Hindawi
Scientific Programming
Volume 2023, Article ID 9821785, 1 page
https://doi.org/10.1155/2023/9821785

Retraction

Retracted: Research on the Flow Control of a Piston Cooling Nozzle

Scientific Programming

Received 1 August 2023; Accepted 1 August 2023; Published 2 August 2023

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope
(2) Discrepancies in the description of the research reported
(3) Discrepancies between the availability of data and the research described
(4) Inappropriate citations
(5) Incoherent, meaningless and/or irrelevant content included in the article
(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] X. Zeng, J. Zhang, L. Li, G. Hu, and W. Xie, "Research on the Flow Control of a Piston Cooling Nozzle," *Scientific Programming*, vol. 2022, Article ID 9283300, 9 pages, 2022.

Hindawi
Scientific Programming
Volume 2022, Article ID 9283300, 9 pages
https://doi.org/10.1155/2022/9283300

Research Article

Research on the Flow Control of a Piston Cooling Nozzle

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Received 4 August 2022; Revised 27 August 2022; Accepted 16 September 2022; Published 29 September 2022

Academic Editor: Juan Vicente Capella Hernandez

The flow rate of a piston cooling nozzle is usually adjusted by changing the parameters of convergent length and inner diameter of the nozzle in engineering. However, the influence law and quantitative relationship between the flow rate and them are not clear. In this paper, the structural model and three-dimensional model of internal flow field of piston cooling nozzle are established by analyzing the structural characteristics and actual working conditions of piston cooling nozzles. Based on Fluent software, the flow field of piston cooling nozzles is simulated and analyzed. The distribution of velocity and pressure inside the piston cooling nozzle are obtained. The flow rate of fluid field is also obtained inside a piston cooling nozzle. In addition, the variation law of flow rate of the piston cooling nozzle is studied with the increasing of nozzle convergent length and diameter through several simulation experiments, respectively. The results show that the flow rate of piston cooling nozzle decreases linearly with the increase of the nozzle closing length. The flow rate of nozzle increases nonlinearly with the increase of the convergent diameter. Compared with the convergent length, the change of convergent diameter has a greater influence on the flow rate of piston cooling nozzles. Finally, the analytical expression of the flow rate of piston cooling nozzle about the convergent diameter is obtained, which is of great value and guiding significance to the nozzle engineering design.

1. Introduction

With the development of technology of internal combustion engine, especially after the introduction of supercharging technology, the output power of the engine is further increased and the thermal load of the piston is also increasing, so the cooling of the piston has become an important research hotspot [1]. When the engine works, the piston reciprocates within the cold oil chamber at high speed along the axial direction of the cylinder. Therefore, great heat is produced by the friction between the piston and cylinder and the head temperature of the piston is very high. In order to ensure the working performance of the piston, it is necessary to cool the piston head [2]. If the cooling nozzle cannot work normally, it will cause the working temperature of the piston to rise sharply, causing cylinder pulling and the whole engine to be scrapped [3]. Therefore, it is extremely critical to cool the piston head. The following cooling methods are as follows: free nozzle cooling, oscillation cooling, and forced oscillation cooling of internal cooling oil channel [4].

In the traditional design, only one cooling nozzle is usually provided for the piston and the injection direction of cooling oil is fixed regardless of the working condition of the engine. In recent years, scholars have also done a lot of research work [5] on the effect of cooling and heat release of the nozzles. A series of results are also achieved. Nasif et al. used the finite volume method to calculate the convective heat transfer of impinging jet during piston cooling by a numerical method. The results show that the cooling jet can significantly reduce the temperature of the piston [6]. Agarwal et al. studied the heat conduction from the piston cooling nozzle to the piston and numerically simulated it and predicted the coefficient of heat release under the piston. The cooling effect [7] on piston was studied with variety of injection speed of cooling-oil, nozzle diameter, and the distance from nozzle to piston. In addition, some scholars have also conducted experimental research on the cooling effect of piston cooling nozzle. Easter and Liu et al. conducted experimental research on the cooling performance of piston cooling nozzle and established the average heat transfer correlation of suitable area, namely, the Nusselt number. The results show that the Nusselt number is strongly correlated with nozzle diameter and injection viscosity but weakly correlated with the distance from nozzle to wall [8, 9].

