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Study on Internal Flow of Intersection Nozzle under Different Shrinkage Coefficients

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Abstract:

Three dimensional numerical simulation of internal flow in intersection hole with three different geometric shrinkage coefficients under different pressure is carried out by using the mixed multiphase flow additional cavitation model. The internal pressure distribution, velocity distribution, internal cavitation flow distribution and flow coefficient are analyzed, and compared with single injection hole. Analysis found: For the intersection hole (K less than 0), the discharge coefficient, mass flow rate and velocity at the outlet of the nozzle are slightly smaller than that of the single orifice. For equal section (K equals 0) intersection spray hole and tapered (k greater than 0) intersection nozzle, the discharge coefficient, mass flow and velocity at the outlet of nozzle are larger than that of single injection hole. In the four nozzle .The flow coefficient of the tapered intersection hole at the outlet is the highest, which is about 30% higher than that of the conventional single jet hole.

Keywords: Diesel Engine; Internal cavitation flow; intersection nozzle; numerical simulation**.**

1. Introduction

In order to meet the increasingly stringent emission regulations and improve fuel atom- ization, the injection pressure of diesel engine is gradually increased [1]. However, the fuel injection system becomes very unstable due to the increase of the injection pressure in the diesel engine, and the internal flow of the nozzle has a great influence on the spray [2-3] .so the flow state in the injector orifice has been paid more and more attention as an important factor for the influence of the fuel atomization in the diesel engine [4-5].

In order to overcome the pressure instability in high pressure injector, Long et al proposed a design method of intersection nozzle and achieved the effect to a certain extent, And the simulation is done with CFD, It is found that the nozzle with intersecting holes can suppress cavitation [6].However, there is not enough knowledge about the different shrinkage coefficients internal flow state of intersection nozzle at different press drop, In order to further understand this phenomenon, In this paper, the flow state of intersection nozzle at three different geometric shrinkage coefficients under different pressure drop is analyzed, so as to provide some reference for the design of diesel engine.

2. Theoretical models

In this paper, an additional Schnerr-Sauer cavitation model of multiphase flow is applied .The flow state of four kinds of spray holes under different pressure difference is analyzed. The flow state of the liquid in the nozzle and the development state of the cavitation are solved. The basic turbulence models

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using standard K-ξ. The standard wall turbulence model, the wall is fixed without slip, using simplce algorithm to solve. The transmission equation of Schnerr-Sauer cavitation model is as follows:

$$\frac{\partial}{\partial_t}(\alpha\rho_v) + \nabla(\alpha\rho_v\vec{V}) = \frac{\rho_v\rho_l}{\rho}\frac{D\alpha}{Dt} \tag{1}$$

Where α is the gas phase volume fraction, ρ_v is vapor density, and ρ_l is liquid density, $\vec{V}$ is gas velocity, time is t. The bubble radius R_B is obtained by the following equation:

$$\mathrm{R} = \frac{\rho_v\rho_l}{\rho}a\,(1-\mathrm{a})\,\frac{3}{R_B}\sqrt{\frac{2}{3}\frac{(P_v-P)}{\rho_l}} \tag{2}$$

$$R_B = \left(\frac{a}{1-a}\frac{3}{4\pi}\frac{1}{n}\right)^{\frac{1}{3}} \tag{3}$$

R is the mass transfer rate, P_v is gas static pressure, P is Hydrostatic pressure.

In order to describe the flow in the tube better, the flow coefficient C_d and the geometric shrinkage coefficient K are introduced. Flow coefficient is a very important parameter in pipe flow. It reflects the relationship between actual flow and ideal flow. The geometric shrinkage coefficient reflects the extent of shrinkage. The flow coefficient can be obtained by the combination of Bernoulli equation and continuity equation. The equation as follows:

$$C_d = \frac{Q}{A\sqrt{2\rho\,(P_{in}-P_{out})}} \tag{4}$$

Where Q is the mass flow of liquid, A is the intersection-sectional area of the geometrical parameters of the spray hole, and P_{in} is Inlet pressure, P_{out} is Outlet pressure. The geometric contraction coefficient K is defined as follows:

$$\mathrm{k} = \frac{D_{in}-D_{out}}{L} \times 100\% \tag{5}$$

On above, D_{in} is the entrance diameter of the nozzle orifice, D_{out} is the outlet diameter of the sub orifice, L is the length of sub nozzle hole, The intersection nozzle L is defined as the minimum distance from the orifice outlet to the orifice pressure chamber.

