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RESEARCH ARTICLE

STUDY ON DYNAMIC INJECTION CHARACTERISTICS OF EXPLOSION-PROOF DIESEL ENGINE OIL CAVITY

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ABSTRACT

Explosion-proof diesel engine has a strong adaptability to harsh environment, but also has strict requirements for oil injection characteristics. According to the theory of hydrodynamics, a physical model was built to test the capture rate under different spacing between nozzle hole and oil inlet. The relationship between injection temperature and pressure in injection chamber and injection characteristics of nozzle was obtained. When the second-order effect of piston reciprocating motion is neglected, the diffusive angle of the nozzle holes with vertical structure is smaller under the experimental parameters. It can be seen that the size of injection cross-section has little effect on the capture rate, and the reflux characteristic of the oil chamber is the key factor affecting the capture rate.

INTRODUCTION

There are a lot of flammable gases and explosive dust in the working environment of mines and roadways, so the driving device must meet the explosion-proof requirements. As an important internal combustion engine equipment, explosion-proof diesel engine has a very important application in trackless vehicle, monorail crane, rail tractor and other transportation equipment (WANG, 2010 and GAO, 2017). Explosion-proof diesel engine requires more stringent working temperature and pressure. When working, the piston in the oil chamber will move in a straight line at high speed. The injection rate is required to be stable, and the instantaneous injection speed needs to be greater than the maximum speed of piston movement. The injection temperature does not exceed 90 □. Finally, the exhaust gas is discharged through the corresponding exhaust system, and the temperature does not exceed 70 □. The injection characteristics of the oil chamber have a key influence on the ultimate working ability of the explosion-proof diesel engine. Therefore, this paper adopts the experimental method to study the injection efficiency, and analyses the relationship between the injection temperature and pressure of the injection chamber and the injection characteristics of the nozzle, which provides an important basis for the structural optimization design and performance improvement of the explosion-proof diesel engine.

Theory of Oil Chamber Injection for Explosion-proof Diesel Engine

Injection momentum equation: The injection structure inside the oil chamber is called the nozzle hole, which is generally designed as a circular structure and can control the symmetry of the injection cross section more accurately. There is a certain distance between the nozzle hole and the inlet end of the oil chamber, which has a significant influence on the flow field characteristics of the injection. The flow characteristics of injection can be analyzed by hydrodynamic theory (WANG, 2015). According to the law of momentum conservation of viscous fluid, momentum on the cross section is always constant in the process of oil injection, and its expression is as follows:

$$\int \rho u^2 \mathrm{d}A = \rho \pi R_0^2 u_0^2 = \mathrm{const} \qquad \ldots\ldots\ldots\ldots\ldots(1)$$

Where ρ is the oil density; A is the area of the injection cross-section; u is the injection speed at the cross-section; R_0 is the radius of the nozzle hole; u_0 is the injection speed of the nozzle hole.

Construction of Injection Model

In order to study the characteristics of jet flow field, the injection model is established as shown in Figure 1. Among them, the x-axis direction is the direction of injection distance, and the y-axis direction is the direction of injection width. Convert Eq.1 into dimensionless form as follows

$$2\int_0^{\frac{R}{R_0}} \left(\frac{u}{u_0}\right)^2 \frac{y}{R_0} \mathrm{d}\frac{y}{R_0} = 1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

The installation design of nozzle holes in the explosion-proof diesel engine studied in this paper is vertical, which is helpful to the cooling of oil and the stability of viscous fluid.

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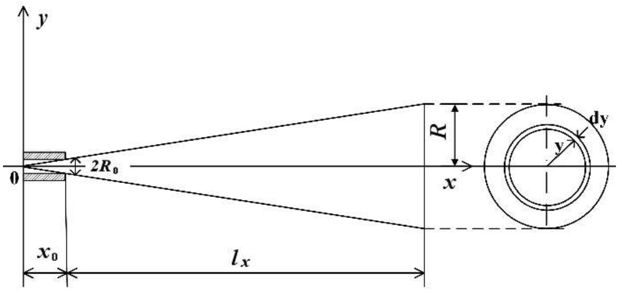


Fig.1 Section diagram of injection model

The injection cross section can be calculated in a circular way. According to Eq.2, the dynamic characteristics of injection can be analyzed quantitatively. Among them, the dimensionless velocity u_+ can be expressed as

$$u_+ = \frac{u}{u_\mathrm{m}} \cdot \frac{u_\mathrm{m}}{u_0} \qquad \text{.............(3)}$$

Dimensionless coordinate y_+ can be expressed as

$$y_+ = \frac{y}{R} \cdot \frac{R}{R_0} \qquad \text{.............(4)}$$

Where u_m is central speed of nozzle hole, R is Radius of jet cross section.