Other scholars have done a lot of research work on the injection and heat release performance of the nozzle in other fields, such as fuel injection [10] and thermosiphon [11]. Kawaguchi et al. [12] carried out an in-depth study on the morphological fluctuation of the external flow field of the nozzle jet and believed that the fluctuation of the external jet was caused by the fluctuation of the internal flow field of the nozzle. However, because the heat of the piston is carried away by the cooling oil ejected from the nozzle, the flow rate of nozzle is critical to the heat dissipation of the piston. Cao et al. studied the heat transfer characteristics of oscillating flow in oil chamber of the piston and pointed out that the nozzle flow should not be too large or too small. The heat dissipation effect could not be achieved if the flow was too small. Excessive flow will reduce the thermal efficiency of the engine and increase the thermal stress of the piston [13]. Deng et al. studied the internal flow field of piston cooling nozzle and obtained the variation trend of flow rate of nozzle on the different length of oil inlet and diameter of inner hole of nozzle [14]. However, he did not give the quantitative relationship between flow rate of nozzle and the diameter of inner hole of nozzle. It is not very clear for the engineer to design nozzle parameters. Due to the structure layout in a small space of the engine and piston stroke requirements, there are not enough spaces to change the shape of the nozzle. Therefore, the diameter and convergent length of the nozzle are changed to adjust the injection flow while the overall flow length remains the same.

Under the same piston structure and thermal power conditions, the piston cooling effect is significantly different with the flow rate provided by the piston cooling nozzle. In this paper, the internal flow characteristics and flow control of the piston cooling nozzle are studied. The internal flow field of the piston cooling nozzle of an engine is modeled. The flow rate is compared between the physical experiment and simulation experiment and the most optimal model is obtained in line with engineering practice. The simulation experiments are conducted on the basis of optimal simulation model of flow field. Finally, the changing law of the flow rate of nozzle is obtained when the convergent length and diameter of nozzle change under the same total length of the flow channel of nozzle. The analytical expression of the flow rate of nozzle is obtained by polynomial fitting. This work has important guiding significance to nozzle design.

2. Experiment and Methods

2.1. Research Methods. The finite element method (FEM) is usually used to solve the fluid domain problems. All fluid particles in the nozzle domain follow three equations of fluid mechanics:

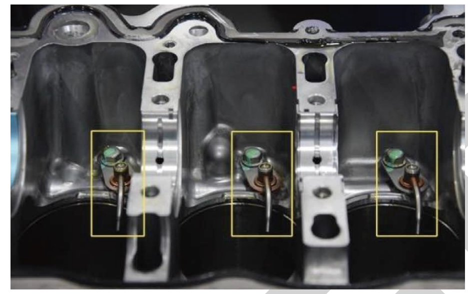

Figure 1: The installation position of the nozzle.

$$\begin{cases} \dfrac{\partial \rho}{\partial t} + \operatorname{div}(\rho \vec{v}) = 0, \\[2ex] \dfrac{\partial \vec{v}}{\partial t} + (\vec{v} \cdot \nabla)\vec{v} = \vec{F} - \dfrac{1}{\rho}\nabla p + v\Delta \vec{v}, \\[2ex] \dfrac{\mathrm{D}}{\mathrm{D}t}\left(\dfrac{1}{2}u_i u_i\right) = u_i F_{x_i} + \dfrac{1}{\rho} u_i \dfrac{\partial p_{ij}}{\partial x_j}, \end{cases} \tag{1}$$

where ρ is density, $\vec{v}$ is the fluid particle velocity vector, u_i is that velocity component of fluid particle, $\vec{F}$ is mass force, p is the surface force, v is the kinematic viscosity of the fluid, and t is the time. By solving the three equations of fluid simultaneously, the flow properties of the fluid field inside the piston cooling nozzle can be obtained, such as velocity distribution, pressure distribution, and flow rate.

Due to the rapid development of computer technology, the inner fluid domain of piston cooling nozzle is calculated by the finite element method according to the computational fluid dynamics method, and the calculation process is fixed in the Fluent software.

Furthermore, a piston cooling nozzle is fixed on the target testbed, and the volume flow rate is tested under the given pressure at the nozzle inlet. At the same time, the viscosity, density, and other fluid parameters of the cooling oil are recorded. Then, the three-dimensional model of the flow field of the nozzle is established according to the corresponding nozzle structure. Then, the 3D model is imported into the Fluent software to set the boundary conditions consistent with the experiment. Many calculation models are adjusted to make the simulation experiment consistent with the physical experiment and the optimal calculation model is selected.

Because of the compact structure of the engine, the installation position and space of the piston cooling nozzle are restricted. Therefore, the convergent length and diameter of nozzle are mainly considered in the design change of nozzle structure while the overall geometric parameters are basically the same. The *convergent length* refers to the length of a contraction part of the nozzle at the outlet of the nozzle, which has been clearly marked in Figure 1. Finally, the outlet diameter and the convergent length of the nozzle are adjusted to study the changing flow of different nozzle

Figure 2: BCYD-800 viscosity tester.

Figure 3: Viscosity test experiment.

