STUDY ON THE DESIGN AND MATCHING OF INJECTION PARAMETERS OF HIGH PRESSURE COMMON RAIL DIESEL ENGINE

Jixin LIU [1], Shuangfeng HAN [1,*], Fengju HU [1], Runqiang LIU [1]

This article aims to explore the matching performance of the injection parameters of the high-pressure common rail diesel engine. A three-dimensional CFD simulation model of the working process in the diesel engine cylinder is established using AVL_ FIRE software. The influence of structural parameters, including the number of injection holes, the diameter of injection holes, the injection pressure, the angle of injection cone and the extending height of nozzle on the matching of oil-gas-chamber in cylinder are analyzed. By comparing the two initial vortex ratio schemes of 0.4 and 0.85, the spray atomization effect of the 6-hole injector is the best when the initial vortex ratio is 0.4, and the spray atomization effect of the 5-hole injector is the best when the initial vortex ratio is 0.85.The results show that the selection of the number and the diameter of the injection holes has an important influence on the mixture quality of the oil-gas in the cylinder and the spatial distribution of the mixed gas. The increase in the number of injection holes and the decrease in the diameter of the injection holes are beneficial to the fuel vaporization and atomization before combustion. It is a positive correlation between the injection pressure, the angle of injection cone and the air utilization. There is a positive correlation between the injection pressure and the air utilization, and a positive correlation trend is evident from the initial stage. The instantaneous heat release rate of the crankshaft increases with the increase of the crank angle, and the maximum instantaneous heat release rate shows a positive correlation with the injection pressure. The increase of fuel injection pressure is helpful for fuel atomization and the after combustion period. The higher injection pressure is conducive to the enhancement of air utilization ratio. There is a positive correlation between the cone angle and the air utilization rate. However, when the cone angle of fuel injection increases to a certain value, the change of air utilization rate is not obvious and basically stabilizes. There is a significant negative correlation between the protruding height and air utilization.

Keywords: Common rail; Fuel injection; Diesel engine; Injection pressure; Matching study

1. Introduction

With the development of science and technology, high pressure common rail fuel injection system has been produced. At the same time, because of the

[1] Institute of Intelligence & Manufacture, Qingdao Huanghai University, China
* Corresponding author: Shuangfeng Han; email: 869313750@qq.com

advantages of accurate injection pressure, injection quantity and injection rate and it is convenient, it has been successfully applied to large power machinery, and as the main fuel supply system [1,2]. With the application of diesel high-pressure common rail fuel injection system has become increasingly widespread, it has been favored by many experts and scholars at home and abroad, and is considered to be the third leap in the development of diesel engine technology [3]. In foreign countries, Masahiko and others carried out the relevant research on the electronic control system of high pressure fuel injection system [4], K. Gebert and others carried out conceptual design of high-pressure common rail fuel system [5]. In China, Xin Zhe and others carried out the relevant experimental research on fuzzy control of rail pressure in high pressure common rail system of diesel engine [6], Yuan Fangen and others studied the effect of high pressure common rail injection system parameters on diesel engine performance [7]. Wang Yawei and others carried out a series of development of typical CB18 type light diesel common rail system [8]. Deng Jingwei and others calibrated and tested the electronic control system of high pressure common rail diesel engine [9]. Mao Xiaojian and others developed the hardware of high pressure common rail system for GD-1 diesel engine [10]. Ding Shiyong and others designed the common rail tube in the high pressure common rail system of BF6M1015C diesel engine [11]. Feng Xiulan and others studied the automatic assembly technology of diesel high pressure common rail system [12]. Although the number of domestic and foreign experts and scholars studying on the high-pressure common rail fuel injection system increasing year by year, most of them aimed at electronic control system, related hardware and automatic assembly technology of the fuel system. Research on parameters matching performance of high pressure common rail injection in diesel engine is still relatively weak [13]. Therefore, this paper takes the common rail fuel system of a certain diesel engine as the research object. In this paper, based on the relevant results of AMESim simulation, 3D CFD (Computational Fluid Dynamics) simulation model of the working process in the cylinder of diesel engine using AVL_FIRE software. The influence of structural parameters of injection system on oil gas chamber matching in cylinder is simulated. This will provides guidance for optimizing matching of high pressure common rail fuel system in diesel engine in the future.

2. The Establishment of CFD Simulation Model

2.1 Structural parameters of diesel engine

To establish the three-dimensional CFD simulation model of a diesel engine cylinder working process, we need to choose the basic parameters of the diesel engine. The engine parameters of the diesel engine selected in this paper are shown in Table 1:

Table 1

Structural parameters of diesel engine

Parameter / Unit	Numerical Value
cylinder diameter/*mm*	165
stroke/*mm*	185
compression ratio/-	12.3
clearance height/*mm*	2.2
Linkage ratio/-	3.69
intake valve opening angle/ °CA	112 before TDC
intake valve closing angle/ °CA	248
exhaust valve opening angle/ °CA	462
exhaust valve closing angle/ °CA	95 after TDC

2.2 The steady flow blowing model

The purpose of this paper is to use AVL_FIRE to simulate the working process accurately, so it is very important to calculate the initial condition in cylinder. The initial conditions of the cylinder will have a certain impact on the ignition delay, premixed combustion and diffusion combustion index in the combustion process of direct injection diesel engine, and the intake swirl has a direct impact on the cylinder flow in diesel engines [14]. Therefore, it is necessary to set the swirl ratio of the cylinder in the initial compression time more accurately.

