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Simulation research of fire water cannon nozzle based on fluent

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ABSTRACT

Fire water cannon is the main equipment in fire protection work, which is evolving towards large flow, long distance and high shooting. As an important core component of fire water monitor, the structural design of nozzle plays an important role in jet performance. The Fluent fluid simulation software was used to simulate the internal flow field of the fire nozzle model with different outlet diameters and convergence angles. The average jet velocity and turbulent kinetic energy under different parameters were compared to obtain the optimal size parameters of the fire nozzle. The results show that when the inlet diameter is 100 mm, the inlet pressure is 1.2 MPa, the length of the rectifier section is 95 mm, the outlet diameter is 50 mm, and the convergence angle is 11 °, the jet performance of the fire monitor nozzle is the best. The simulation results can provide reference for the structural design and practical application of fire water monitor nozzle.

KEYWORDS

Fire water cannon; Jet performance; Structural design; Numerical simulation spray.

1. PREFACE

With the progress of the times, the number of high-rise buildings, large warehouses and petrochemical plants in the city has risen sharply. The flammable substances in these places are more abundant, and the incidence of fires is also increasing. This has brought huge losses to our economy, but also brought great danger to our lives [1-3]. Fire water cannon is the most commonly used efficient fire extinguishing equipment in today 's society. As the core component, nozzle has become a hot spot for researchers at home and abroad.

Liu Zhengqin [4] analyzed the influence of nozzle, pressure, flow, pitch angle, installation height and other parameters on the jet trajectory. Hu Guoliang et al. [5] analyzed the structure design and water jet characteristics of fire water cannon, especially the structure of flow channel and nozzle of fire water cannon. L GENG [6] established a mathematical model of thrust calculation, and verified that the thrust is closely related to the nozzle height and diameter by numerical calculation. Zhang Lijie [7] used Fluent to simulate the flow field of three different inner contour structures of the fire water monitor nozzle, and determined the best structure of the inner contour of the water monitor nozzle. [8] proposed a nozzle with three convergent section flow channel curves of inclined straight line, Witozinsky curve and the steepest curve. It is found that the jet performance of the steepest curve nozzle is the best. Most of the above studies are only a general overview and comparison of the nozzle structure, and few are accurate to the specific size in discussing its influence on the jet trajectory. Therefore, this paper will simulate the fire nozzle and obtain the optimal structural parameters of the nozzle.

In this paper, the standard k-epsilon model is used to simulate the turbulent flow field, and the SIMPLE algorithm is used to solve the flow value of the flow velocity in the flow field. At the same time, the momentum, turbulent kinetic energy and turbulent dissipation are set to Secong Order Upwind. The influence of different outlet diameters and convergence angles of the nozzle on the jet performance is analyzed, and the optimal structural parameters of the nozzle are obtained.

2. FIRE WATER MONITOR NOZZLE STRUCTURE DESIGN

2.1. The definition and classification of fire water cannon nozzle

The nozzle is a kind of energy conversion element, which converts pressure energy into kinetic energy by converting energy during jet operation, and finally jets outward in the form of high-speed jet to extinguish fires within a certain distance. [9-10] Therefore, a nozzle with good performance can greatly improve the efficiency of fluid medium jet and obtain good jet performance.

There are many kinds of nozzles, which can be divided into: spiral nozzle, cylindrical nozzle with straight hole, conical nozzle and so on. In the actual project itself, conical nozzle and cylindrical nozzle with straight hole are often used. The cylindrical nozzle with straight hole has two functions of nozzle and spray gun. Although the structure is simple, the range and service life are short. The conical nozzle has a straight section with a bunching effect and a conical inlet with a diversion effect. It has a long range, simple design and easy processing. According to different structures, it can be divided into: diversion nozzle and direct current nozzle. The structure of diversion nozzle is complex, which can realize the mutual conversion between direct current and spray jets. The DC nozzle jet has good clustering, simple appearance and easy operation. In the same state, the range is much larger than that of the diversion nozzle, which is why most of the fire water cannons with long range, high shooting height and large flow rate adopt the DC nozzle [11-12].

Because the range of fire monitor is closely related to its nozzle structure and size [13], this paper mainly studies the straight cone nozzle.

2.2. Structure calculation of fire water monitor nozzle

The structural parameters of other components of the fire water monitor can refer to the diameter of the main channel. The nozzle design can be based on the provisions of the national fire monitor (GB 19156-2019) [14]. The given parameters are; working pressure P0 = 1.2MPa, inlet flow Q = 80L / s, rectifier section length L = 95mm, nozzle overall length 450mm, gun body outlet diameter can be calculated by Formula (1) [15].