3. Results and discussion

In this paper, the simulation of four nozzles is simulated by fluent, A is a single injection hole, and A-4, A0，A4 are symmetrical intersection holes, the intersection nozzle is formed by the intersection of two sub orifices along the flow direction, The mesh model of the nozzle is shown in Fig. 1, and the model is meshed with ICEM mesh, The number of grids is respectively: A is 202168 Element, A-4 is 257152 Element, and A0 is 267686 Element, A4 is 272124 Element. Four kinds of spray holes have been locally encrypted at the sub hole, the outlet diameters of the spray holes are 0.14mm.

The difference between contractions coefficients of symmetric intersection spray holes, the specific geometric dimensions are shown in Table 1.The fluid medium in the spray hole is ordinary diesel, the density is830kg/m^3, the viscosity is2.36×10^{-3}Pa · s, surface tension is 0.026N/m, and the saturated vapor pressure is 892Pa.

The initial volume fraction of liquid phase diesel was 100%, and the initial volume fraction of gaseous diesel was 0%. After repeated calculation and experimental verification, when the bubble volume density value is1.6× 10^{14}, the simulation results are closest to the experimental results. The boundary condition is that the outlet pressure is constant 10MPa, the inlet pressure is 60MPa~160MPa, and use none slip wall is adopted.