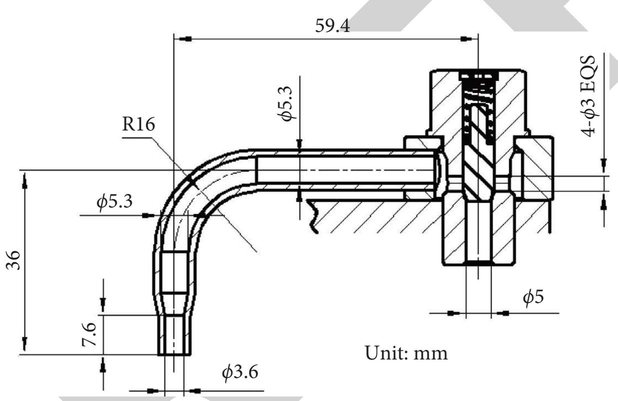

Figure 4: Section drawing of the piston cooling nozzle.

structures through simulation experiment with the optimal calculation model in the Fluent software.

2.2. Physical Experiment. First, the cooling oil was blended with engine oil and diluent. The ratio of the engine oil and diluent was adjusted repeatedly, and the viscosity test was carried out, so that the viscosity of the cooling oil tested in the experiment was 10.5 cst. The viscosity of cooling oil was tested by the BCYD-800 kinematic viscosity tester. Figures 2 and 3 show BCYD-800 viscosity tester and viscosity test experiment, respectively.

The prepared cooling oil is added into the shooting testbed of piston cooling nozzle and the jet experiment of piston cooling nozzle is carried out. The parameters such as pressure and flow rate of cooling nozzle were obtained. Figure 4 shows the size of internal flow channel of the tested nozzle, and 10 nozzles manufactured according to Figure 4 are tested for the jet flow experiment. The flow rate of the tested nozzles are listed in Table 1. Through several groups of test experiments, the average flow rate of piston cooling nozzle is 12.3 L/min with 400 kPa of the inlet oil pressure. Figure 5 shows the testbed of piston cooling nozzle and Figure 6 shows the experiment site of piston cooling nozzle.

2.3. Simulation Experiment. First, the three-dimensional model of piston cooling nozzle is established according to the structure of piston cooling nozzle in Figure 4, and then, the flow field model of piston cooling nozzle is extracted.

2.3.1. Three-Dimensional Modeling of Piston Cooling Nozzle. The main function of the piston cooling nozzle is to inject the oil into the cooling oil chamber in the piston head of engine accurately and quantitatively, so as to achieve the purpose of cooling the engine piston. Figure 7 shows the actual photo of the nozzle which is mainly installed at the end of the cylinder of engine. Its installation position is marked by yellow wire frame in Figure 1.

The piston cooling nozzle is mainly composed of valve head, injection pipe, position block, plunger, metal ring, and spring. Figure 8 shows a schematic diagram of its structure. From the Figure 8, it can be seen that when the cooling oil enters from the oil inlet, it pushes the plunger to compress the spring and move upwards. Then, the cooling oil enters the injection pipe and is sprayed out through the oil outlet to cool the engine piston.

SolidWorks software is usually used to model the piston cooling nozzle in three dimensions. Figures 9 and 10 show the three-dimensional model of the piston cooling nozzle.

2.3.2. Flow Field Modeling of the Piston Cooling Nozzle. In order to study the fluid flow state in the piston cooling nozzle, it is necessary to establish a three-dimensional model of the fluid domain. Therefore, the outer surface of the nozzle model is extracted in the SolidWorks software, and the oil inlet and outlet are closed and filled to obtain the solid model of the piston cooling nozzle. Then, the Boolean subtraction is done between the solid model of piston cooling nozzle and the original nozzle model. Therefore, the fluid domain model of the piston cooling nozzle is obtained, as shown in Figure 11.

2.3.3. Mesh Generation. First, the flow field inside the piston cooling nozzle should be divided into small elements. Therefore, the whole fluid domain should be divided into several tiny elements. If the element is too large, the amount of calculation is very small accompanied by low precision. On the contrary, the fine mesh produces high precision. Although the calculation accuracy is very high, it takes more

Table 1: The flow rate of tested nozzle.

No	1#	2#	3#	4#	5#	6#	7#	8#	9#	10#
Flow rate (L/min)	12.2	12.14	12.3	12.18	12.49	12.52	12.34	12.28	12.17	12.3

Figure 5: The testbed of the piston cooling nozzle.

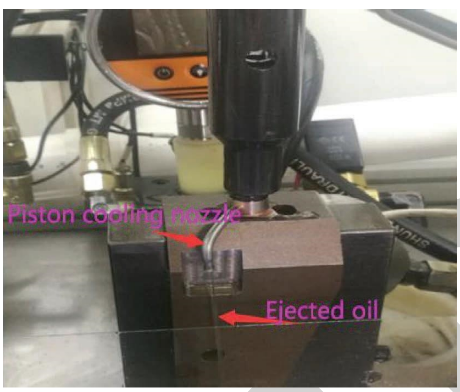

Figure 6: The jet experiment of the piston cooling nozzle.