Flow through nozzle outlet Q

$$Q = C_0 A \sqrt{\frac{2P_0}{\rho}} \tag{1}$$

In the equation:

Q—Fire water monitor rated flow, that is, nozzle outlet flow, L/s;

C0—Nozzle flow coefficient ; the fire water monitor nozzle end shrinkage is obvious, the flow loss is bigger, Therefore take 0.8;

A—nozzle area, mm2, $A = \frac{\pi d^2}{4}$, d is the outlet diameter of fire water monitor;

P0—Fire water cannon inlet static pressure, namely the rated working pressure MPa;

ρ—Medium density, water density, 1×103kg/m3。

From the above formula, the nozzle cross-sectional area A

$$A = \frac{Q}{C_0}\sqrt{\frac{\rho}{2P_0}} \tag{2}$$

Fire water cannon outlet diameter d

$$d = \sqrt[4]{\frac{8\rho}{{C_0}^2\pi^2 P_0}}\sqrt{Q} \tag{3}$$

According to the working parameters of the designed fire water monitor, the outlet diameter of the water monitor is calculated.:

$$d = \sqrt[4]{\frac{8 \times 1 \times 10^3}{0.8^2 \times \pi^2 \times 1.2 \times 10^6}} \times \sqrt{80 \times 10^{-3}} = 0.051m = 51mm$$

According to the actual investigation, the flow rate of the water system extinguishing agent in the pipeline is about 10 m/s, and the general design requirement should be less than 12 m/s. According to this, the diameter D of the nozzle inlet of the fire water monitor can be calculated.

By the formula of nozzle cross-sectional area

$$A = \frac{\pi D^2}{4} = \frac{Q}{V} \tag{4}$$

Fire water monitor nozzle inlet diameter D

$$D = \sqrt{\frac{4Q}{\pi V}} = \sqrt{\frac{4 \times 80 \times 10^6}{\pi \times 10 \times 10^3}} = 101mm$$

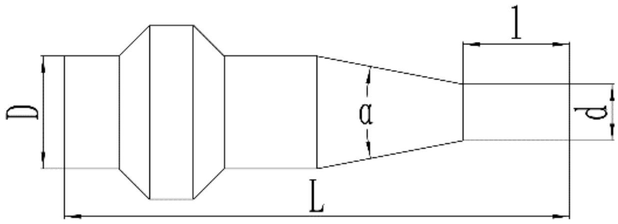
According to the definition and selection criteria of the nominal size of pipe components in the national standard (GB/T 1047-2019) [16], the pipes with pipe specifications of DN50 and DN100 are selected as the outlet and inlet of the fire water monitor nozzle respectively. At this time, the average flow rate of the nozzle inlet pipe is 10.2 m / s, which meets the actual operation requirements.

At this time, the nozzle outlet velocity v

$$v = \frac{Q}{A} = \frac{4Q}{\pi d^2} = 39.2m/s$$

2.3. Structural design of fire water monitor nozzle

According to the above design criteria, the nozzle structure of the fire water monitor designed in this paper is shown in Figure 1, and the design parameters are shown in Table 1.



D- Nozzle inlet diameter d- Nozzle outlet diameter

a- Nozzle convergence angle L- Overall length of nozzle l- Length of nozzle rectifier section

Fig.1 Fire water cannon nozzle structure diagram

Table 1. Structural parameters of fire monitor nozzle

structure	parameter
Nozzle inlet diameter D/mm	100
Nozzle outlet diameter d/mm	50
Nozzle convergence angle a/°	11
Overall length of nozzle L/mm	450
Length of nozzle rectifier section l/mm	95

3. FIRE NOZZLE FLOW FIELD SIMULATION MODELING

When water flows through the nozzle, the whole nozzle model is composed of fluid domain and nozzle shell. Since this paper simulates the flow field region, the simulation model is the fluid domain of the nozzle, and the three-dimensional model of the fluid domain is shown in Figure 2.

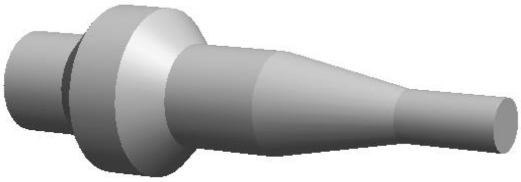


Fig.2 Three-dimensional model of fluid domain

In order to improve the calculation accuracy, the ICEM grid division with both structured grid and unstructured grid is adopted. The grid quality is high, which is beneficial to improve the simulation analysis results. The fluid domain grid division results are shown in Figure 3.