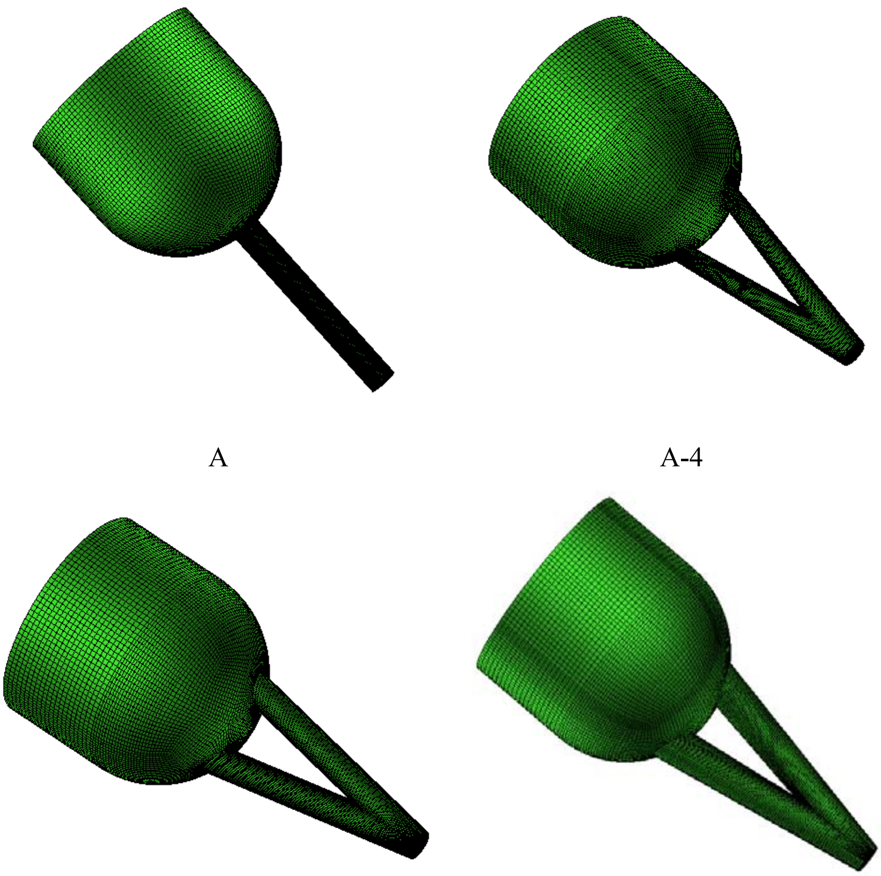


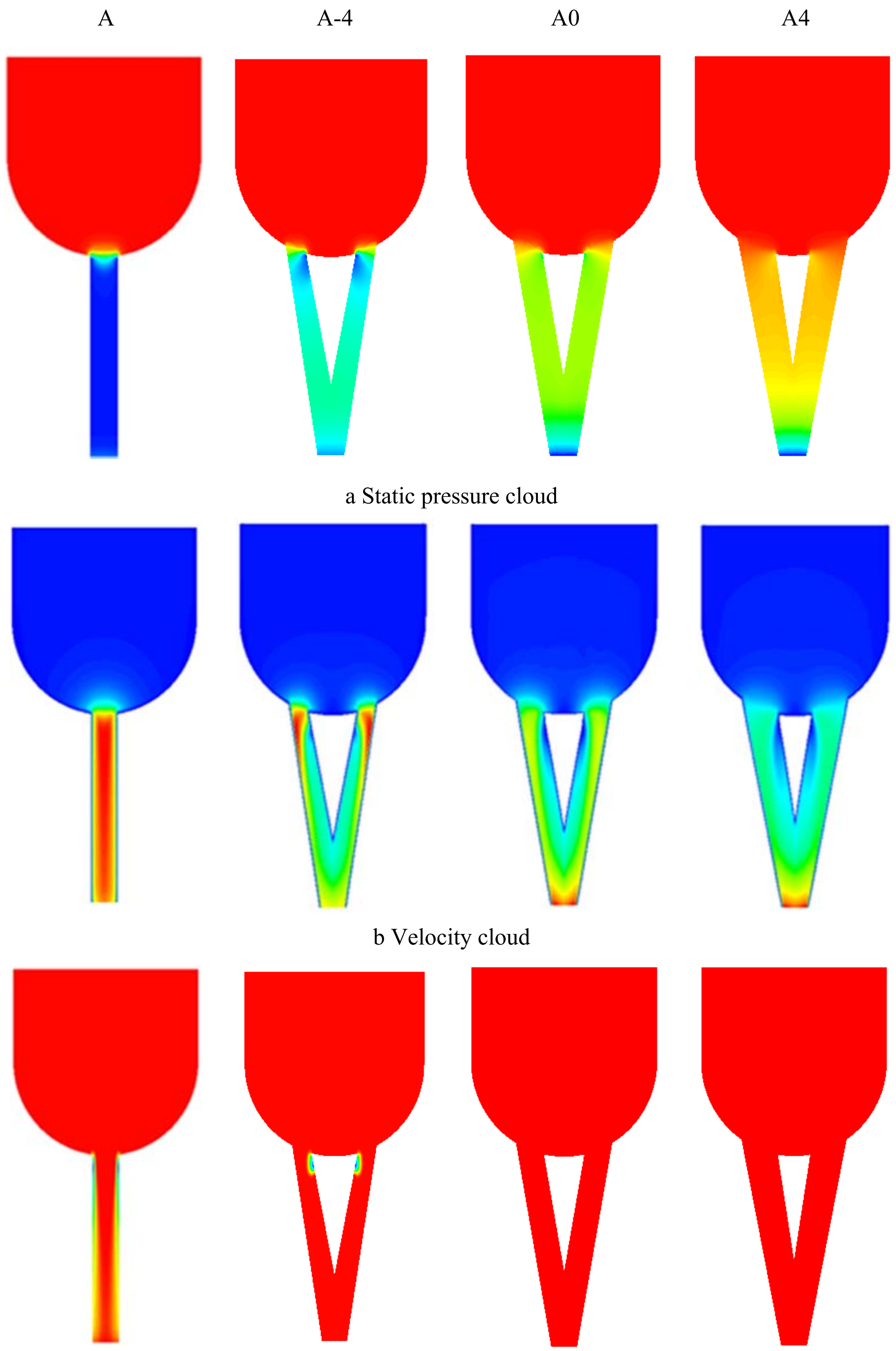
Fig. 1. Four nozzle mesh models

Table 1. Geometric parameters of nozzle hole

group	A	A-4	A0	A4
Intersection angle	0	20	20	20
Contraction coefficient	--	-4	--	4
Inlet diameter（mm）	0.14	0.10	0.14	0.18
Outlet diameter (mm)	0.14	0.14	0.14	0.14
Nozzle hole length(mm)	1	1	1	1

3.1. Cloud images under the same pressure difference

Fig. 2 is 10MPa back pressure, inlet pressure is 130MPa, A A-4 A0 A4 nozzle static pressure, velocity cloud image and hole cloud image. It can be seen from Figure 2a that under the same inlet and outlet pressure, the pressure value of the nozzle hole of A model orifice is the smallest, The negative pressure zone appears near the wall, Secondly, the pressure value of A-4 jet hole appears negative pressure area in the inner part of the entrance of the sub jet hole, Low pressure values cause cavitation in the area, There is no severe pressure drop in the transition zone between the pressure chamber and the sub nozzle of A0 and A4 nozzle, Compared with A A-4, the pressure transition is smoother, However, the pressure at the exit of A0 and A-4 is lower than that of A4.



c cavitation cloud

Fig. 2. Nozzle nephogram results

It can be seen from Figure 2b that the A nozzle has a larger velocity inside the nozzle hole, The velocity of A-4 nozzle at the inlet of the injector orifice is larger, and decreases gradually along the radial direction. The velocity transition of A0 nozzle in the nozzle hole is relatively smoother, at the outlet, the velocity is larger. The A4 nozzle has the most uniform velocity transition in the four nozzle holes and the maximum velocity at the outlet.