Figure 7: Actual photo of the nozzle.

time and needs higher requirements for computer hardware. Therefore, the number of elements should be reduced as much as possible under the condition of satisfying the accuracy of calculation. Meshing should follow the following principles: (1) The number of nodes should be as large as possible in order to obtain more accurate results. (2) The difference between the maximum size and the minimum size of the elements should not be too large, and the best value range is between 1.2 and 1.4 times. (3) The nodes should be connected to adjacent element nodes as far as possible and not placed on adjacent boundaries. (4) The mesh should be fixed as much as possible, which is convenient for the computer to automatically generate the mesh.

In this paper, automatic meshing tools are used. The specific operations are as follows: first, the inlet, outlet, and boundary are determined and named, respectively. Considering that the flow velocity of the liquid attached to the wall is 0 and the central flow velocity is larger than the boundary, there is a span of flow velocity between them. Inflation is set upon the boundary layer to solve this problem. Figure 12 shows the meshed model.

In order to ensure the convergence of iterative solution, it is necessary to evaluate the mesh quality. The meshing tool provides the detailed evaluation indicators, as shown in Table 2. In this paper, the skewness and orthogonal quality are mainly selected for evaluating. Figure 13 shows the mesh quality distribution under the skewness parameter. Figure 14 shows the mesh quality distribution under orthogonal quality parameters.

Considering the skewness, it can be seen from the skewness evaluation that the value of 0~0.13 accounts for 7%, that of 0.13~0.35 accounts for 72%, that of 0.35~0.55 accounts for 15%, and that of above 0.55 accounts for 5%. Comparing the abovementioned values to the data in Table 1, it is concluded that the mesh quality is good. From the orthogonal analysis of the mesh quality, it can be seen from the orthogonal quality map that about 38% lies in 0.8~1, about 62% lies in 0.7~0.95, and about 17% lies in 0.63~0.7. It is same as the skewness. The overall mesh quality is relatively good. According to the statistics, the nozzle is meshed into 35,603 nodes and 93,448 units.

2.3.4. Boundary Conditions. According to the actual working conditions of the piston cooling nozzle, the inlet oil pressure is determined to be 400 kPa and the outlet is connected with the atmosphere, which is defined as a standard atmospheric pressure. Accordingly, the inlet, outlet, and wall are named as *inlet*, *outlet,* and *wall,* respectively, in mesh. To import the mesh into the Fluent software, we set the corresponding parameters in *Boundary Conditions* of Fluent, respectively. According to the abovementioned parameters, the default setting of the wall is used in the software.

2.3.5. Properties of Fluid Materials. At present, engine oil with viscosity of 10.5 cst is mainly used to cool the engine piston. Therefore, the density of the fluid material is set to 910 kg/m^3, corresponding dynamic viscosity of 0.009555 Pa•s. Figure 15 shows the interface of material parameter setting.

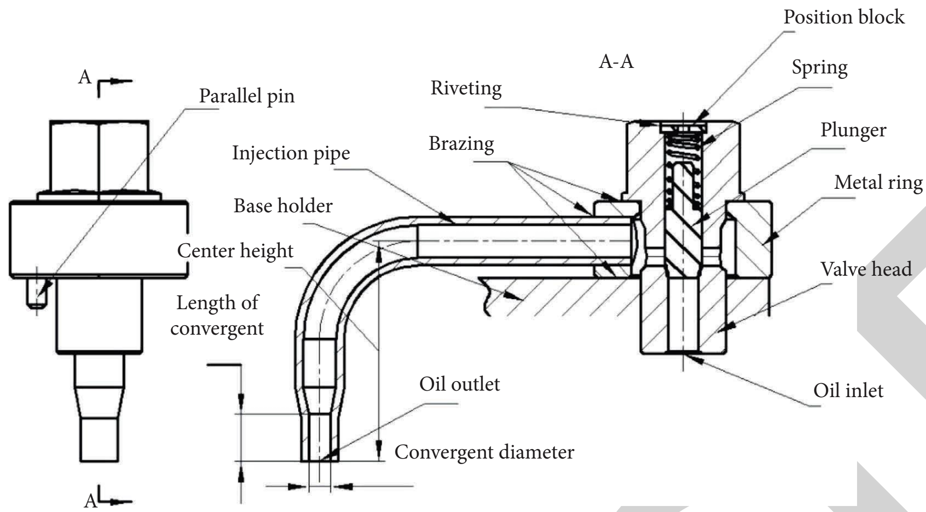

Figure 8: Structure drawing of the piston cooling nozzle.

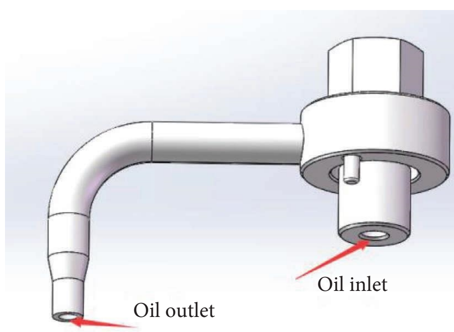

Figure 9: The three-dimensional model of the piston cooling nozzle.