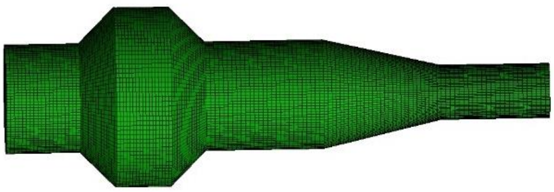


Fig.3 Fluid domain meshing

The water in the nozzle fluid domain of the fire water monitor is an incompressible fluid. Without considering the heat exchange, Fluent is used to simulate the nozzle fluid domain of the fire water monitor. The pretreatment settings are shown in Table 2.

Table 2. Nozzle fluid domain pre-processing parameter settings

attribute	option	parameter
Time	Steady	—
Models	k-ε	Standard k-ε
Materials	Water-liquid	—
Boundary Conditions	Pressure-inlet	1.2Mpa
	Pressure-outlet	0Mpa
	Wall	Stationary Wall
Solver	Scheme	SIMPLE
Discretization	Momentum	Second Order Upwind
	Turbulent Kinetic Energy	Second Order Upwind
	Turbulent Dissipation Rate	Second Order Upwind

4. FIRE NOZZLE FLOW FIELD SIMULATION RESULTS ANALYSIS

The fire nozzle jet performance can be measured by the average outlet velocity and turbulent kinetic energy. The larger the average outlet velocity, the smaller the turbulent kinetic energy, the better the jet performance. According to the study of the influence of different parameters on the jet performance of the nozzle, the optimal combination of structural parameters such as inlet pressure, rectifier length, outlet diameter and convergence angle of the nozzle is determined. The simulation of fire water cannon nozzle under different convergence angles and different outlet diameters is analyzed in detail.

4.1. Simulation analysis of nozzle convergence angle

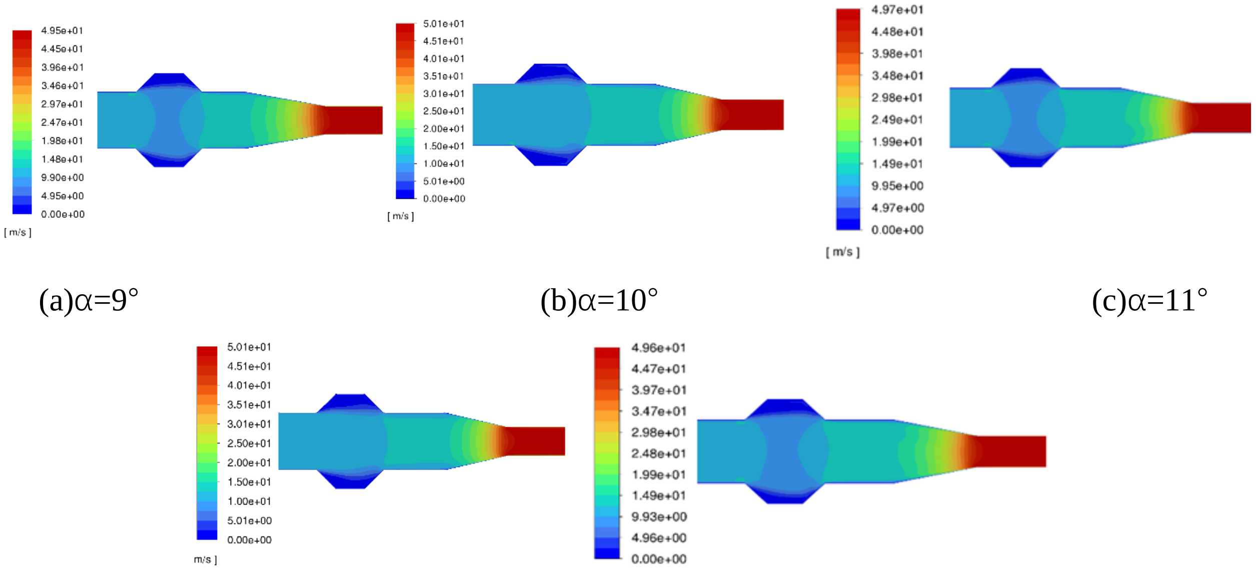
The convergence angle of the nozzle will change the fluid motion pattern of the fire water cannon, thus affecting the jet performance. Five groups of different convergence angles α are selected to establish a three-dimensional model and simulate it. The jet performance of fire water monitor is quantitatively analyzed, and the optimal convergence angle parameters are obtained.