According to the engine intake swirl setting experience, for a diesel engine using a helical airway, the definition of the initial vortex in the cylinder at the initial time of compression has certain relation with the calculation method: When using the airway steady state calculation method, the cylinder swirl at the initial time of compression is equal to *the swirl ratio of the maximum lift time of the intake valve* × *current engine speed* × *0.7*. This paper uses the AVL_FIRE software to build a steady flow blowing model, to complete numerical simulation of air flow in air duct and simulated cylinder liner and get the swirl rate. Its empirical formula is shown in formula (1).

$$\begin{cases} S_R = \dfrac{n_D}{n_E} \\ n_E = \dfrac{c_m \cdot 30}{S} \\ c_m = \bar{u}_{ax} = \dfrac{\dot{m}}{\rho \cdot A} \end{cases} \tag{1}$$

In the formula, n_D is the wind speed meter speed (*r/min*), n_E is the engine analog speed (*r/min*); c_m is the average velocity of piston motion (*m/s*); $\bar{u}_{ax}$ is the average velocity of gas axis (*m/s*); $\dot{m}$ is the air mass flow (*kg/s*); *A* is cylinder cross-sectional area (m^2); *D* is cylinder diameter(*m*); *S* is distance of run(*m*). The boundary condition of inlet and outlet is set by pressure boundary condition. The inlet pressure is set to total pressure, and the outlet pressure is set to static pressure. According to the boundary conditions provided by the original machine, the intake pressure is 3.15bar and the exhaust pressure is 2.5bar. The boundary conditions provided by the original machine are taken as initial values, to input the steady flow blowing model based on AVL_FIRE software. The steady-state vortex ratio at the maximum lift time of valve is calculated by several iterations, which is 1.22. According to the above empirical calculation method, the calculated cylinder swirl ratio corresponding to the initial compression time is 0.85.

2.3 Cylinder working process simulation model

According to the geometry parameters of combustion chamber, the basic combustion chamber geometry model is shown in Figure 1. The piston upper stop point is 0 time during intake. The calculation process °CA of the model is 112 of intake valve closing time to the exhaust valve opening time of 462 °CA . The parameters set in the model are shown in table 2. In order to reduce the computation scale, a single oil beam is used as the calculation object, 5 hole injector calculation model is taken as an example: The maximum grid number of the 1/5 model is 68380, and the corresponding total number of grids is 341900.The number of grids at TDC after reconstructing is 18980, and the corresponding total number of grids is, which meets the precision requirement of simulation.

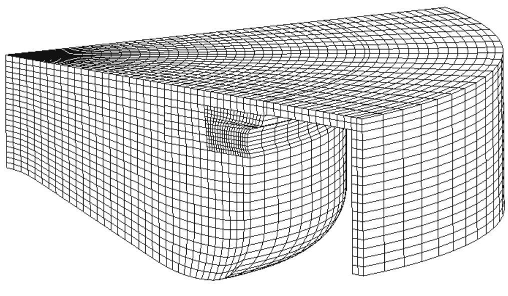

Fig. 1. Combustion chamber model

Table 2

Simulation boundary condition parameter table

Parameter/Unit	Numerical Value
Starting time of calculating /°*CA*	248
Ending time of calculating/°*CA*	465
engine speed/*r/min*	2000
cylinder head surface temperature/*K*	550
piston top surface temperature/*K*	470
liner temperature/*K*	590
inlet pressure/*MPa*	0.315
inlet temperature/*K*	340
turbulent kinetic energy/m^2/s^2	111.8
turbulence Length Scale/*m*	0.0065
swirl rate/-	0.85
excess air coefficient/-	1.53

3. The Simulation Calculation Mathematical Model

The air and fuel mixing and combustion process of diesel engine cylinder is extremely complicated, whose reason lies in: Fuel injection, atomization and mixing process with the air are very complex, and are constantly changing in the process. Moreover, the above parameters play an important role in the combustion and emission of diesel engines [15]. Therefore, we need to use a variety of relevant theoretical models and assumptions.

3.1 Turbulence model

In the whole working cycle of internal combustion engine, turbulent motion is one of the main forms of gas charge in cylinder, which determines the transport and spatial distribution of various gas impulses in cylinders, and has a direct and essential impact on the formation and concentration field of combustible mixture, the flame propagation rate, burning quality, the cylinder wall heat transfer and the Formation of pollutants. $k-\varepsilon$ double equation turbulence model is turbulent viscosity coefficient model in the turbulent transport model. It has the advantages of high computational stability and low computational resource requirements, and is a kind of more mature turbulence model which is used to study the air flow in cylinder. Therefore, the model is used to simulate the gas flow in the cylinder.

$k-\varepsilon$ partial differential equations of the model are shown in equation (2):

$$\begin{cases} \dfrac{\partial(\rho k)}{\partial t} + div(\rho k U) = div\left[\left(\mu + \dfrac{\mu_t}{\sigma_k}\right) grad \cdot k\right] - \rho\varepsilon + \mu_t P_G \\ \dfrac{\partial(\rho \varepsilon)}{\partial t} + div(\rho \varepsilon U) = div\left[\left(\mu + \dfrac{\mu_t}{\sigma_\varepsilon}\right) grad \cdot \varepsilon\right] - \rho C_2 \dfrac{\varepsilon^2}{k} + \mu_t C_1 \dfrac{\varepsilon}{k} P_G \end{cases} \tag{2}$$

Among them ($\mu_t = \rho C_\mu \frac{k^2}{\varepsilon}$), C_μ is empirical constant, which taken 0.09. In the formula ($U = \overrightarrow{u_i} + \overrightarrow{v_j}$), σ_k, σ_ε are corresponding Prandtl number of the turbulent kinetic energy and turbulent dissipation rate,which taken 1.0, 1.3. C_1 and C_2 are empirical constants, which taken 1.44, 1.92.

