Effect of Injection Advance Angle on the Performance of Butanol-Diesel Dual-fuel Engines

Chenxi Yang[1], Zheng Cai[1], Yibin Wang[1,2*], Jinyu Fan[1,2], Pinfang Li[1,2], Jialiang Huang[1,2]

[1] Marine Engineering Institute, Jimei University, Xiamen 361021, China.
[2] Key Laboratory of Ship and Marine Engineering, Fujian Province, China.

Abstract: In order to further investigate the performance of the butanol-diesel dual-fuel engine, this paper uses the 4190Z$_L$C-2 marine medium-speed diesel engine as a prototype and establishes a dual-fuel engine high-pressure cycle model using AVL-FIRE simulation software. The injection advance angle was set to 16.6°, 18.6°, 20.6° and 22.6° respectively, and its effect on the performance of the dual-fuel engine was investigated by varying the injection advance angle. The results show that as the injection advance angle increases, the in-cylinder pressure and temperature also increase. When the injection advance angle is 22.6°CA, compared with the original engine, CO emission is reduced by 16.8%, NO emission is increased by 7.4%, carbon smoke emission is reduced by 16.9%, and the indicated power is 52.6kW, which is increased by 1.8%.

1.Introduction

With the rapid development of the shipping industry, the widespread use of diesel engines has brought economic prosperity as well as problems such as air pollution to the fore[1]. The search for renewable resources, the optimisation of diesel engine structures and the exploration of new combustion methods can achieve effective energy saving and emission reduction goals[2]. Butanol, as a new second-generation fuel, has the advantage of good mutual solubility with diesel and does not stratify after a long mixing time, which makes it good economics[3]. Zheng Zunqing et al[4]. from Tianjin University conducted a diesel-butanol fuel blending test on a diesel engine and the results showed that the addition of butanol improved the volatility of the fuel blend and carbon soot emissions were effectively improved. Chen Zheng et al[5].studied the combustion and emission characteristics of diesel engines blended with butanol in combination with both direct and dual injection by means of simulation combined with experiments. The results showed that the moment of ignition was significantly delayed when the fuel mixture was burned, which was mainly due to the higher latent heat of vaporisation of butanol. Therefore, in order to further investigate the performance of the butanol-diesel dual fuel engine, this paper uses AVL-FIRE to build a combustion high-pressure cycle model, setting the injection advance angle to 16.6°, 18.6°, 20.6° and 22.6° respectively. By varying the injection advance angle size, the combustion and emission characteristics of the dual-fuel engine are investigated and analysed.

2.Object of study and development of the simulation model

2.1 Basic diesel engine parameters

The 4190ZLC-2 four-stroke medium-speed diesel engine produced by Jinan Diesel Engine Factory was selected for this study, and its basic structure and operating parameters are shown in Table 1.

Table 1.Basic performance indicators for diesel engines.

No. of cylinders	Total Displacement/L	Compression ratio
4	23.82	14:1
Number of holes	Rotational speed/(r·min)	Calibration torque(N·m)
8	1000	2100
Rated power/kW	Effective pressure(MPa)	Orifice diameter(mm)
220	1.109	0.3

2.2 Calculation sub model selection

This article selects k-ε Model simulation of turbulent flow; Select the KH-RT model with higher accuracy as the droplet fragmentation model; Using the Enable model as the diffusion model; Select Walljet1 as the droplet collision model; Select the recommended Multi component model in the system as the evaporation model. In the selection of emission models, Frolov Kinetic model is selected as the Soot generative model; Zwldovich is used as the generative model of NOx emission mass fraction[6].

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* Corresponding author: 13950008366@163.com

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2.3Establishment and Verification of High Pressure Cycle Simulation Model

In this paper, with reference to the geometry of the 4190ZLC-2 diesel engine, a one-half model of the central section of the combustion chamber is drawn by SolidWorks software, where the red linear direction is the fuel injection direction, as shown in Figure 1.

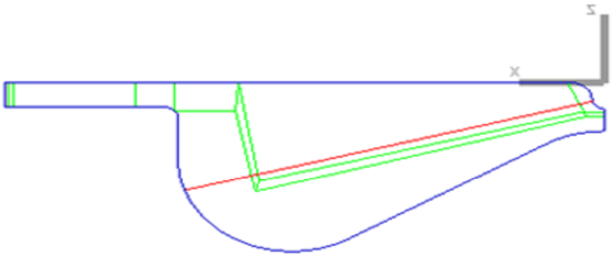

Fig.1. Schematic diagram of the central 1/2 section of the combustion chamber.

This was then imported into the DIESEL module meshing tool in AVL-FIRE and automatically calculated into a three-dimensional mesh of the combustion chamber after division. As the combustion chamber is a centrosymmetric structure, 1/8 space of the combustion chamber is selected as the calculation area in order to simplify the calculation cycle of the model. This is shown in Figure 2.