These two parameters (u_+ and y_+) mainly depend on the injection cross section and the distance between injection poles, and have nothing to do with the relative position of reference nodes in the injection cross section. Under ideal conditions, the semi-jet cross section can be used as the reference object for jet calculation, i.e. the position of 0.5 u_m is taken as the half-width standard, and the corresponding y coordinate is the half-width radial coordinate. Based on this principle, the measurement and analysis of the motion characteristics of oil injection can be effectively realized through reasonable experimental design.

Capture rate: In order to study the influence of nozzle hole structure parameters on injection efficiency, the capture rate parameter C_A is introduced in this paper, which represents the ratio of injection cross-section area to injection cross-section area. The expression is as follows:

$$C_\mathrm{A} = \frac{A_\mathrm{j}}{A_\mathrm{n}} \qquad \text{.................(5)}$$

Where A_j is oil injection cross-sectional area, A_n is Oil intake cross-sectional area.

According to the installation characteristics of nozzle hole, the distance of oil injection increases gradually with the piston moving from bottom to top, the cross-section area of injection increases, the capture rate increases, and the oil entering the oil chamber increases. According to the model shown in Fig. 1, the equation for calculating the radius R of the jet cross section can be obtained as follows.

$$R = l_x \cdot \tan\theta + R_0 \qquad \text{.................(6)}$$

Where l_x is Distance between injection section and injection section, θ is the diffusive angle of oil injection.

Theoretical analysis shows that assuming that the piston moves under ideal conditions and ignores the second-order motion, the size of injection cross-section mainly depends on the oil injection diffusion angle and injection distance. These two parameters are related to capture rate, so the influence of capture rate parameters can be studied by experimental methods.

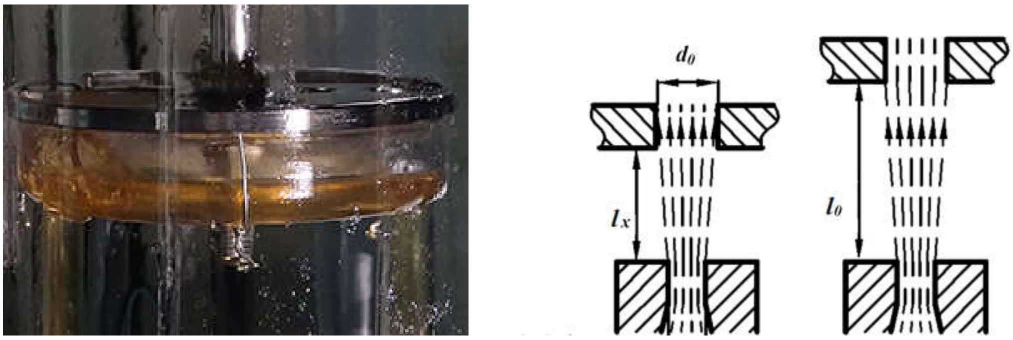
Experimental study on injection characteristics