The research shows that in the conical nozzle, the jet performance of the fire water monitor is the best when the contraction angle of the fire water monitor is a =12°~16° [17]. Therefore, it is particularly important to select the appropriate parameters for simulation. The parameter settings of the simulation model with different convergence angles are shown in Table 3.

Table 3. Parameter Setting of Simulation Model with Different Convergence Angle

structure	parameter
Nozzle inlet diameter D/mm	100
Length of nozzle rectifier section l/ mm	95
Inlet pressure P/ MPa	1.2
Overall length of nozzle L/mm	450
Nozzle convergence angle α/°	9-13
Nozzle outlet diameter d/ mm	50

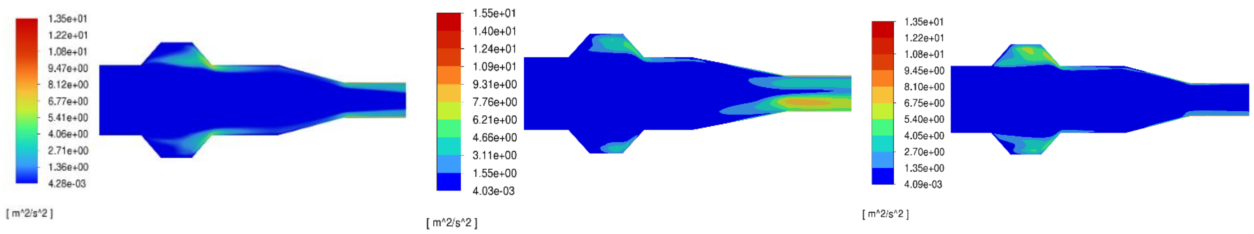
The velocity contours of 5 groups of different convergence angles of fire water cannon are shown in Fig.4, and the turbulent kinetic energy contours are shown in Fig.5.



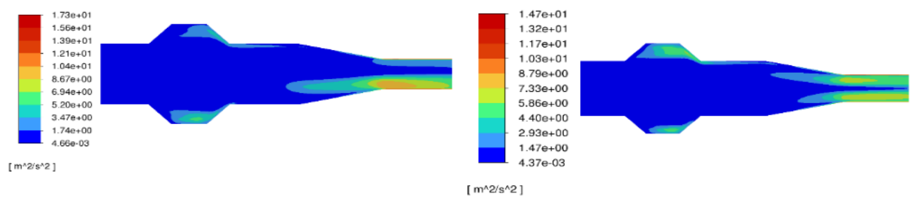
(a)α=9° (b)α=10° (c)α=11°

(d)α=12° (e)α=13°

Fig. 4 Velocity clouds of different convergence angle mod



(a)α=9° (b)α=10° (c)α=11°



(d)α=12° (e)α=13°

Fig.5 Turbulence kinetic energy clouds of different convergence angle model

In order to observe the influence of the convergence angle on the internal flow field more intuitively, the average velocity and turbulent kinetic energy of the cross section at different distances from the nozzle inlet (45 cm is the nozzle outlet) are plotted, as shown in Figure 6 and Figure 7.

From Figure 4 and Figure 6, it can be seen that the average speed of the fire water monitor increases with the increase of the distance from the nozzle inlet position during the injection process, and reaches the maximum value at the nozzle outlet position; when the convergence angle of the nozzle is in the range of 9°~13°, the average outlet velocity increases first and then decreases gradually with the increase of the convergence angle of the nozzle. When the convergence angle is 11 °, the average outlet velocity is the largest, which is 48.995 m / s.

It can be seen from Fig.5 and Fig.7 that when the convergence angle of the fire water cannon nozzle is in the range of 9°~13°, when other parameters are fixed, the convergence angle is 11 °, and the turbulent kinetic energy at the nozzle outlet is the smallest, which is 3.11 m2 / s2.