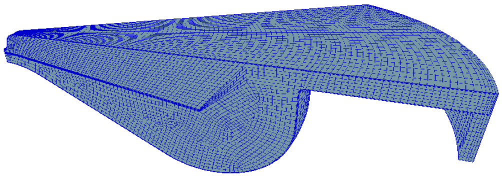

Fig.2. Diesel combustion chamber 1/8 calculation model.

In order to verify the accuracy of the model, the butanol blending ratio was set to 0 at rated working conditions, and the cylinder pressure and exothermic rate curves were compared between the simulated and tested values. As shown in Figure 3, the trends between the two curves are basically the same, and the overall curve matches more than 95%, indicating that the simulation model is more accurate and can be used for the subsequent in-cylinder combustion process simulation test[7].

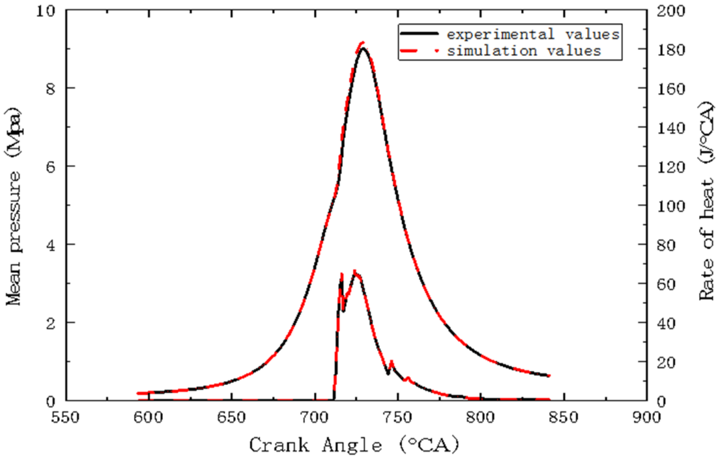

Fig.3. Comparison of cylinder pressure/heat release rate curves.

3.Effect of injection advance angle on diesel engine combustion and dynamic

Figure 4 shows the in-cylinder temperature section field under different injection advance angles. In the longitudinal analysis, under the same crankshaft angle, with the increase of injection advance angle, the area of high temperature gathering area in the cylinder is increasing, the temperature of the nozzle oil beam are higher than the surrounding temperature. This is because with the increase of the injection advance angle, the stall period is extended, the fuel and air in the cylinder mix more fully, optimising the combustion process in the cylinder. From the lateral analysis, with the piston movement, the high temperature area in the cylinder spread, the oil beam from the spray into the cylinder, in the crater out of the rebound and adhesion makes the oil droplet diffusion, and then the combustion.