3.2 Spray model

In the diesel engine, the fuel injection, atomization, evaporation and its mixing with the air have an important influence on the combustion and emission of the engine. It is very important to understand and choose the spray model correctly to simulate the formation of the spray (namely, the mixing process of fuel and air).

In Fire, the primary atomization and the second atomization are related to the different models. However, due to the lack of experimental data, the settings method in the initial atomization often uses the default settings recommended by Fire. At the same time, the establishment and the selection of the spray model is mainly about the characteristics of the second crushing process. AVL_FIRE software has many classic broken model, such as TAB (Taylor Analogy Break-up) model, RD (Reitz and Diwakar) model and WAVE model. In this paper, WAVE model is adopted in the spray model.

Table 3

WAVE model parameter table

Parameter	Significance	Interval value	value
C1	Determine the stable diameter of the droplet.	(0,∞)	0.61
C2	Determine the breaking time	(5,60)	12
C3	0: inviscid fluid; 1: viscous fluid;	0or1	1
C4	Affect the number of droplets, the smaller the value, the more the number of droplets;	(0,1)	0.1
C5	Affect the mass of droplets, the larger the value, the more mass liquid droplets occupies;	(0,1)	1
C6	Affect the size and distribution of droplets: -1: uniform distribution; 0: no distribution; 1: triangular distribution;	-1, 0, 1	0

3.3 Combustion model

The CFD technology is widely used to solve the problem of the diesel engine combustion process. According to the characteristics of CFD technology, the solving process can be equivalent to solving the problem of multi - component fluid mechanics with chemical reaction. Because the solution to the problem of fluid mechanics usually needs to consider the fluid velocity and flow characteristics, it is very important to construct the combustion model to establish the relationship between chemical reaction rate and turbulent flow [16]. The combustion model used in this study is Eddy Breakup Model. The model considers that the turbulent combustion zone is filled with burned air mass and unburned air mass, the interface of which will occurs a chemical reaction, and that the average rate of chemical reaction is determined by the rate at which the unburned air mass is broken down into a more compact group under turbulence, and the fragmentation rate is proportional to the decay rate of turbulent kinetic energy. The combustion process of a diesel engine is the process of producing a central fire core and spreading, and the place where it spreads is burning. The model should follow the following assumptions:

(1) The time scale of chemical reaction is much smaller than the turbulent time scale, so the combustion time scale is determined by the turbulent time scale.

(2) The reactants are contained in different vortices.

(3) The breakup and mixing of the vortex particles determine the reaction rate;

(4) The reaction rate is also affected by the minimum concentration of the material.

4. The Matching Optimization of the Design Parameters

4.1 Optimum matching of geometrical parameters of nozzle holes

Under the condition of constant injection pressure, a certain amount of circulating fuel supply, and constant injection hole diameter, with the increase of the number of holes, the injection rate increases, and the fuel injection duration decreases [17]. As the fuel injection rate increases, the decrease of fuel injection duration leads to the decrease of the oil injector passing distance, and the energy of the spray impinging on the top surface of the piston is smaller. Taking into account that the mixing process of fuel and air is closely related to the uniformity of fuel distribution in the cylinder, it is necessary to analyze the distribution of fuel equivalence ratio in the cylinder by usstarting the air utilization rate. The air utilization rate is, when the fuel air equivalence ratio satisfies the constraint conditions, the ratio of the total volume of the grid and the total volume of the grid in the CFD computing area. The specific description is shown in (3).

$$AU = \sum_{i}^{n} \frac{V_i}{V_{tol}}, 0.5 \le \phi \le 1.5 \tag{3}$$

In the formula, V_{tol} is the total volume of one cylinder. V_i is the volume of the cells for which the relative air-fuel ratio is in the flammable range 0.5 to 1.5. ϕ is the fuel air equivalence ratio. The air utilization ratio is used to characterize the uniformity of the fuel droplet distribution after the fuel is injected into the cylinder. The larger the air utilization ratio is, the more uniform the concentration distribution in the cylinder. Figure 2 describes the relationship between the injection rate and the air utilization ratio of the cylinder and the crankshaft angle when the number of holes is increased from 4 to 6 and the hole diameter of 0.5mm keeps constant. According to figure 2 it can be seen: After the number of nozzle hole increases, the injection rate increases and the injection duration is shortened. There is a negative correlation between the air utilization and the number of nozzles, and the relationship between the air utilization ratio and the crank angle shows the opposite trend. The reason lies in: Initially, the cylinder air utilization rate increases with the increase of the number of holes. However, with the combustion, the uneven distribution of fuel in the longitudinal plane of the cylinder leads to a decrease in the mixing quality of the fuel and air, thus resulting in the air utilization rate after 20 °CA ATDC began to decline. Especially for the 6-hole injector, the fuel is concentrated in the bottom area of the combustion chamber, and the air utilization ratio is significantly lower than that of the 4-hole and the 5-hole injector.