In summary, under certain conditions of other parameters, when the nozzle convergence angle is 11 °, the average outlet velocity of the nozzle is the largest, the turbulent kinetic energy is the smallest, and the jet performance is the best

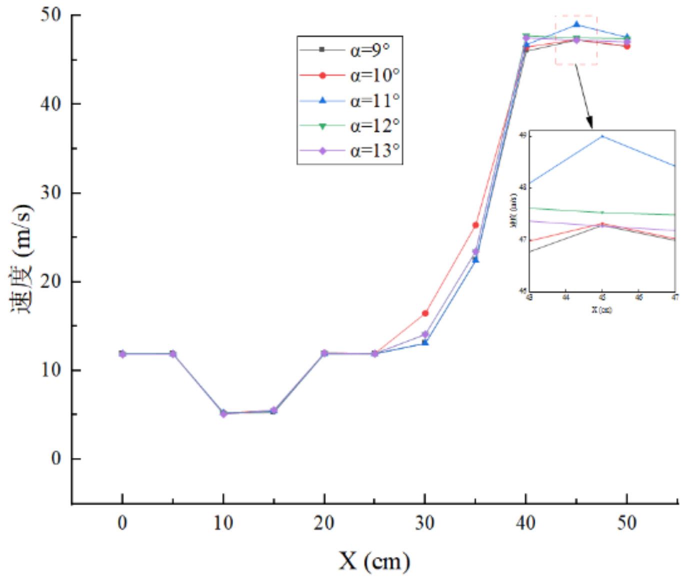


Fig.6 Average velocity distribution of models with different convergence angles

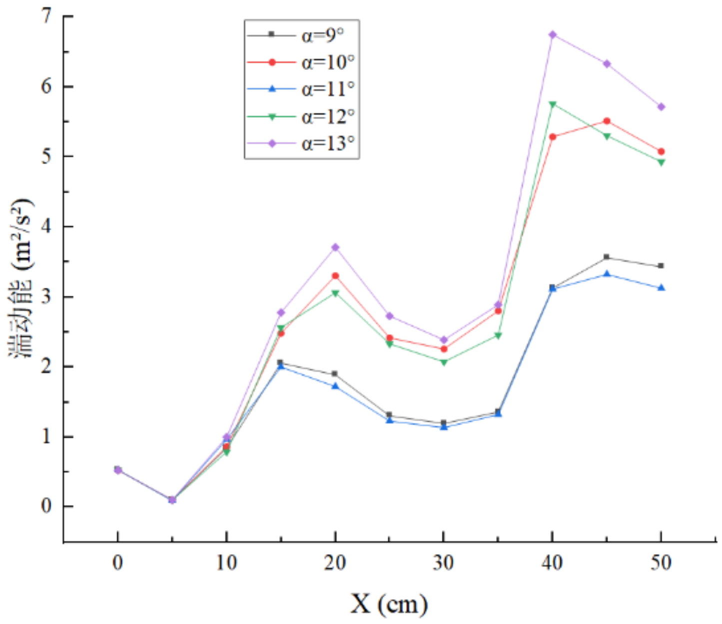


Fig.7 The turbulent kinetic energy distribution map of different convergence angle models

4. 2. Simulation analysis of nozzle outlet diameter

It can be seen from Formula (3) that the equivalent diameter d of the water cannon outlet is related to the flow rate, rated working pressure, flow coefficient and other factors. Under certain conditions of other parameters, the larger the outlet diameter is, the lower the jet velocity will be. The smaller the outlet diameter is, the higher the jet velocity will be, but the energy loss inside the nozzle channel will increase. Therefore, it is particularly critical to select the appropriate nozzle diameter for the jet performance. Now, five groups of models with different outlet diameter d are selected for simulation analysis, and the average outlet velocity and turbulent kinetic energy are analyzed to obtain the best structural parameters. The simulation model parameters are shown in Table 4.

Table 4. Different outlet diameter simulation model parameter settings

structure	parameter
Nozzle inlet diameter D/mm	100
Length of nozzle rectifier section l/ mm	95
Inlet pressure P/ MPa	1.2
Overall length of nozzle L/mm	450
Nozzle convergence angle α/°	11
Nozzle outlet diameter d/ mm	30-70

The velocity contours of five groups of different outlet diameters of the fire water monitor nozzle are shown in Figure 8, and the turbulent kinetic energy contours are shown in Figure 9.