Comparing the liquid volume fraction of the four orifices can be seen (Fig. 2c) A severe cavitation phenomenon occurred at the entrance of the nozzle at A nozzle, and the cavity developed along the wall facing the nozzle exit. There was a severe cavitation phenomenon in the local region of the A-4 nozzle at the entrance of the injector orifice, and the cavitation disappeared at the exit. Cavitation phenomena were not observed in A0 and A4 nozzles. Contrast A-4 A0 A4 nozzle results can be obtained, the reason of cavitation formation in A-4 jet hole is that the section area from inlet to outlet expands gradually and the flow area at the entrance is less than the area of A0 A4 nozzle.

3.2. Mass flow under different pressure

Fig. 3 is the variation of mass flow at the outlet of four nozzles with the inlet and outlet pressure difference, it can be seen from the diagram that the mass flow rate of the four nozzles increases with the increase of pressure difference. Under the same inlet and outlet pressure, the mass flow at the outlet of A4 nozzle is the largest, which is higher than the mass flow rate of single hole 29%~31%, A0 is second, higher than A mass flow rate 19%~20%, A-4 flow is smaller than A mass flow.

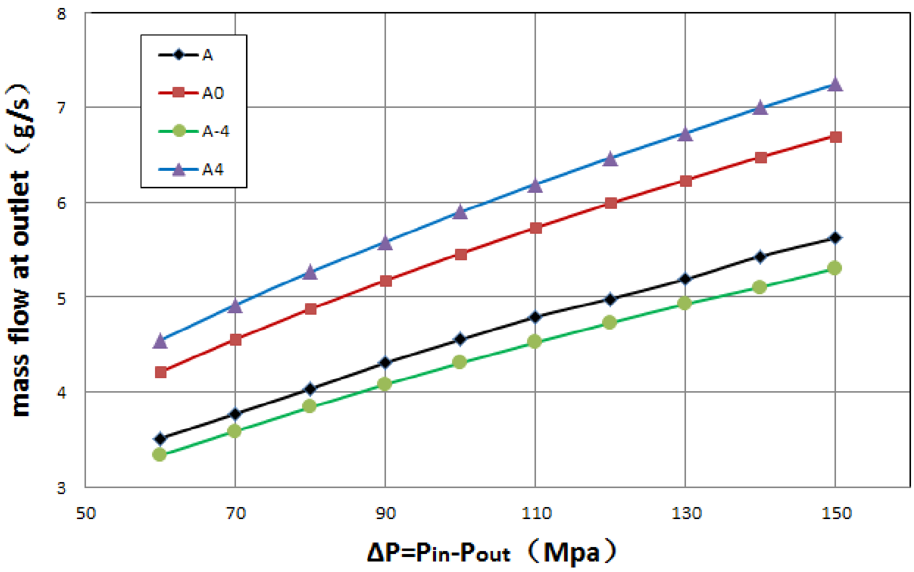


Fig. 3. Mass flow at outlet agree with pressure difference

It shows that the intersection jet hole promotes the mass flow in the nozzle at a certain extent, For the A-4 nozzle, The intersection-sectional area of the entrance shrinks so that the fluid area that flows in the area are shrinks, At the same time, the cavitation phenomenon at the entrance of the area hinders the flow of the fluid in the flow direction, making the flow rate at the outlet of the nozzle smaller than A orifice.

3.3. Velocity under different pressure

From (Fig. 4) the Variation of four nozzle outlet speeds with pressure difference we can see the velocity at the exit of the four orifices increases with the increase of the pressure. Under the same pressure inlet condition, the A4 nozzle has the largest velocity at the exit. Contrast figures 5 and figures 4 can be found that, the variation trend of the velocity of the four orifices with the pressure difference is basically the same as the variation trend of the flow rate with the pressure difference.