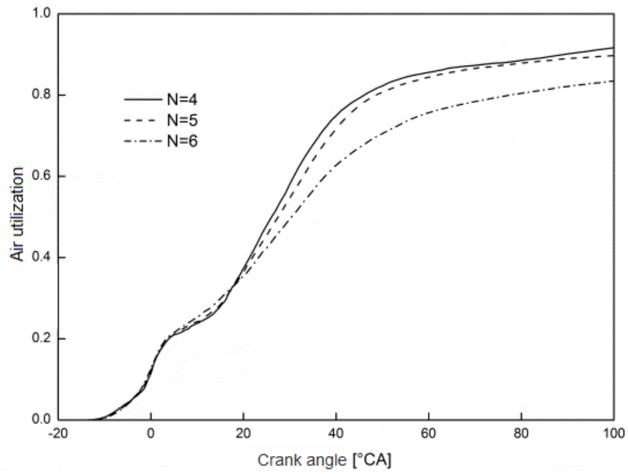

Fig. 2. Effect of orifice number on air utilization

Nozzle diameter is also one of the important parameters of injector. Figure 3 illustrates the relationship between the cylinder air utilization and the crank angle of the 6-hole injector with different orifice diameters. According to Figure 3 it can be seen: In the initial stage, the influence of the orifice diameter on the air utilization rate is not obvious. With the combustion of the gas in the cylinder, there is a significant negative correlation between the diameter of the jet hole and the air utilization rate. The reason lies in: The increase of nozzle diameter enlarges the amount of fuel injected. On the one hand, the diameter of the fuel droplet is increased, which has an adverse effect on the evaporation of fuel oil and the full mixing of oil and gas. On the other hand, due to the increase of injection rate, the relative velocity between the fuel and air is increased, thereby promoting the mixing between the oil and the gas. In the early stage of injection, due to the relatively large particle size of the fuel spray atomization, the droplet penetration rate and evaporation rate are slower, and the distribution range of the equivalence ratio is small. It is multiple injection. TDC of injection advance angle is 10 degrees, and injection duration is 20°. After the start of combustion, due to the mixture of oil and gas of the large orifice diameter is not sufficient, and the increase of pressure and temperature in the cylinder is slower, which further inhibits the mixing between the fuel and air, so the increase of the diameter of the jet hole is harmful to the improvement of the air utilization.

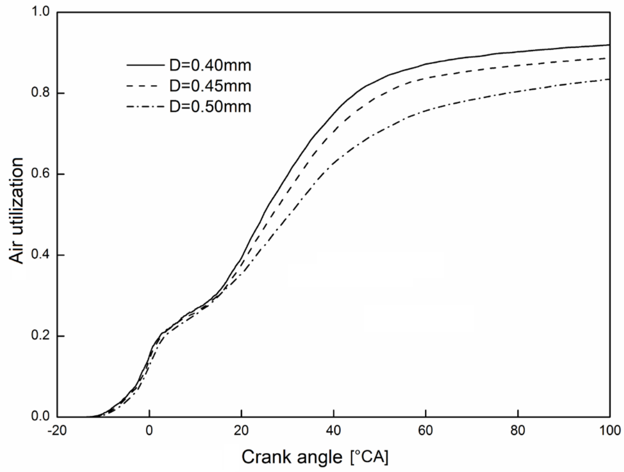

Fig. 3. Effect of orifice diameter on air utilization

According to the above analysis, it can be seen that the change of the number of spray holes and the diameter of nozzle hole will have a certain impact on the quality of the mixture and the combustion characteristics of the engine. However, under the condition that the total fuel injection rate remains unchanged, the change of the number of injection holes or the diameter of the jet hole will have an impact on the fuel injection duration, so that the combustion process also has a corresponding impact. Therefore, it is especially important to analyze the two independent parameters of the number of holes and the diameter of the nozzle. Figure 4 illustrates the relationship between injection rate and in cylinder air utilization when injector orifice number and orifice diameter are 4 (orifice) × 0.55 (*mm* aperture), 5 × 0.50, 6 × 0.45 and 8 × 0.40. According to Figure 4 it can be seen: When the number of nozzle holes is coupled with the orifice diameter, the larger the nozzle number, the smaller the nozzle diameter, the lower the air utilization ratio, fuel injection rate and injection duration are the same. In the initial stage, the number of nozzle holes is larger and the diameter of nozzle hole is smaller, the utilization rate of air in cylinder is higher. However, with the combustion, the air utilization ratio of the combination of hole 4, 5, 6 is smaller, and the air utilization rate of the 8-hole injector is obviously reduced.