Design of test scheme: The capture rate of oil can measure the filling and injection characteristics in the oil chamber, which is related to various working parameters. Among them, the pressure and temperature of oil in the oil chamber are the key parameters affecting the injection characteristics [4]. In this paper, pressure and temperature are used as single factor variables to test the flow characteristics of oil. The experimental bench used in the oil injection test is shown in Fig.2 (a), which consists of a mechanical oil injection simulator and an electrical control console. The basic structure of the mechanical oil injection simulator includes oil control valve, pressure regulating valve, hydraulic control system, oil chamber, cylinder block, tie rod, etc. It can accurately simulate the injection process of the internal oil chamber of the explosion-proof diesel engine. In order to facilitate observation, the material of oil chamber is heat-resistant transparent plastic, which is formed by 3D printing. The overall structure of the oil chamber is shown in Fig.2 (b). For the control of temperature parameters, constant temperature heating pipe is used in the experiment, and for the control of oil hydraulic pressure, oil control valve and pressure regulating valve are used in the experiment. At the beginning of the test, the coordinate system should be defined according to the position of the oil inlet of the equipment, and the circular nozzle tooling should be set to simulate the nozzle hole of the diesel engine, both of which have the same diameter as d_0. Then, the printed transparent oil chamber should be loaded into the transparent cylinder block and coaxially installed with the tooling, as shown in Fig.2 (c). At this time, the oil should be introduced into the oil chamber and the flowmeter should be installed according to the sensor. Calibrating oil pressure, oil temperature and injection speed, slowly adjusting the vertical height of the oil chamber (simulating reciprocating motion of the piston) through the tie rod, and finding out the critical divergence position of oil in the nozzle hole (obtained by flowmeter) according to different test conditions, that is, the critical distance l_0 between the nozzle hole and the oil inlet, referred to as the critical distance between the orifices, as shown in Fig.2 (d).

Parameter design of test process: In explosion-proof diesel engines, there is usually a water-cooling system for injection, so the actual injection temperature is generally 10 C lower than that before cooling. According to the working requirements of explosion-proof diesel engine in industrial production, the test conditions for setting injection pressure p and injection temperature T are shown in Table 1. In the test, the oil pressure range is 0.25-0.45 MPa, and the injection temperature range is 60-90 □. When the oil pressure is used as a single factor, the temperature is constant at 75 □. When the oil temperature is used as a single factor, the oil pressure is constant at 0.25 MPa.

(a) the overall structure of the test bed

(b) the shape of the oil chamber



(c) Schematic diagram for installation

(d) Principle of oil injection metering

Fig. 2. Test design scheme

Tab.2 Test conditions

Univariate variable	Range setting
p/MPa	2.5 ~ 4.5
T/°C	60 ~ 90
l_0/mm	To be measured

In the initial stage of the test, the oil in the oil chamber is in a low temperature state and needs constant temperature preheating. After starting the hydraulic system, adjust the control valves to control the oil pressure in the test conditions. In order to improve the accuracy and reliability of the test, the average number is taken as the final test result three times per single factor test. For the capture rate test, this paper converts the oil cross-section area into the oil injection flow rate to calculate, thus it can be concluded that the capture rate C_Q in the test scheme is as follows.

$$C_{\mathrm{Q}} = \frac{Q_{\mathrm{j}}}{Q_{\mathrm{n}}} \cdot 100\% \qquad \text{……………}(7)$$

Where Q_j is injector flow rate, Q_n is injector flow rate.

ANALYSIS OF TEST RESULTS

The relationship between hole spacing and capture rate: Under the conditions of oil temperature 75 ℃ and oil pressure 0.25 MPa, the capturing rate variation characteristics under different hole spacing can be obtained as shown in Fig. 3. It can be seen that with the increase of hole spacing, the capturing rate decreases gradually. According to the experimental results, combined with the injection mechanism expressed in Fig.1 and Fig. 2(d), when $l_x < 72$ mm, the capturing rate keeps between 98% and 100%, and the injection efficiency is very high. But beyond the critical position, the capture rate decreases sharply, especially when the aperture spacing is in the range of 100-150 mm. The calculation shows that the diffusive angle of oil injection at the critical time is about 0.45 degrees. The variation of capture rate with hole spacing can provide a basis for calculating the transient combustion efficiency of the whole combustor. When the explosion-proof diesel engine works, the reciprocating motion of the piston will change not only the area capture rate, but also the mass capture rate. It can also be seen that under the condition of multi-crankshaft rotation, the loads on crankshaft bearings with different rotation angles have typical non-linear characteristics.

The relationship between temperature and critical hole spacing: The variation of critical orifice spacing at different temperatures is shown in Fig. 4. It can be seen that the critical orifice spacing decreases linearly with the increase of oil temperature. This is because the oil is an ideal viscous fluid [5, 6]. With the increase of preheating temperature, the dynamic viscosity of the oil decreases, and the divergence of the injection is more significant, which greatly shortens the critical orifice spacing and changes linearly under the condition of constant injection pressure. With the increase of oil temperature, the average filling rate in the oil chamber will decrease, so it is necessary to control oil temperature.