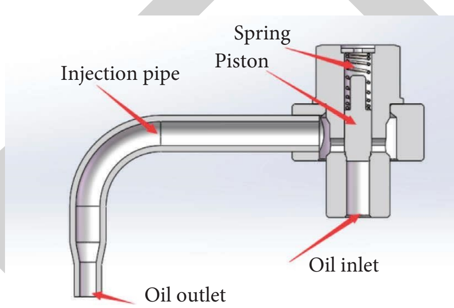

Figure 10: Sectional view of the nozzle assembly.

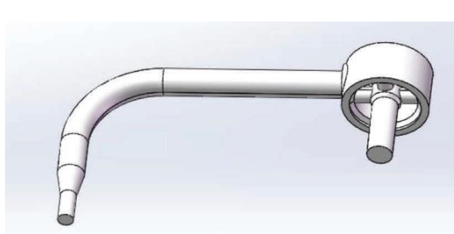

Figure 11: The fluid domain model of the piston cooling nozzle.

2.3.6. Flow Field Solution. Fluent provides three basic methods: coupled implicit solution, coupled explicit solution, and uncoupled solution. Uncoupled solution is generally used for incompressible fluid flow or compressible fluid flow with a low Mach number. However, this paper only involves the internal flow field, so uncoupled solution is chosen. Otherwise, Fluent provides lots of calculation models. Many calculation models are tested compared to physical experiment and the optimal calculation model is used.

Solving linear equations is generally the relaxation iteration method, and the relaxation iteration method has a relaxation factor to adjust the convergence rate of equations. The under-relaxation factors are set as Table 3. The convergent residuals of each parameter of the equation are shown in Table 4. The turbulence intensity and viscosity ratio at inlet of the nozzle are set at 5% and 10%, respectively, and the reflux turbulence intensity and viscosity ratio at the outlet are also set at 5% and 10%, respectively.

Simple algorithm is used for numerical solution in Fluent. The pressure and momentum are solved by a second-order upwind scheme. The turbulent kinetic energy and the turbulent dissipation rate are solved by a first-order upwind scheme. The standard initialization is selected. Each parameter is initialized to 0 and calculation program computes from inlet of the nozzle. The maximum iteration step is set to 1000.

3. Results

Many calculation models are selected, respectively, to solve the flow field of the piston cooling nozzle under the same boundary condition. Table 5 shows the flow rate of nozzle under the vary calculation models and physical experiment.

It can be concluded that the simulation result of the k-epsilon standard model is closest to the experimental data from the Table 5. Figure 16 shows a nephogram of velocity of flow field in the piston cooling nozzle under k-epsilon standard model. When the oil just enters the injection pipe,

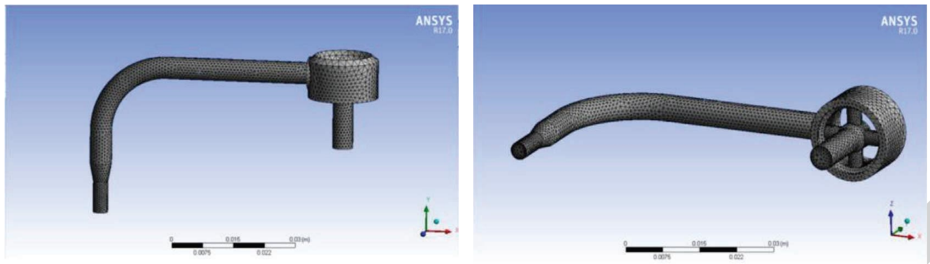

FIGURE 12: The meshed model of the piston cooling nozzle.

TABLE 2: Quality evaluation standard of fluid mesh.

Item	Excellent	Very good	Good	Acceptable	Poor	Unacceptable
Evaluation of inclination	0~0.25	0.35~0.5	0.5~0.8	0.8~0.9	0.9~0.97	0.98~1
Orthogonal quality evaluation	0.95~1	0.7~0.95	0.2~0.69	0.1~0.2	0.001~0.1	0~0.001

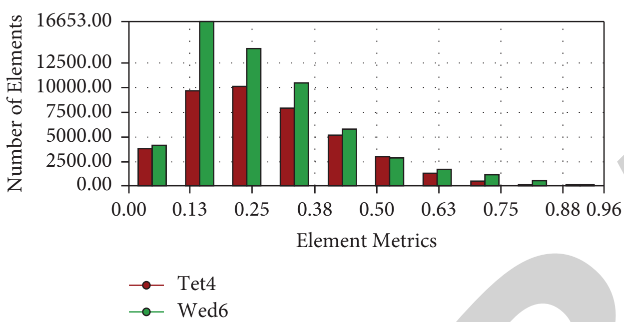

FIGURE 13: Mesh quality distribution under the skewness.