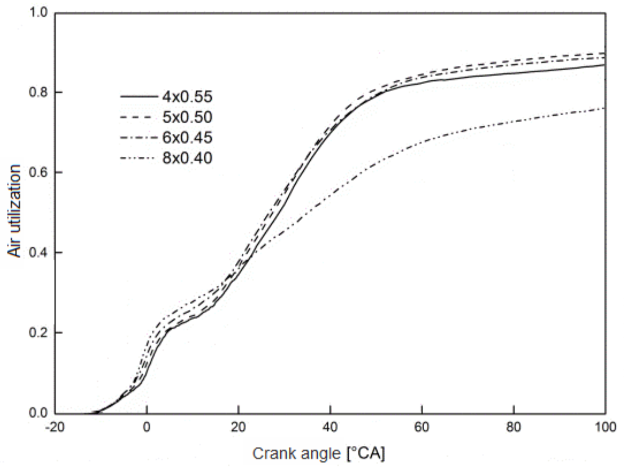

Fig. 4. Effect of injection pressure on cylinder pressure

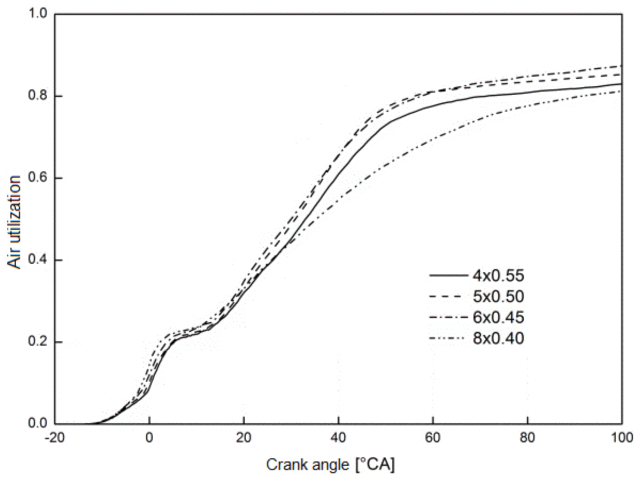

Fig. 5. The law of air utilization at the initial swirl ratio of 0.4

Figure 5 is the law of air utilization when the initial swirl ratio is about 0.4. Comparing Figure 5 with figure 4 (the swirl ratio is 0.85), it can be seen: In the initial stage of fuel injection, for different initial swirl ratio, the increase of the number of holes and the decrease of the diameter of the jet hole are helpful to improve the mixing of the oil and gas and the initial combustion rate. But in the later stage of the injection process, too small diameter of the injection will lead to the decrease of penetration, which causes the decrease of the air utilization rate and affects the later combustion, resulting in decreased heat release. Based on the above results, it is found that there is a matching relationship between the swirl ratio and the combination of number of nozzle holes and nozzle diameter. When the initial swirl ratio is 0.4, the 6-hole injector is the best.

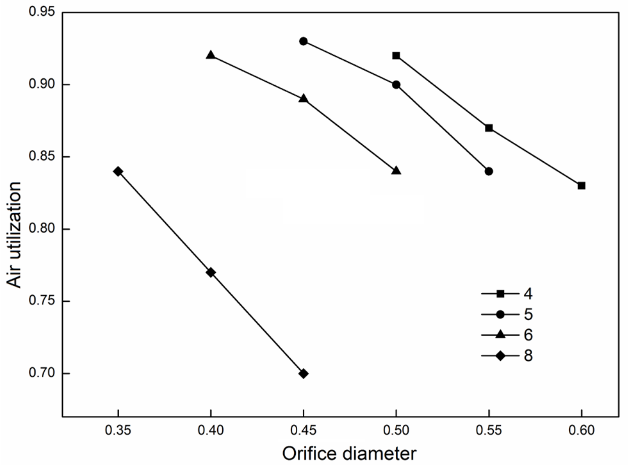

Fig. 6. Effect of different geometric parameters on air utilization

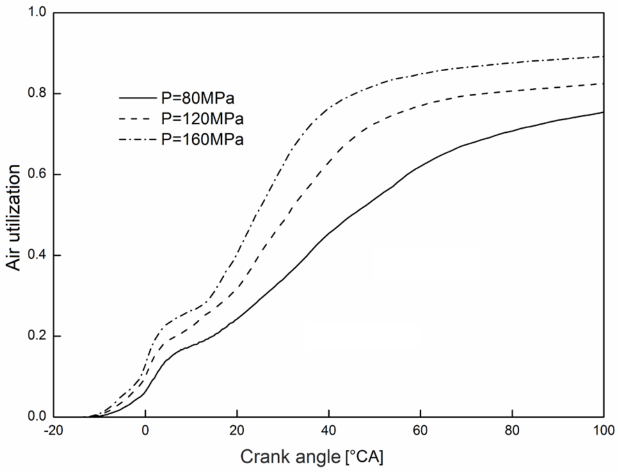

Fig. 7. Effect of injection pressure on air utilization

To sum up, both the number of nozzle holes and the diameter of nozzle hole have great influence on the working process of diesel engine. Moreover, the two kinds of fuel injection parameters are mainly used to control the working process in the cylinder by changing the air utilization rate. It can be seen from Figure 6 that the air utilization rate of the 5 × 0.45 (the number of nozzle holes is

5 and the nozzle diameter is 0.45 *mm*) is the highest. Therefore, the scheme is selected for the next step.

4.2 Influence law of injection pressure

Figure 7 depicts the influence relationship curve injection pressure on air utilization. According to Figure 7 it can be seen: there was a positive correlation between the jet pressure and air utilization rate, and there was a significant positive correlation trend from the initial stage. The reason lies in: Keep the total injection volume unchanged, injection pressure increases, the injection duration is shortened, the fuel injection rate increases, the relative speed between the fuel and air is increased, the mixing speed between the oil and the gas is accelerated, which is favorable for the pulverization and atomization of the fuel, and the air utilization ratio is improved [18].