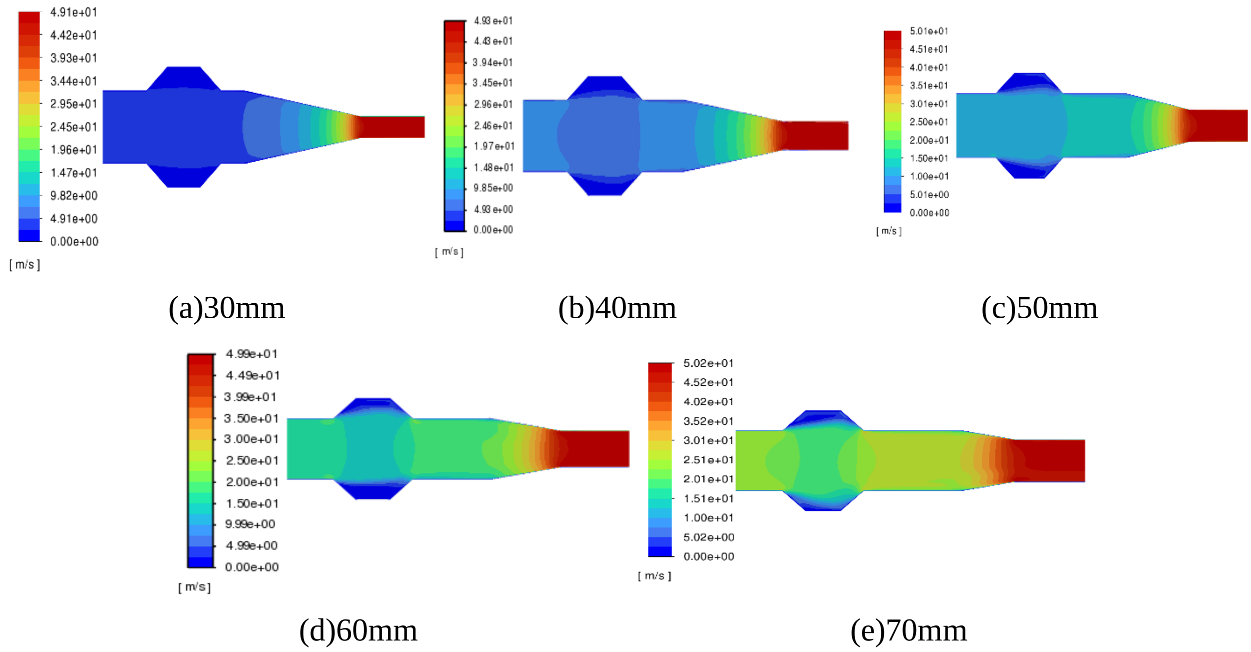


Fig.8 Speed cloud diagram of different outlet diameter model

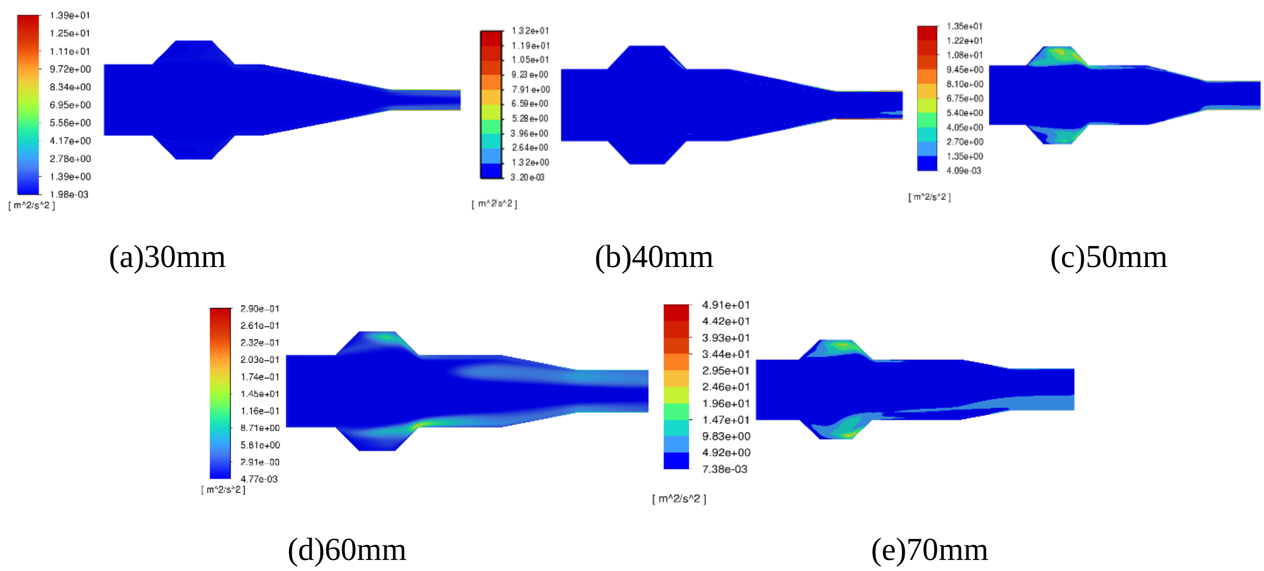


Fig.9 Turbulent kinetic energy cloud diagram of different outlet diameter models

The flow of water inside the nozzle is incompressible fluid flow, and heat exchange is not considered. At this time, the boundary condition is set to the pressure inlet and outlet, so the energy is kinetic energy, turbulent kinetic energy and potential energy. Since the outlet pressure is set to 0, the potential energy is equal. According to the law of conservation of energy, kinetic energy and turbulent kinetic energy have the opposite relationship in the form of expression. In the fluid flow, the larger the turbulent kinetic energy is, the greater the friction loss is. Therefore, only when the turbulent kinetic energy is small and the kinetic energy is large can a good jet effect be obtained.