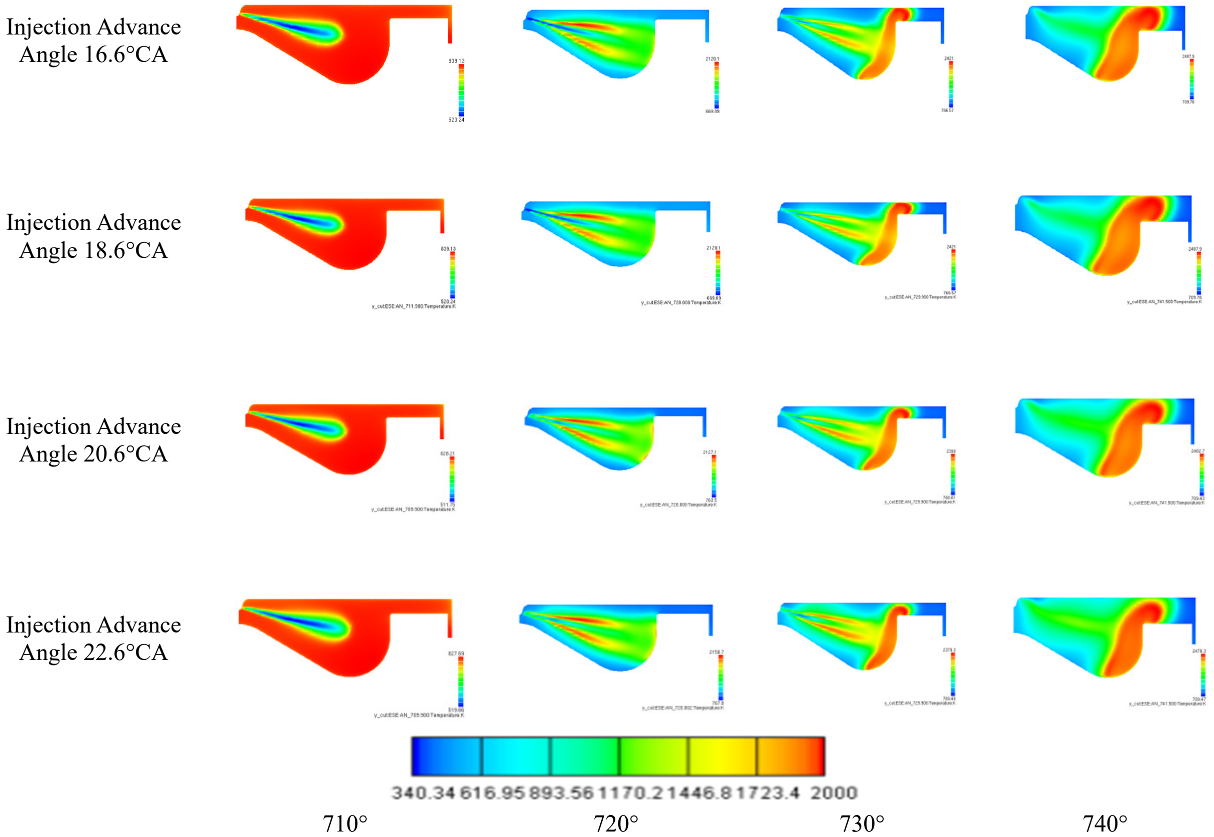

Fig.4. In-cylinder temperature field at different crankshaft angles for different injection advance angles.

Figure 5 shows the in-cylinder pressure curve at different injection advance angles. As can be seen from the graph, with the increasing injection advance angle, the overall in-cylinder pressure curve shifts forward and the maximum burst pressure also increases, the corresponding phase of which is advanced and the stall period is extended. Compared with the original injection advance angle of 18.6 ° CA, the maximum burst pressure in the cylinder is 9.12MPa, corresponding to the crankshaft angle of 8.7 ° CA after the upper stop: when the injection advance angle of 22.6 ° CA, the maximum burst pressure in the cylinder is 9.38MPa, an increase of about 2.9%, corresponding to the crankshaft angle of 7.9 ° CA, the forward shift of 0.8 ° CA. The reason for this phenomenon is : When the injection advance angle is continuously increased, the moment when the mixed fuel is injected into the cylinder is advanced, and it is fully mixed with air, which enhances the pre-flame reaction of the mixed gas. The stall period is extended, the moment of ignition is advanced and a better quality combustible mixture is formed in the cylinder, which allows the fuel to burn fully and exothermally at the upper stop, increasing the maximum burst pressure in the cylinder.

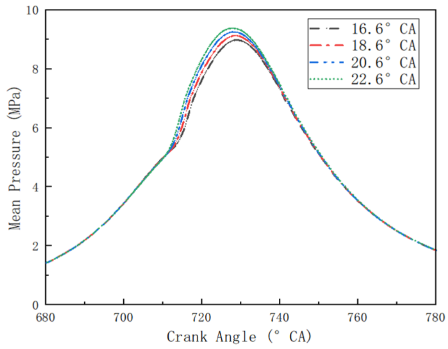

Fig.5. In-cylinder pressure curve at different injection advance angles.

Figure 6 shows the indicated power curve at different injection advance angles. The indicated power is positively correlated with the injection advance angle and increases when the injection advance angle increases. This is because as the injection moment is continuously advanced, the oil and gas mixture is optimised during the stall period, and the mixture releases a lot of heat when it burns at the upper stop, pushing the piston to do work quickly and improving the conversion efficiency, which makes the indicated power increase. Compared to the original machine, when the injection advance angle is 22.6°CA, the indicated power is 52.6kW, an increase of approximately 1.8%.

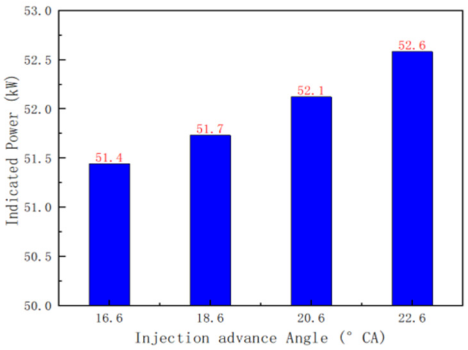

Fig.6. Indicated power curve at different injection advance angles.

4.Effect of injection advance angle on diesel engine emissions

Figure 7 shows the NO emission mass fraction curve of the diesel engine when the exhaust valve is open at different injection advance angles. As can be seen from the graph, the mass fraction of NO generated increases gradually with the increase of injection advance angle. The change in injection timing directly affects the in-cylinder temperature of the dual-fuel engine, and the temperature is the dominant factor in the NO generation conditions. When the injection advance angle increases, the stall period is prolonged and the fuel mixture in the cylinder is fully mixed with air, making the combustion more complete and the in-cylinder temperature increases to promote the production of NO. Compared with the original injection advance angle of 18.6°CA, the NO generation mass fraction is 1.48×10^{-4}, when the injection advance angle is 22.6°CA, the NO generation mass fraction is 1.59×10^{-4}, an increase of about 7.4%.