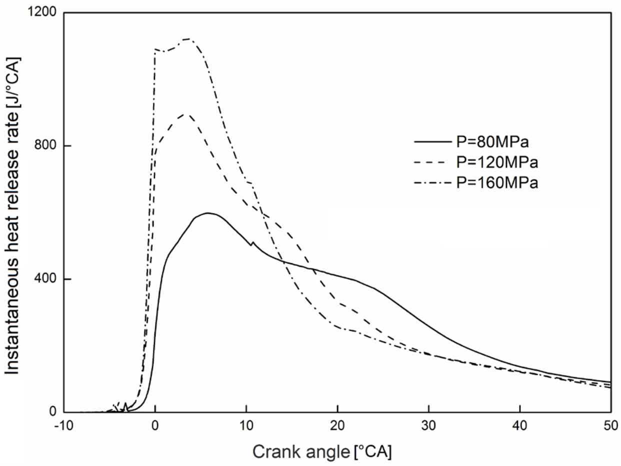

Fig. 8. Effect of injection pressure on instantaneous heat release rate

Figure 8 depicts the effect of injection pressure on the air utilization. According to Figure 8 it can be seen: With the increase of crank angle, the instantaneous heat release rate increases rapidly to the maximum, then decreases rapidly and finally decreases slowly, and the maximum instantaneous heat release rate is positively correlated with the injection pressure. The reason lies in: With the increase of injection pressure, the amount of fuel injected into the cylinder in unit time increases, premixed mixture increases at ignition time, the heat release rate of premixed combustion increases rapidly, the rising slope of exothermic rate curve increases, maximum instantaneous heat release rate increases, explosive pressure increase, indicator diagram tends to fullness, the combustion temperature also increases, the work capacity of the engine increases. In the stage of diffusion combustion, the improvement of injection pressure can reduce the amount of fuel gathered in the bottom of the piston top pit and the clearance, and promote the mixing quality of oil and gas, and promote the combustion. The total heat release rate is accelerated, and the post combustion condition is greatly improved. The injection pressure is different, but the injection quantity is the same, so the total heat provided is the same. The heat release curve is high, and the engine pressure rise rate is high and the noise is big. The curve is narrow when the instantaneous heat release rate is 160 MPa. Low instantaneous heat release, its curve is low and wide. It shows that it takes a short time to release heat from combustion during high pressure and the engine thermal efficiency is high.

4.3 Optimal matching of fuel injection direction

Figure 9 describes the relationship between the air utilization ratio of the cylinder with different injection angles. According to figure 9 it can be seen: The cone angle of fuel injection and the air utilization ratio are positively correlated. However, when the cone angle increases to a certain value, the change of air utilization rate is not obvious, and tends to be stable. The reason is that the cone angle is smaller and the air utilization ratio is higher at the beginning. With the injection and combustion, the piston moves to form a strong squeeze flow and reverse flow, and the fuel droplets are sucked out of the combustion chamber. When the cone angle of fuel injection is larger, the airflow movement promotes the mixing and atomization of the fuel droplets, and the utilization rate of the air in the cylinder is improved [19].

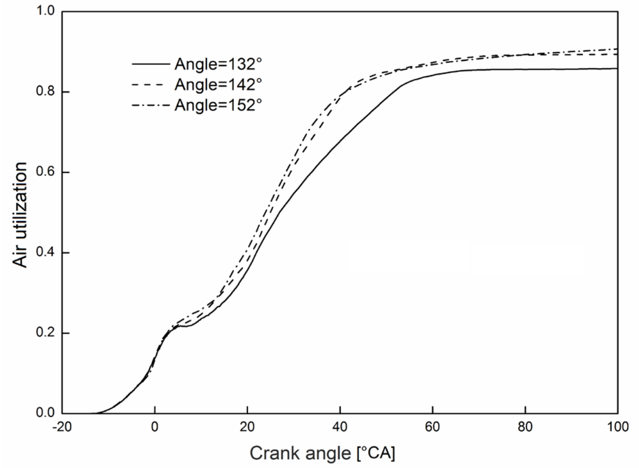

Fig. 9. Effect of spray cone angle on air utilization

Figure 10 depicts the relationship between the different protruding heights of the nozzle and the air utilization ratio. As can be seen in the figure: There is a significant negative correlation between the protruding height and air utilization. The reason is that with the increase of the protruding height, the position of the fuel injection is far away from the wall. The airflow is stronger. The interaction between fuel and air is enhanced. Evaporation atomization speeds up. Therefore, the increase of the initial protruding height of the fuel injection increases the air utilization rate of the fuel. Because the fuel droplet is too concentrated in the combustion chamber bottom, and its strong squeeze flow movement contact with the combustion chamber closing position is less, the evaporation rate of fuel is slowed down, and the utilization ratio of fuel is reduced.

Figure 11 describes the relationship curves of fuel air utilization under the coupling of fuel injection cone angle and nozzle protruding height. When the nozzle protruding height is 2mm, and the injection cone angle is 152°, the air utilization rate is the highest, and the fuel atomization and combustion quality are the best.