In order to observe the jet performance more conveniently, the average velocity and turbulent kinetic energy (45cm for the nozzle outlet) of the cross section at different distances from the nozzle inlet at different outlet diameters are plotted, as shown in Figure 10 and Figure 11.

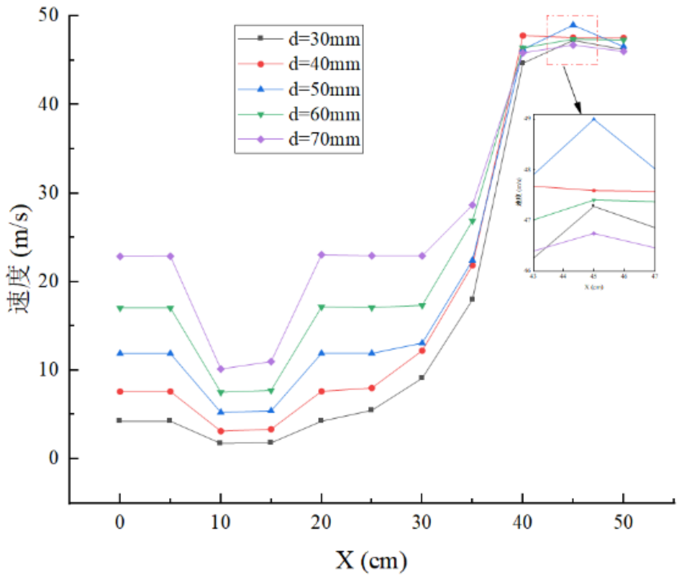


Fig.10 Velocity distribution of different outlet diameter model

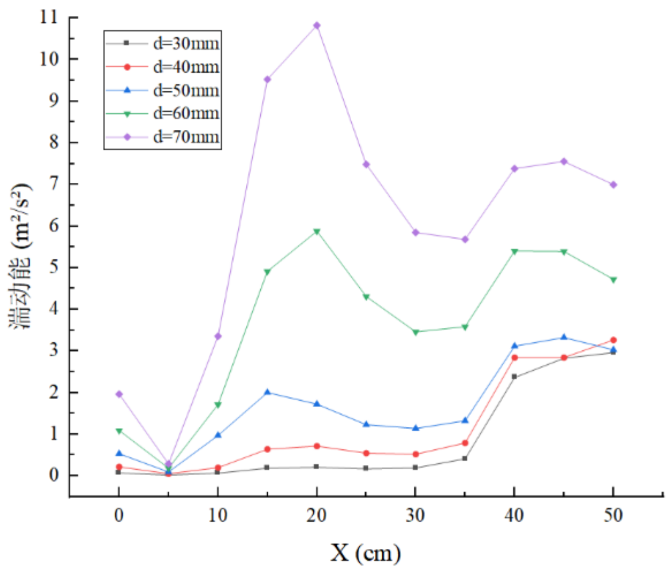


Fig.11 The turbulent kinetic energy distribution map of different outlet diameter model

From Figure 8 and Figure 10, it can be seen that the average speed of the fire water monitor increases with the increase of the distance from the nozzle inlet position during the injection process, and reaches the maximum at the nozzle outlet position (45cm); when the nozzle outlet diameter is 30mm~70mm, the average outlet velocity increases first and then decreases with the increase of the nozzle outlet diameter under the condition of other parameters unchanged. The average outlet velocity is the largest at 50mm, which is 48.995m/s.

From Figure 9 and Figure 11, it can be seen that when the outlet diameter of the fire water monitor nozzle is 30mm~70mm, the turbulent kinetic energy at the outlet of the fire water monitor nozzle increases slowly and then increases rapidly with the increase of the outlet diameter when other parameters remain unchanged. The average growth rate is 8.8 % in the range of 30mm ~ 50mm, and the average growth rate is 51.3 % in the range of 50mm~70mm.