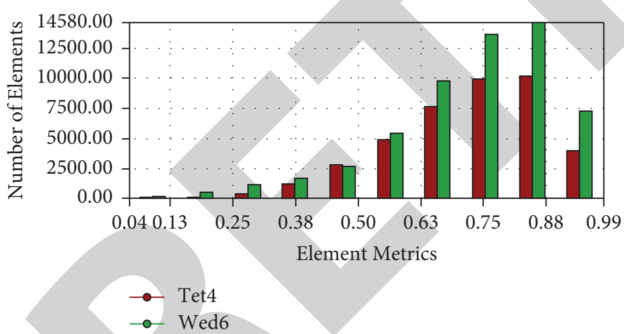

FIGURE 14: Mesh quality distribution under orthogonal quality.

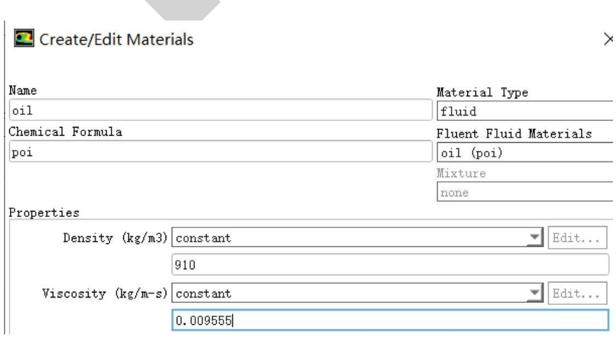

FIGURE 15: The interface of material parameter setting.

the flow state changes from turbulent state to steady state with the minimum speed. After entering the rear pipeline, it can be seen from the figure that the oil flow is basically stable. However, it can still be seen that there are signs of acceleration in the rear part. Then, the oil passes through the nozzle contraction. The speed of the oil suddenly changes and reaches the maximum at the outlet. Almost all the oil can be hit on the piston. It can be seen from Figure 17 that the nozzle flow rate is 0.1898 kg/s under k-epsilon standard model. It equals 12.51 L/min after conversion.

For different engines, the thermal power is different. Therefore, the requirements of the flow rate for piston cooling nozzles are different. Usually, the outlet of the injection pipe is contracted to different shape and size to obtain different injection flows.

3.1. The Influence of the Flow Rate of Piston Cooling Nozzle with Different Convergent Lengths. In this paper, the nozzle in Figure 4 is taken as a model and the convergent diameter is 3.6 mm. The influence of the flow rate of the nozzle with different convergent lengths from 0 to 15 mm is studied under the same length of center height and other geometric parameters which are marked in Figure 8. The other boundary conditions are the same as part 3.3 in this paper and the k-epsilon standard model is used. The 16 values of the convergent length (in Table 6) from 0 mm to 15 mm are calculated by Fluent software, respectively. Table 6 shows the calculated results.

In order to more intuitively reflect the change law of the flow rate of nozzle with different convergent length, the volume flow rate in Table 6 is plotted as a curve, as shown in Figure 18. As can be seen from the figure, with the increase of the convergent length, the flow rate of the nozzle shows a downward trend which is faster in the early stage and slower in the later stage and the overall decline shows a linear change.

3.2. Influence of the Flow Rate of Piston Cooling Nozzle with Different Convergent Diameters. In addition to using different convergent lengths to change flow rate of the nozzle,

Table 3: Under-relaxation factors of all the parameters.

Parameters	Pressure	Density	Body force	Momentum	Turbulent kinetic energy	Turbulent dissipation rate	Turbulent viscosity
Relaxation factor	0.3	1	1	0.1	0.8	0.8	1

Table 4: The convergent residuals of all the parameters.

Parameters	Continuity	x-velocity	y-velocity	z-velocity	k	Epsilon
Residual	0.001	0.001	0.001	0.001	0.001	0.001

Table 5: The flow rate of nozzle under the vary test condition.

Test condition	*Simulation experiment with Fluent software*							Physical experiment
	Laminar	Spalart–Allmaras	k-epsilon standard with standard wall function	k-omega standard	Transition k-k1-omega	Transition SST	Reynolds stress	
Flow rate (L/min)	13.05	12.92	12.51	12.9	12.73	12.92	12.76	12.3

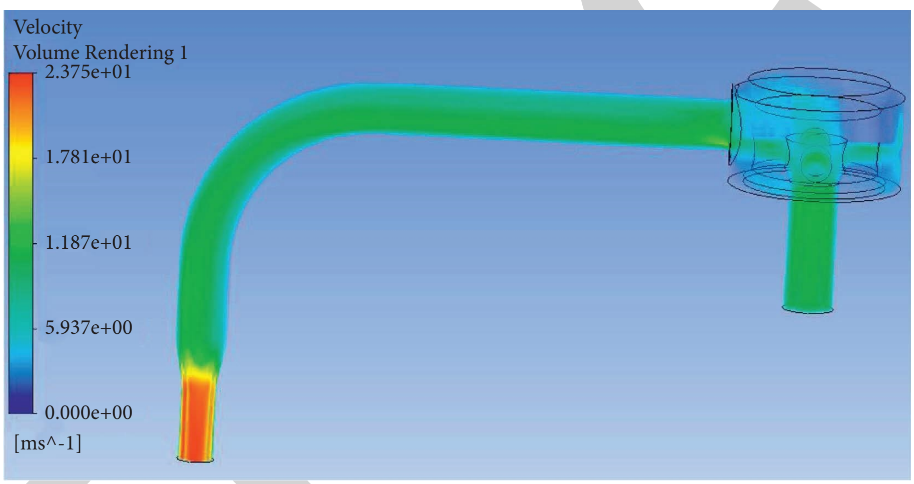

Figure 16: The nephogram of velocity of flow field.

