 20% ~ 30% diesel consumption [1], at the same time reduces NOx emissions by 90%, 20% ~ 25% of CO emissions, less the SOx and Soot emissions and NOx emissions can meet the Tier III request, natural gas as a substitute fuel for its engine combustion with high efficiency, clean environmental protection as well as the price is low wait for an advantage by value [2]. The natural gas diesel dual-fuel engine has little change on the structure of the original diesel engine, and only a set of natural gas supply system is added on the basis of the original engine, which has good interchangeability with the original engine [3]. Abroad did lots of research universities, academy, saran university Antonio and others [4] using visual analysis method on gas/diesel dual fuel engine in low load under different ways of natural gas is introduced into the research. Lim and others [5] through the comparison of the dual fuel engine and the traditional experiment on performance and emissions of diesel engine is different, the study found that the gas replacement rate can reach 89%, PM emissions than conventional diesel engine decreased by 94%, but the CO and HC emissions increase. Sun Lu et al. [6] from Xi 'an Jiaotong University studied the influence of injection advance Angle on the combustion characteristics of dual-fuel engines. In 2015, Zhang et al. [7] from Shandong University experimentally studied the effects of injection pressure and injection time on engine performance at different rotating speeds. They pointed out that when the injection time was advanced, the peak pressure in the cylinder increased, NOx emission increased, fuel consumption decreased, and CO emission increased first and then decreased. Increasing the injection pressure has a negative effect on NOx emission. Huang Lufeng et al. [8] to ACD320DF engine as the research object of the engine NOx emissions caps at the same level, the pilot fuel quantity adjustment test, test shows that under the condition of same NOx emission, pilot fuel quantity is less, the less HC emissions, the overall emission levels improve, the combustion start point lag, the maximum explosion pressure drop, but the combustion duration shortened, engine combustion vibration intensity

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decreased noise is reduced, cylinder pressure curve is more smooth. Li Xucheng et al.[9] simulated the fuel injection mixing and ignition process of a high pressure diesel-ignited liquefied natural gas engine in cylinder, and verified and verified the influence of turbulence model on the simulation results. Huang Chunyan [10] from Tianjin University of Technology studied the influence of natural gas substitution rate on combustion and emissions. The results showed that choosing 30% substitution rate in the medium rotation speed area could obtain moderate combustion speed and heat release concentration in the cylinder, which was beneficial to improving combustion efficiency and power output.

To sum up, the domestic and foreign research scholars on the research of the natural gas/diesel dual fuel engine has focused on the simulation study, a few research through the experimental analysis, in addition, from the point of literature survey, using a simple chemical kinetics mechanism of natural gas/diesel dual fuel, mostly with a single component model to alternative fuels. In this paper, the engine combustion calculation model was built by AVL-FIRE software, and the influence of different initial combustion conditions on the combustion mode and performance in the cylinder was systematically analyzed.

II. MODEL BUILDING

Table 1 shows the basic engine parameters.

Table 1. basic engine parameters.

Serial Number	Name	Specifications
1	Model number	Z6170
2	Stroke	200mm
3	Compression ratio	14.5
4	Fuel injector orifice	5

In this paper, we study the engine of the main parameters as shown in table 1, and the geometry model of the dual fuel engine from the inlet valve close to the exhaust valve opens the combustion in cylinder, regardless of inlet and exhaust gas in the tao disturbance process, is the study of the cylinder from the compression, the expansion of the fuel injection spray combustion, oil and gas mixture, the transient process. The two-dimensional geometric model of the combustion chamber is shown in Fig. 1, in which the straight line in the middle across the combustion chamber is the axis of the injection beam of the injection hole. Considering that the combustion chamber of the original engine is axisymmetric and the number of the injection holes is 5, in order to simplify the calculation, one fifth of the combustion chamber is selected as the simulation calculation area, as shown in Fig. 2.

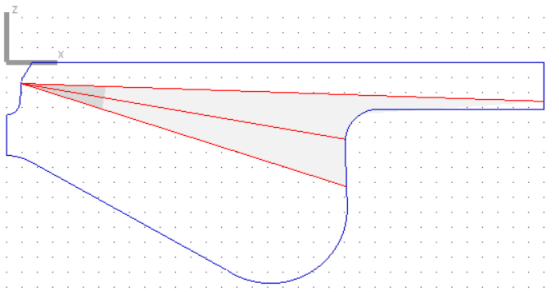

Fig. 1. Two-dimensional plan of the combustion chamber.

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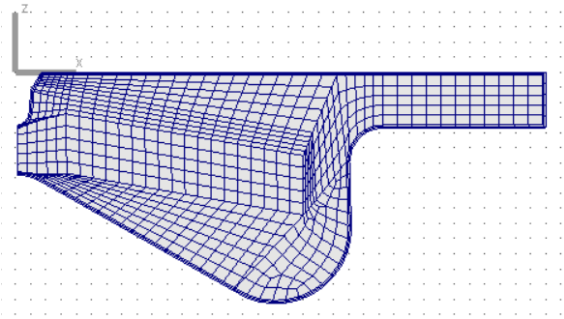

Fig. 2. 1/5 combustion chamber model.