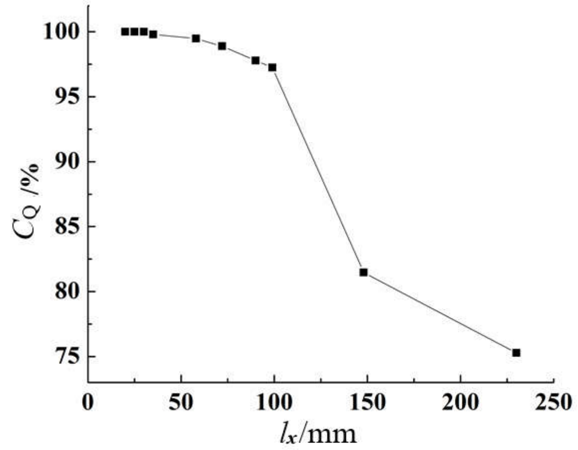


Fig. 3. Relationship of C_O and l_x

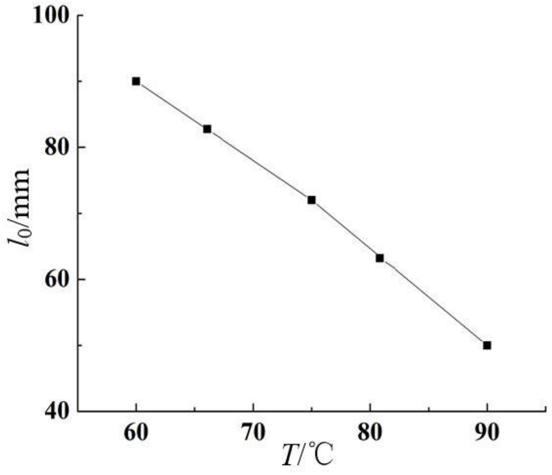


Fig. 4. Relation of l_0 and T

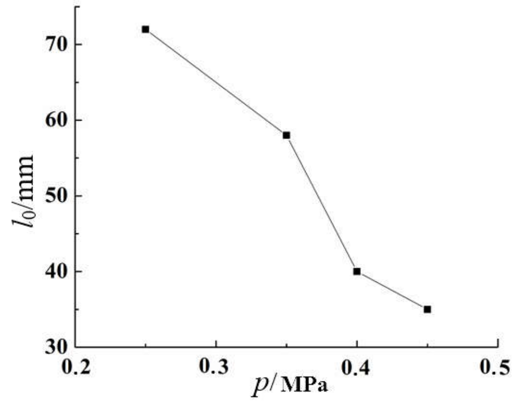


Fig. 5. Relation of l_0 and p

The relationship between pressure and critical hole spacing: The variation of critical orifice spacing under different injection conditions is shown in Fig.5. It can be seen that the critical orifice spacing also decreases with the increase of injection pressure, and the linear trend is not obvious. At present, some engineers and technicians have some misunderstandings in the control of injection pressure. They think that the injection efficiency can be effectively improved by increasing injection pressure. According to the test results, the scheme is not feasible. Excessive injection pressure will lead to distortion or oversize of oil injection diffusion angle, which will lead to serious divergence of oil bundles, which does not meet the optimal installation design requirements of nozzles.

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Conclusions

Compared with other power sources, explosion-proof diesel engine has the advantages of compact size, convenient use and high flexibility. It is an urgent need for industrial production to optimize the design of explosion-proof diesel engine and improve its performance. In this paper, the experimental method is used to simulate the injection process, and the effects of different working parameters on the injection characteristics of the oil chamber are obtained. The following conclusions are drawn: (1) According to the change rule of capture rate with the hole spacing, when the hole spacing is less than the critical value, the capture rate will be maintained steadily in the vicinity of 98-100%, and the injection efficiency is higher. (2) The critical orifice spacing decreases obviously with the increase of oil temperature or injection pressure, but the linear characteristic is more obvious with the change of temperature. (3) The test scheme can provide an important basis for structural optimization and performance improvement of explosion-proof diesel engine, and has good economic and social benefits.

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