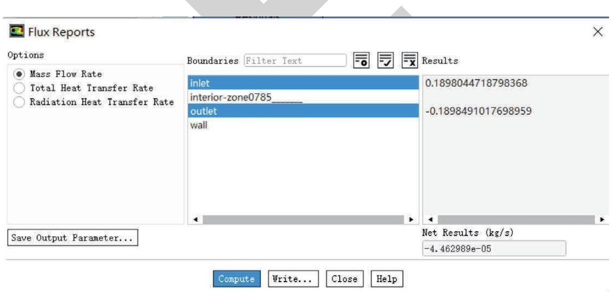

Figure 17: The flow rate of the piston cooling nozzle.

convergent diameter also has a great influence on the flow rate. Similarly, the 3D model of the nozzle is established according to the structure size of the nozzle shown in Figure 4. The other boundary conditions are the same as part 3.3 in this paper. When other conditions remain to be unchanged as part 3.1, the Fluent software is used to calculate the flow rate of nozzle under different convergent diameters. Figure 19 shows the curve of the flow rate of the piston cooling nozzle with different convergent diameters. As can be seen from the figure, the flow rate of the nozzle presents an upward trend with the increase of convergent diameter and the change trend is obviously nonlinear.

Comparing Figures 18 and 19, it can be seen that the change of the convergent diameter has a more significant influence on the flow rate than the convergent length. In order to better realize the engineering application, the simulation data in Figure 19 are polynomial fitted. Figure 20 shows the quadratic polynomial fitting curve, and Figure 21 shows the cubic polynomial fitting curve.

As can be seen from Figure 21, the simulation data of flow rate of piston cooling nozzle are in good agreement with the cubic fitting curve. Therefore, the following analytical expression is obtained as follows:

$$Q = -0.0036d^3 + 0.0327d^2 - 0.0126d + 0.0023, \qquad (2)$$

where Q is the flow rate of nozzle (L/s) and d is the convergent diameter (mm).

Table 6: The flow data of the piston cooling nozzle under different convergent lengths.

Closing length (mm)	0	1	2	3	4	5	6	7
Mass flow (kg/s)	0.197	0.1945	0.1931	0.1917	0.1908	0.1896	0.1885	0.1875
Flow rate (L/s)	0.216484	0.213736	0.212198	0.210659	0.20967	0.208352	0.207143	0.206044
Closing length (mm)	8	9	10	11	12	13	14	15
Mass flow (kg/s)	0.1867	0.1857	0.185	0.184	0.1831	0.1821	0.1813	0.1806
Flow rate (L/s)	0.205165	0.204066	0.203297	0.202198	0.201209	0.20011	0.199231	0.198462

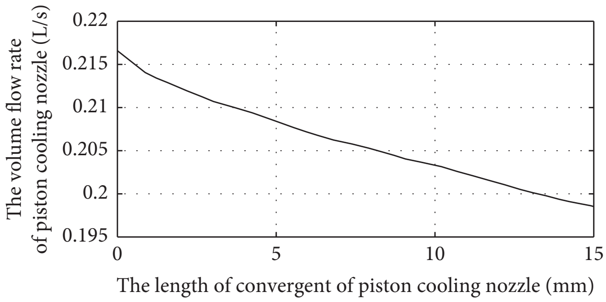

Figure 18: Curve of the flow rate of the piston cooling nozzle with different convergent lengths.

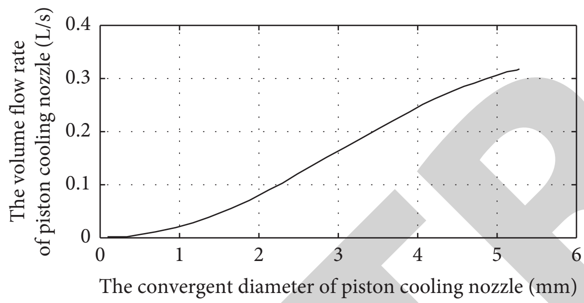

Figure 19: Curve of the flow rate of the piston cooling nozzle with different convergent diameters.