In this paper, the k-ε model is adopted for the turbulent flow model. Enable model is used in the turbulent diffusion model. Wave sub model is used for droplet breakage. Dukowicz model was adopted for evaporation model. Walljet1 model was selected for droplet hitting the wall model. Shell generation model was selected for combustion model. The Zeldovich model is used for NOx and CO emission models. It provides a theoretical basis for the simulation model and the analysis and optimization of engine combustion and emission performance.

A. *Model Verification*

This paper only discusses the process from the inlet valve closing to the exhaust valve opening in the cylinder. The crankshaft rotation Angle corresponding to the top dead center is defined as 720℃A, the inlet valve closing time is 580℃A, and the exhaust valve opening time is 835℃A. In order to facilitate clear comparison, two indicator diagram curves are drawn in the same coordinate diagram, as shown in Fig. 3. It can be seen from the figure that the pressure value of the indicator diagram simulated by the simulation is basically the same as that obtained by the original machine experiment under the same crankshaft rotation Angle, and the maximum pressure has a certain error, but it is within the acceptable range. Therefore, the simulation model established is highly reliable and can be used in simulation research.

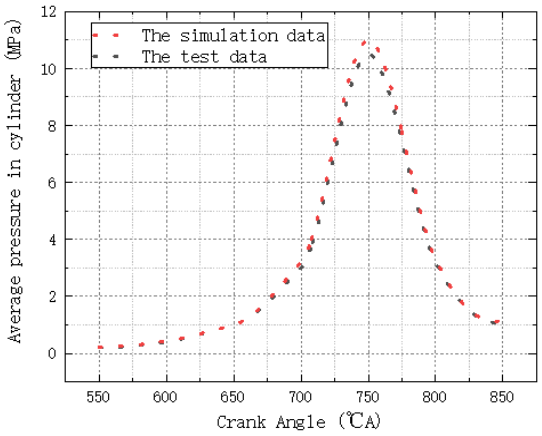

Fig. 3. Comparison between test data and simulation data.

B. *Design of Simulation Test Scheme*

Firstly, the influence rule of the basic parameters of the engine is analyzed under the condition of 75% load. According to the bench test of dual-fuel engine, the best replacement rate is about 70% under medium and high load conditions. Therefore, the influence of initial pressure and initial temperature of dual-fuel engine on the

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combustion process in engine cylinder is studied and analyzed in this paper under the condition of 70% replacement rate under 75% load.

Table 2. Simulation schemes of different initial pressures.

Test Number	Initial pressure
1	0.135MPa
2	0.185 MPa
3	0.235MPa
4	0.275MPa

Table 3. Simulation schemes of different initial temperatures.

Test Number	Initial Pressure
5	335K
6	345K
7	355K
8	365K

III. CALCULATION RESULTS AND ANALYSIS

A. *Influence of Initial Pressure on Combustion and Emission*

At 75% load and gas replacement rate was 70%, under the condition of initial temperature of 345 k is constant, change the size of the initial pressure, the simulation results are shown in figure 4, you can clearly see from the picture, with the increase of inlet pressure, average and maximum explosion pressure in cylinder pressure, cylinder pressure rise within the inflection point in advance, ignition time in advance. Increasing the intake pressure is similar to supercharging, which will lead to the increase of turbulence in the cylinder, which is conducive to the intake and thus promote combustion. But if the intake pressure is too high, it will make the work in the cylinder rough and reduce the work efficiency, so it is necessary to choose the appropriate intake pressure.

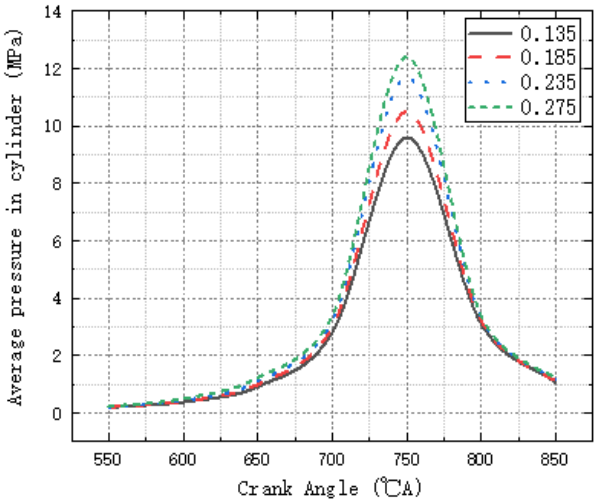

Fig. 4. Influence of initial pressure on the average pressure in the cylinder.