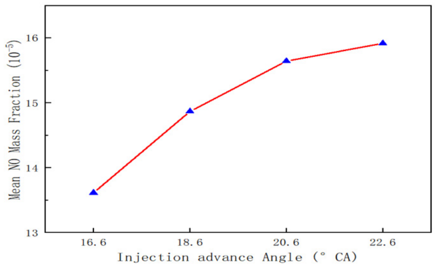

Fig.7.NO mass fraction curves at different injection advance angles.

Soot is generated from hydrocarbon fuel in the diesel engine cylinder through thermal cracking, nucleation, aggregation, surface growth and agglomeration under the reaction, which is generated under high temperature and oxygen deprivation[8]. Figure 8 shows the diesel engine Soot emission mass fraction curve when the exhaust valve is open at different injection advance angles. With the increase of injection advance angle, the diesel engine Soot content decreases continuously, and there is an obvious Trad-off effect with the NO generation curve. This is because when the injection advance angle increases, the stall period is extended, the air in the cylinder mixes more fully with the atomised diesel droplets and reaches the ignition point of the diesel fuel sooner, while the high oxygen content of butanol also nearly inhibits the generation of diesel engine Soot. At an injection advance angle of 16.6°CA, the Soot generation mass fraction was 1.54×10^{-5}; at an injection advance angle of 22.6°CA, the Soot generation mass fraction was 1.16×10^{-5}, a reduction of about 16.9% compared to the original engine.

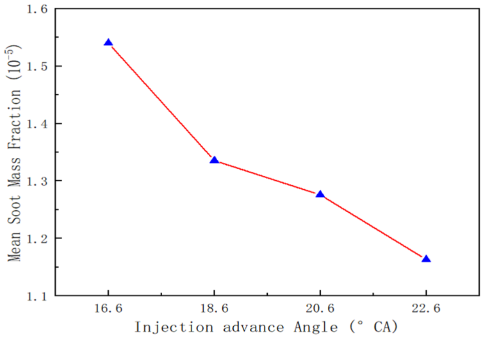

Fig.8. Soot mass fraction curves at different injection advance. angles.

Figure 9 shows the CO emission mass fraction curve for diesel engines with different injection advance angles. As can be seen from the graph, as the injection advance angle gradually increases, the CO emission mass fraction increases at the peak and the corresponding crankshaft angle shifts forward, but the CO final emission mass fraction gradually decreases. This is because when the injection advance angle is increased, the stall period is extended, optimising the combustion process in the cylinder and depleting the oxygen content in the cylinder at the initial stage of combustion, resulting in an anoxic environment that promotes CO production[9]. However, due to the high oxygen content of butanol, the complete combustion of the fuel mixture is increased and the extended stall period also improves the atomisation conditions of the in-cylinder gas mixture, ultimately reducing CO emissions. Compared to the original injection advance angle of 18.6°CA, where the CO generation mass fraction was 3.86×10^{-3}, the CO generation mass fraction was 3.21×10^{-3} when the injection advance angle was 22.6°CA, a reduction of approximately 16.8%.

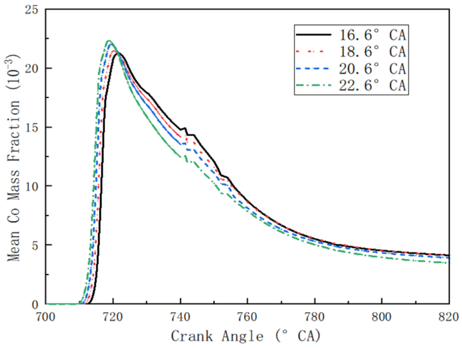

Fig.9.CO mass fraction curves at different injection advance angles.

5.Conclusion

1) By increasing the injection advance angle, the stall period is extended and the fuel and air are more fully

mixed in the cylinder, releasing a large amount of heat from combustion near the upper stop of the piston, raising the cylinder pressure and cylinder temperature, and increasing the power of the diesel engine. When the injection advance angle is 22.6°CA, the maximum in-cylinder burst pressure is 9.38MPa, an increase of about 2.9% compared to the original engine, and the indicated power is 52.6kW, an increase of 1.8%.

2) Under rated operating conditions, increasing the injection advance angle results in lower CO and Soot emissions, but NO emissions show an increasing trend. At an injection advance angle of 22.6°CA, CO emissions are reduced by 16.8%, NO emissions are increased by 7.4% and soot emissions are reduced by 16.9% compared to the original machine.

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