Considering the average outlet velocity and turbulent kinetic energy in the flow field simulation under different outlet diameters, the outlet diameter of the fire water cannon nozzle is 50 mm, and the average outlet velocity is 48.995 m / s and the turbulent kinetic energy is 3.11 m2 / s2.

5. CONCLUSION

(1) The standard k-epsilon model in FLUENT was used to analyze the flow field, and the effects of different nozzle convergence angles and outlet diameters on the jet performance were analyzed. It is determined that when the inlet diameter is 100 mm, the inlet pressure is 1.2Mpa, the length of the rectifier section is 95 mm, the convergence angle is 11°, and the outlet diameter is 50 mm, it is the optimal structural combination of the fire water cannon nozzle.

(2) Under the same conditions, the outlet velocity of the nozzle designed in this paper is 48.995m / s, which exceeds the standard value of 39.2m/s and increases by about 25 %. It provides a certain reference for the structural design and practical application of the fire monitor nozzle.

REFERENCES

[1] WANG Peng-fei,WU Gao-gao,TIAN Chang et al.Structural Parameter Optimization of lnternal Mixing Air Atomizing Nozzle Based on Orthogonal Experiment [J/OL]. Coal Science and Technology:1-11[2022-12-28]. DOI: 10.13199/j.cnki.cst.2022-1446.

[2] WANG Chu,YUAN Xiaoming,YANG Zhigang et al.Investigation on theoretical model of jet trajectory of fire water monitor [J].Journal of Yanshan University,2020,44(05):442-449.

[3] Zhao Ke. Optimized design of S-type Fire Monitor body Based on CFD Technology[D]. China University of Mining and Technology, 2021.DOI: 10.27623/d.cnki.gzkyu.2021.000255.

[4] LIU Zheng-qin. Effects of automatic fire water cannon performance parameters on the jet trajectory[J]. Fire Science and Technology, 2015, 34(11):1471-1474.

[5] HU Guoliang LIU Shihong LI Gang XU Ming et al. Structure Design and Jet Characteristics Analysis of Fire Water Monitor[J]. Machine Tool & Hydraulics,2016,44(1):172-176,183.

[6] YANG L, HU Z, GENG L. Numerical Investigation of the Influence of Nozzle Geometrical Parameters on Thrust of Synthetic Jet Underwater[J]. Sensors & Actuators A Physical, 2018, 269: 111-125.

[7] ZHANG Lijie, WANG Chu, ZOU Yida et al.Numerical Simulation of Flow Field of the Fire Water Monitor' s Nozzle[J]. Machine Tool & Hydraulics, 2019, 47(22):5.

[8] Ma Dezhuang. DESIGN AND RESEARCH ON WATER GUN MECHANISM OF FIRE FIGHTING ROBOT[D].ShangHai: Donghua University,2022.

[9] URBÁN A, ZAREMBa M, MALÝ M, et al. Droplet dynamics and size characterization of high-velocity airblast atomization. International Journal of Multiphase Flow 2017; 95: 1-11.

[10] Jia Chuandi. Structural Design and Performance Study of the Three-phase Jet Fire Monitor[D]. China University of Mining and Technology,2019.

[11] Haoran Song. Structural Optimization and Experimental Study of Internal Mixing Air Atomizing Nozzle[D]. AnHui University of Science and Technology,2022. DOI: 10.26918/d.cnki.ghngc. 2022.000116.

[12] Tong Pirong. A Numerical Investigation for the Flow Field of the DC Fire Monitor Nozzle with Different Contraction Curves[D]. Chongqing University,2017.

[13] Fang Fei,Liu Pingan.Development Design and Test of Fire Monitor with Straight Flow Channel[J].Journal of East China Jiao tong University,2022,39(06):84-89.DOI:10.16749/j.cnki.jecjtu.20221104.006.

[14] Emergency Management Department. Fire Cannon. GB 19156-2019 [S] two thousand and nineteen

[15] Liu Shihong. STRUCTURE DESIGN AND JET PERFORMANCE STUDY OF FIRE WATER MIST MONITOR WITH LOW PRESSURE AND LONG RANGE[D]. East China Jiaotong University,2016.

[16] State Administration for Market Regulation and China National Standardization Administration Definition and selection of nominal dimensions for pipeline components: GB/T 1047-2019 [S] two thousand and nineteen

[17] Yang Guolai,Zhou Wenhui,Liu Fei.Simulation of flow field of high-pressure water-jet from nozzle with FLUENT[J].Journal of Lanzhou University of Technology, 2008, 34(2): 49—52.