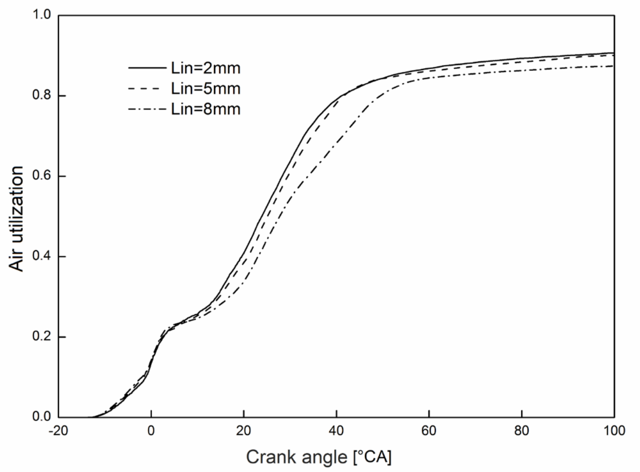

Fig. 10. Effect of nozzle protruding height on air utilization

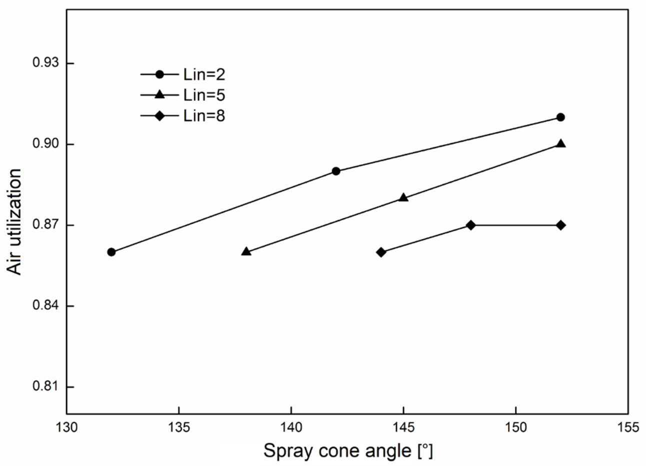

Fig. 11. Effect of injection direction parameters on air utilization

In China, Huang Hao studied the influence of spray pressure and nozzle diameter on the spray characteristics of blended fuel. The results show that under the same injection pressure, the higher the volatility of the blended fuel, the greater the penetration distance and the spray cone angle (far field and near field). With the increase of injection pressure and spray cone angle, the spray penetration angle increased linearly [20]. Gao Jie studied the influence of fuel injection advance angle on diesel engine performance at rated speed, and determined the change trend of the best injection advance angle under different working conditions. The results show that with the decrease of atmospheric pressure, the performance of diesel engine can be improved by increasing the injection advance angle within a certain range [21]. Xu Yue studied the matching of combustion chamber parameters. The design factors of the combustion chamber structure suitable for high-pressure injection are analyzed, and the combustor models with different penetration distance, diameter ratio and diameter depth ratio are established. The results show that the combustor with large diameter and shallow pit is a reasonable scheme [22]. This paper mainly studies the influence of the number of injection holes, the diameter of injection holes, the injection pressure, the cone angle and the nozzle extension height on the in cylinder air utilization rate, and according to the influence rules, the matching of injection parameters is carried out for the diesel engine.

It can be seen from Figure 6 that the air utilization rate in cylinder is negatively correlated with the diameter and number of spray holes. The main reason is that the increase of the diameter and number of the injection holes will reduce the initial velocity of fuel injection under the same injection quantity and pressure. However, when the number of spray holes is less than six, the change trend of the air utilization rate in cylinder is not very obvious.

The change of injection pressure mainly corresponds to the change of diesel engine load. When the diesel engine is in the external characteristic working condition, the higher injection pressure can make the diesel droplet fully broken under the air flow in the cylinder, so as to increase the air utilization rate in the cylinder, improve the performance of the diesel engine and reduce the post-treatment pressure.

The fuel injection cone angle and nozzle extension height affect the air utilization rate in the cylinder by acting on the direction of the fuel beam. It can be seen from Figure 11 that the influence of nozzle extension height on air utilization rate in cylinder is not obvious. However, the increase of the injection cone angle will increase the air utilization rate in cylinder. Therefore, for the diesel engine studied in this paper, a larger injection cone angle should be adopted.

5. Conclusions

The number of nozzle holes and the diameter of nozzle hole have a crucial influence on the mixing quality of oil and gas in the cylinder and the spatial distribution of the mixture, and the increase of the number of holes and the decrease of the diameter of the jet hole are beneficial to the evaporation of the fuel before combustion. When the number of holes is increased from 4 to 6 and the hole diameter of 0.5mm keeps constant, 6 hole's injection rate increases and the injection duration is shortened and the air utilization ratio is significantly lower. However, if the number of nozzle holes is too large or the orifice diameter is too small, fuel injection continues to increase, and the oil and gas do not match, and the mixing quality of oil and gas will be poor, and the post burn will aggravate. To compare two kinds of initial swirl ratio schemes of 0.4 and 0.85, when the initial swirl ratio is 0.4, the spray atomization effect of the 6-hole injector is the best; when the initial swirl ratio is 0.85 the spray atomization effect of the 5-hole injector is the best.

The injection pressure is different, but the injection quantity is the same, so the total heat provided is the same. The heat release curve is high, and the engine pressure rise rate is high and the noise is big. The curve is narrow when the instantaneous heat release rate is 160 MPa. Low instantaneous heat release, its curve is low and wide. It shows that it takes a short time to release heat from combustion during high pressure and the engine thermal efficiency is high. The maximum instantaneous heat release rate is positively correlated with the injection pressure. The increase of injection pressure plays an important role in the atomization of fuel droplets and the subsequent diffusion and combustion, which shortens the ignition delay, and increases the heat release rate and the air utilization.

The cone angle of fuel injection and the air utilization ratio are positively correlated. There is a significant negative correlation between the protruding height and air utilization. The cone angle of fuel injection and the protruding height of the spray nozzle influence the falling points of fuel spray and the distribution of spray in combustion chamber. When the nozzle protruding height is 2mm, and the injection cone angle is 152°, the air utilization rate is the highest, and the fuel atomization and combustion quality are the best.

Acknowledgment

This research was financially supported by Qingdao Huanghai University Doctoral Research Fund Project (2017boshi02), and "Machinery Engineering" Key Subject Construction Project.