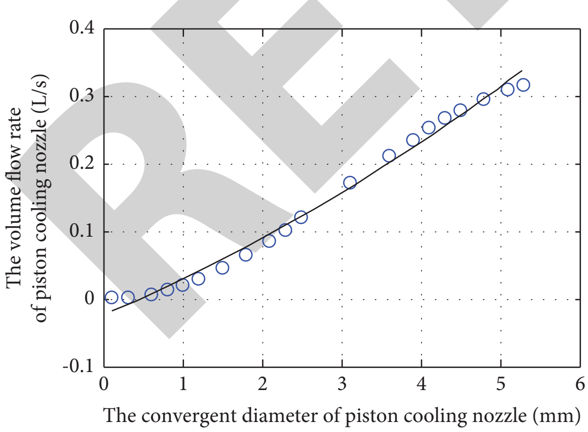

Figure 20: Quadratic polynomial fitting curve of the flow rate.

4. Discussion

As you can see from Figure 16 that the flow velocity of oil in the nozzle is up to 23.75 m/s. Therefore, the Reynolds Number is gained.

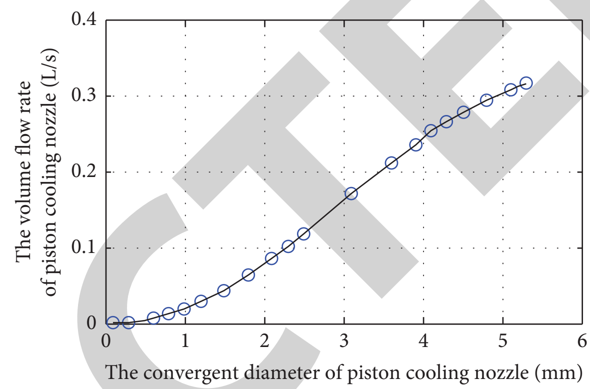

Figure 21: Cubic polynomial fitting curve of the flow rate.

$$\mathrm{Re} = \frac{\rho v D}{\eta} = \frac{910 \times 23.75 \times 0.0036}{0.009555} = 8142.9. \quad (3)$$

Because the Reynolds number of flow in the nozzle is relatively high, the laminar flow model is not applicable. Because of the large amount of dissipation by turbulence, the actual flow rate is relatively small. Therefore, the flow rate calculated by the laminar flow model is larger than the actual flow rate. However, the k-omega model introduces vorticity in the eddy viscosity coefficient, which is relatively stable for the flow near the wall. For the region with low Reynolds number, the distance to the wall does not need to be calculated under the k-omega model. The boundary layer is very thin in the nozzle because of the high Reynolds number. So, the calculated flow rate in the nozzle by k-omega model will be larger than the actual station. Therefore, among all kinds of calculation models, the standard k-epsilon model has the closest calculation results. From the simulation results, the calculation results of the standard k-epsilon model are closest to the physical experimental results. Therefore, it is reliable to use the standard k-epsilon model to simulate the flow field of piston cooling nozzle.

5. Conclusion

In this paper, the three-dimensional models of piston cooling nozzle and its internal fluid field are established. The working boundary conditions are obtained by analyzing the actual working condition of the piston cooling nozzle. Finally, the internal flow field of the piston cooling nozzle under actual working conditions is simulated and analyzed by the Fluent software based on the theory of computational fluid dynamics. Therefore, the theoretical injection flow rate of the piston cooling nozzle is obtained. Otherwise, the reliability of the fluid model simulation analysis results is verified by the experimental test. Finally, the change law of the flow rate of piston cooling nozzle with different convergent length and diameter is studied by means of simulation analysis. The results show that:

(1) The flow rate of the piston cooling nozzle shows a linear downward trend with the increase of the convergent length.
(2) The flow rate of the piston cooling nozzle increases nonlinearly with the increase of the convergent diameter.
(3) By fitting the simulation data with cubic function, the analytical expression of the flow rate of the piston cooling nozzle with respect to the convergent diameter is obtained.

Data Availability

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Additional Points

This research is mainly applied to nozzle jet control, and the results have important reference value for the structure design of engine cooling nozzle.

Disclosure

The work has applied for national utility model patent in China (No: 202220770640.0).

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

Conceptualization was done by X.Z. and J.Z.; methodology was done by L.L.; software was designed by W.X.; validation was done by X.Z., G.H., and J.Z.; investigation was done by L.L.; data curation was done by W.X.; J.Z. wrote the original draft; X.Z. reviewed the manuscript; supervision was done by X.Z.; project administration was done by X.Z.; funding acquisition was done by X.Z. All authors have read and agreed to the published version of the manuscript.

Acknowledgments

This work of physical experiment was supported by the Jiujiang Huirui Machinery Co., Ltd., China. This research was funded by the science and technology project of Education Department of Jiangxi Province of China (grant number: GJJ201811), the Science and Technology Project of Jiangxi Science and Technology Department of China (grant number: 20203BBE52W017), and Innovation and Entrepreneurship Training Program for College students of Jiujiang University (grant number: X202111843153).

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