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Fig. 5 shows the curves of the influence of different intake pressures on the emission of dual-fuel engines. It can be seen from the graph that the variation trend of NOx under different intake pressures is consistent. With the increase of intake pressure, the production of NOx decreases, this is because the generation of NOx is related to the temperature, the higher the intake pressure, the lower the temperature in the cylinder, the more conducive to the production of NOx, so the appropriate increase in intake pressure can reduce NOx emissions; The uncombustible HC emission is opposite to NOx emission. With the increase of air inlet pressure, the emission has been on the rise. The CO emission decreases first and then increases with the increase of initial pressure.

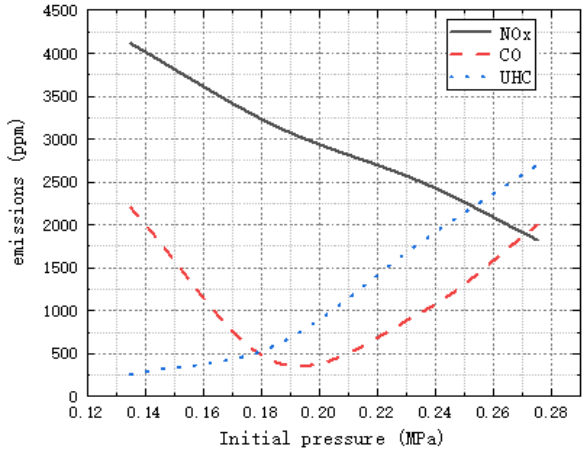

Fig. 5 Impact of initial pressure on emissions

B. *Influence of Initial Temperature on Combustion and Emission*

Fig. 6 is the curve of the average pressure in the cylinder at different initial temperatures. It can be seen from the graph that, with the increase of the intake temperature, the inflection point of pressure rise in the cylinder is advanced, the ignition time is advanced, and both the average pressure and the maximum value increase. This is due to the increased initial temperature, which speeds up the chemical reaction of the fuel in the cylinder, allowing the mixture to burn more quickly and release more heat.

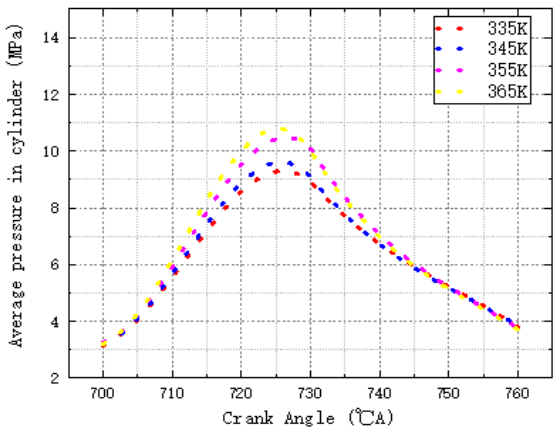

Fig. 6. Influence of initial temperature on average pressure in cylinder.

Fig. 7 shows the NOx, CO and unburned HC emissions of dual-fuel engines at different initial temperatures. When the initial temperature rises, the NOx emissions increase.CO content decreased; Unburned HC emissions

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do not vary with temperature. Since NOx is the product of high temperature reaction while CO and unburned HC are the products of incomplete combustion of fuel, the temperature and pressure in the cylinder increase with the increase of initial temperature, which promotes the generation of NOx. The higher the initial temperature in the cylinder is, the wider the high temperature area is, and the combustion reaction is more likely to occur near the top dead center, leading to a decrease in CO emissions.

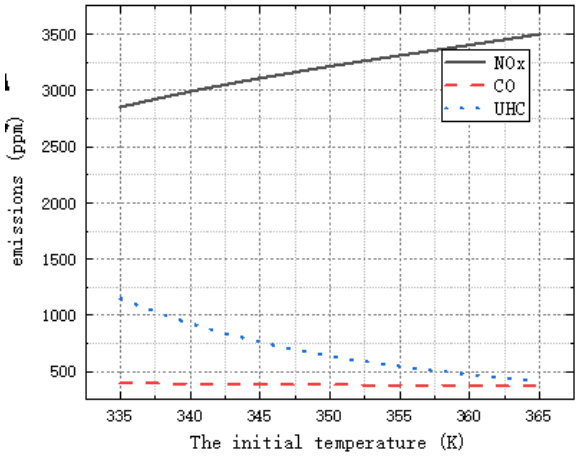

Fig. 7. Impact of initial temperature on emissions.

IV. CONCLUSION

1. With the increase of the initial pressure in the cylinder, the ignition time of the fuel is advanced. The diesel oil bundle injected into the cylinder is small, and the flame is not easy to spread to the cylinder wall area. Increasing the intake pressure can increase the average pressure in the cylinder, reduce the average temperature and reduce CO emissions, and achieve better power performance and emissions.

2. With the increase of the initial temperature, the average pressure and average temperature in the cylinder increase, the CO emission decreases, and the NOx emission increases. Appropriate increase of intake temperature is beneficial to improve power performance and economy.

3. In the process of simulation calculation, many places have been simplified, and the simulation results and the actual test data may have some errors, but the trend is consistent.

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