REFERENCES

[1]. *Chu Xiao Zheng*. Optimization of Three Dimensional Simulation of Marine Diesel Engine room. Harbin: Harbin Engineering University, 2013.

[2]. *Li Qin, Ding Fei, Wang Xiao Rong*. Simulation Study on the Influence of Injector Parameters on the Combustion Characteristics of Marine Low Speed Engine. Ship Engineering, 2015 (05).
[3]. *Lou Di Ming, Wu Yang, Hu Zhiyuan, Tan Piqiang, Lin Jianjun*. Study on the Effect of Pre-injection on the Combustion and Emission Characteristics of Biodiesel Engine. Car Engine, 2014 (05).
[4]. *Masahiko Miyaki, Hideya Fujisawa, Akira Masuda, and Yoshihisa Yamamoto*. Development of New Electronically Controlled Fuel Injection System ECD-U2 for Diesel Engines, 2011.
[5]. *K. Gebert, R.L. Barkhimer, N.J. Beck, D.D. Wickman, K.V. Tanin, S. Das and R.D. Reitz*. An Evaluation of Common Rail, Hydraulically Intensified Diesel Fuel Injection System Concepts and Rate Shapes, 2008
[6]. *Xin Zhe, Li Yaping, Zhang Yunlong, Niu Jianbin, Zhao Xulong*. Diesel High Pressure Common Rail System of Rail Pressure Fuzzy Control and Test. Journal of agricultural engineering, 2016, S1: 34-41.
[7]. *Yuan Fangen, Lin Xuedong, Huang Y, Gao Ying*. Research on the Influence of High Pressure Common Rail Injection System Parameters on Diesel Engine Performance. Internal Combustion Engine Engineering, 2012, 02: 11-19.
[8]. *Wang Yawei, Wu Chu, Miao Miao, Mao Qiang*. Light Diesel Engine High-pressure Common Rail System CB18. Internal Combustion Engine Engineering, 2012, 02: 20-27.
[9]. *Deng Jingwei, Chen Xingning, Li Shaohe, Chen Zhaowen*. Calibration and Testing of Electronic control System for High Pressure Common Rail Diesel Engine. Science and Technology Vision, 2012, 32: 125-126.
[10]. *Ding Shiyong, Lin Xiuxia, Zhao Yilei, Li Ming, Fang Hui, Fang Bo*. Design of Common Rail Tube in High Pressure Common Rail System of BF6M1015C Diesel Engine. Small Internal Combustion Engine and Motorcycle, 2011, 05: 47-51.
[11]. *Feng Xiulan*. Diesel High Pressure Common Rail System of Automatic Assembly Technology, Modular Machine Tool and Automatic Manufacturing Technique, 2010, 10: 107-108+112.
[12]. *Zhang Zhenyu*. Coupling Simulation and Experimental Research on the Working Process of Qpposed-piston Two-stroke Diesel Engine. Beijing: Beijing Institute of Technology, 2015.
[13]. *Oliver Hofmann, Daniel J. Rixen*. Aging Tolerant Control of Direct Injection Engines. Control Engineering Practice, 2018.
[14]. *Xue Guangming, Zhang Peilin, He Zhongbo, Li Dongwei, Yang Zhaoshu, Zhao Zhenglong*. Displacement Model and Driving Voltage Optimization for a Giant Magnetostrictive Actuator Used on a High-pressure Common-rail Injector. Materials & Design, 2016.
[15]. *H.P. Wang, D. Zheng, Y. Tian*. High Pressure Common Rail Injection System Modeling and Control. ISA Transactions, 2016.
[16]. *Sun Zuoyu, Li Guoxiu, Chen Chuan, Yu Yusong, Gao Guoxi*. Numerical Investigation on Effects of Nozzle's Geometric Parameters on the Flow and the Cavitation Characteristics within Injector's Nozzle for a High-pressure Common-rail DI Diesel Engine. Energy Conversion and Management, 2015.
[17]. *Prinz, Kemmetmüller, Kugi*. Mathematical Modelling of a Diesel Common-rail System. Mathematical and Computer Modelling of Dynamical, 2015, (4).
[18]. *Lin Xuedong, Han Xiaomei, Li Degang, N. Akram Muhammad*. Design and Evaluation for Target Indicated Torque Based Engine Starting Control Strategy in a High Pressure Common Rail Diesel Engine. Mathematical Problems in Engineering, 2016.
[19]. *Chris A. Satkoski, Neha S. Ruikar, Scott D. Biggs, Gregory M. Shaver*. Piezoelectric Fuel Injection: Cycle-to-cycle Control of Tightly Spaced Injections. Control Engineering Practice, 2012, (11).

[20]. *Huang Haozhong,* An Yanzhao, Su Wanhua. Effect of Injection Pressure and Nozzle Hole Diameter on the Spray Characteristics of Diesel Engine Mixed Fuel. Journal of Internal Combustion Engine, 2013, 03: 31-49.
[21]. *Gao Jie*, *Xue Dongxin*, *Qi Yuantao*, *Wang Hongfeng*. Research on the Fuel Injection Advance Angle of a Supercharged Diesel Engine under Plateau Conditions. Internal Combustion Engine and Distribution, 2017, 03: 49-51.
[22]. *Xu Yue, Liu Qi*, *Zhu Anzhou*. Matching Design of High Pressure Common Rail TBD620 Diesel Engine Combustor. Internal Combustion Engine, 2013, 02: 26-27.