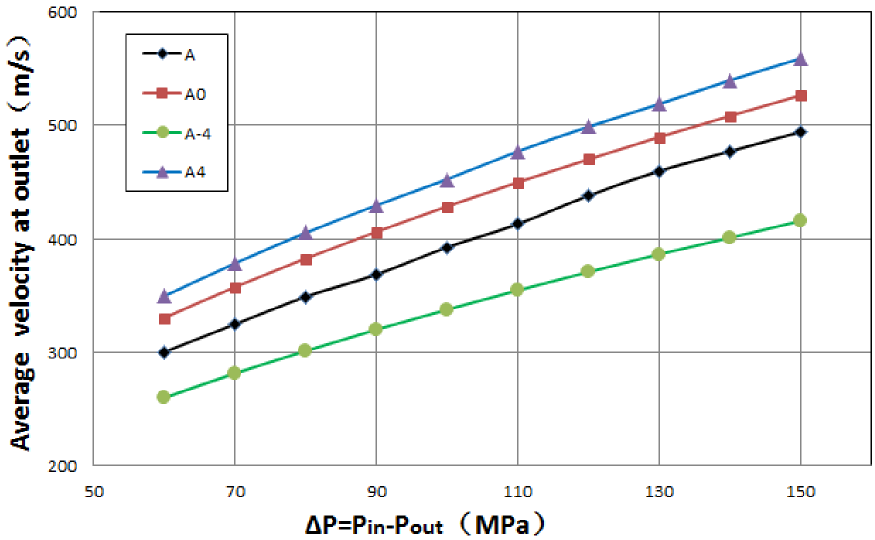


Fig. 4. Velocity at outlet agree with pressure difference

3.4 discharge coefficients at different Reynolds numbers

Figure 5 is the relationship between the Reynolds number and the discharge coefficient of the four orifices. A nozzle decreases with the increase of Reynolds number because of the increase of pressure difference, the cavitation in the whole increases, hindering the flow of the fluid in the nozzle. The change of flow coefficient in A0 and A4 nozzle basically does not change with Reynolds number, which indicates that intersection nozzle, is more difficult to produce cavitation.

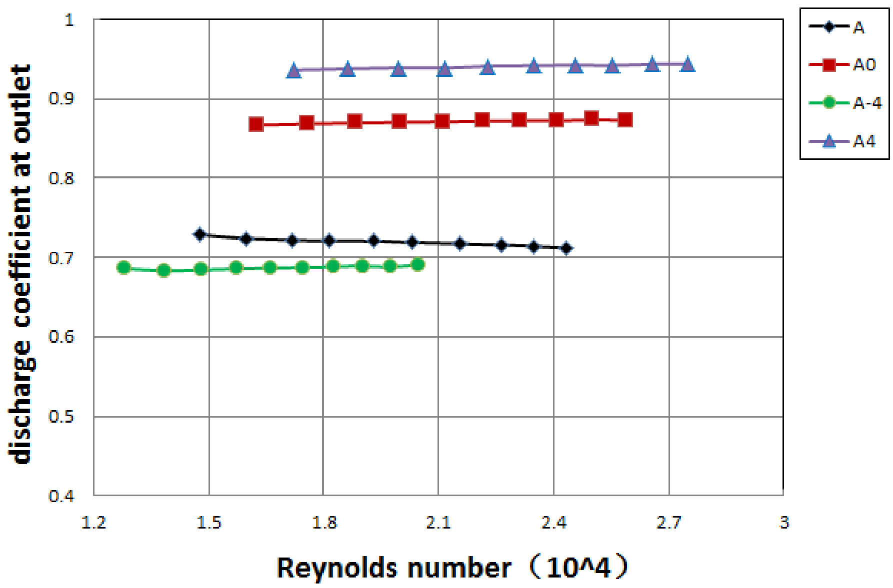


Fig. 5. Relationship between flow coefficient and Reynolds number

The discharge coefficient of A-4 is the smallest in the four orifices, this is because the contraction of the inlet intersection section reduces the import flow area, at the same time, and cavitation phenomenon at the inlet also leads to the decrease of the discharge coefficient in the nozzle.

4 Results and discussion

(1) When the backpressure is constant, the mass flow rate of the four orifices increases approximately linearly with the increase of inlet pressure. At the same time, the mass flow rate of intersection hole in K=0 and k=4 is 21% and 31% higher than that of single injection hole respectively. Under the same injection condition, the flow coefficient increases with the increase of K value of geometric shrinkage coefficient, When K>0, the discharge coefficient of intersection jet hole is more than 21% higher than that of single hole。

(2) The cavitation state for the conventional nozzle is from the nozzle inlet gradually extended to the exit. For intersection spray holes, When the coefficient of contraction is K<0, the cavitation occurs at the entrance of the sub nozzle at the inner side, At K>0, cavitation is not observed in the intersection jet hole, which promotes the flow of the liquid in the nozzle. In summary, it is shown that the intersection spray hole with contraction coefficient K>0 has better atomization effect in high pressure jet diesel engine.

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