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Aerodynamic Performance Experiment and Numerical Simulation Study of the Axial-flow Fire-fighting Fan

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Abstract: The aerodynamic performance experiment of 3 kinds of axial-flow pneumatic extinguishers about different blade angle have been carried out firstly. Based on the N-S equation and the K-ε model, the internal flow field numerical simulation of axial-flow fire-fighting under the design condition has been completed. The internal flow field contours of center section have been obtained, the internal flow situation of axial-flow pneumatic extinguisher under the design condition has been analysed. The performance curve by the numerical simulation and the results by the aerodynamic performance experiment were in a good agreement, which indicated the validity and correctness of the numerical simulation. Finally the aerodynamic performance of 6 blade numbers, 38° blade angle axial-flow fire-fighting fan is best and it can be used in the design of the axial-flow pneumatic extinguisher.

Key words: Axial-flow fire-fighting fan, Computational Fluid Dynamics (CFD), aerodynamic performance experiment, numerical simulation

INTRODUCTION

Axial-flow fire-fighting fan is the core component of the axial-flow pneumatic extinguisher, the characteristics of axial-flow fan is large volume, high efficiency, is widely used in the wind-assisted sprayer. The air flow phenomenon of the internal flow field in the axial-flow fire-fighting fan directly affects the aerodynamic performance of fire-fighting fan and can reflect the design quality of the axial-flow impeller (Yuan *et al*., 2006). In order to analyze the internal flow field of axial-flow fire-fighting fan, in this study, the internal flow field of axial-flow fire-fighting fan is studied by the aerodynamic performance experiment on the fan test platform and numerical simulation, the flow loss mechanism is revealed, it has the guiding significance for improved design of axial-flow fire-fighting fan and internal flow structure.

EXPERIMENTAL MEASUREMENT OF AERODYNAMIC PERFORMANCE

Aerodynamic experimental equipment: Aerodynamic performance test equipment of axial-flow fire-fighting fan is refered to the test device simulated by the axial-flow fire-fighting fan aerodynamic performance in the laboratory condition. The test equipment consists of a small-sized frequency conversion motor, experimental support, intermediate transmission parts, gear box holder and the axial-flow fire-fighting fan. Axial-flow fire-fighting fan consists of axial-flow fan and fire-fighting duct. The axial-flow fan is composed of axial-flow impeller and circular axial-flow air duct. Fire-fighting duct is composed of conical jet air duct and rectifier grid. Axial-flow fire-fighting fan aerodynamic performance test device overall structure as shown in Fig. 1.

Fig. 1: Physical map of axial-flow fire-fighting fan test equipment

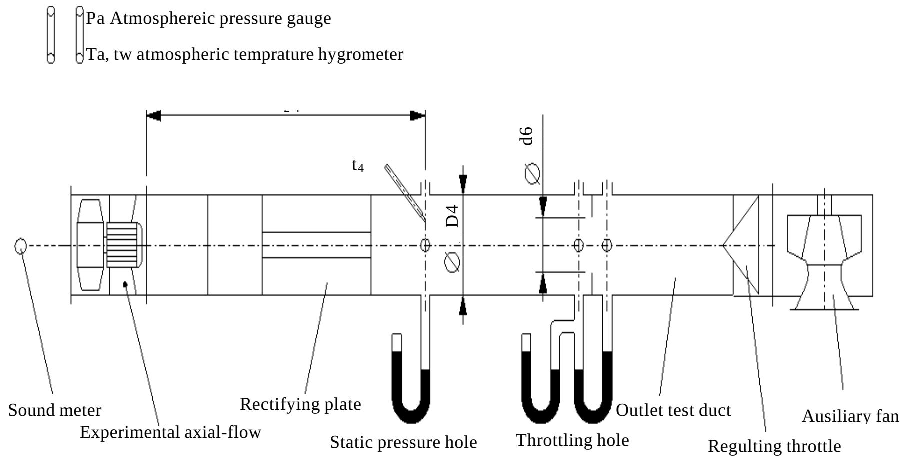

Fig. 2: Schematic diagram of B-type test system for axial-flow fan outlet performance

Table 1: Basic parameters table of the test axial-flow impeller

Axial-flow impeller No.	Leaf No. Z	Blade tip section sketch Leaf edge chord b_t (mm)	Leaf edge setting angle β_t (°)
1	6	37	30°
2	6	42	34°
3	6	48	38°

Axial-flow fire-fighting fan aerodynamic experiment is completed in the forestry fan aerodynamic performance test platform. The small forestry fan performance test platform adopts wind-pipe B-type outlet test device, uses the free import and pipe export, the axial-flow fan exhaust experiment is carried out by the B-type fan test device, as shown in the Fig. 2. Fan performance test platform uses flow measurement by hole-plate differential pressure, differential pressure and static pressure measurement by gas pressure transmitter, input power measurement by the motor power test instrument, the fan speed changed by the frequency converter.

The main parameters of axial-flow fire-fighting fan:The main parameters of the experimental model for the axial-flow fire-fighting fan is (Yu *et al*., 2010): Circular axial-flow duct diameter 200 mm, impeller diameter 190mm,radial clearance 5 mm, hub ratio 0.2, axial-flow impeller speed 2500 r min^{-1},conical jet air duct outlet diameter 100 mm, length of 600 mm; test duct diameter 100 mm (Li and Wu, 2006).The designed axial-flow impeller is selected as test object, the number of impeller leaves is fixed, the test regularly changes the blade angle to form three types of experimental axial-flow impeller, as shown in Table1.

NUMERICAL CALCULATION METHOD

Three-dimensional modeling: Axial-flow fire-fighting fan is made up of three main parts: axial-flow impeller, circular

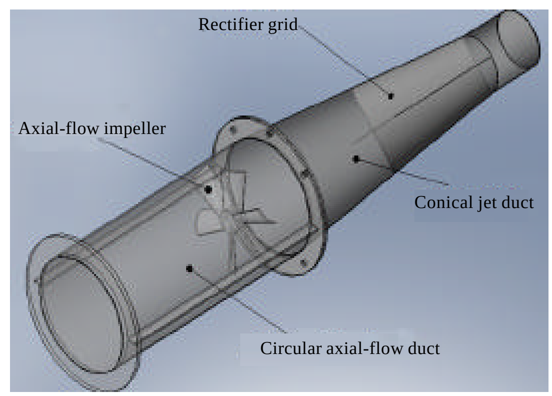

Fig. 3: Geometry model of axial-flow fire-fighting fan

axial-flow duct and conical jet duct. To make up the numerical analysis of internal flow field for axial-flow fire-fighting of the axial-flow pneumatic extinguisher, the three-dimensional geometric model of the axial-flow fire-fighting fan is established by the 3D CAD geometric modeling software firstly, to ensure the reliability and precision of calculation results, in addition to power transmission connecting parts between inner square hole of axial-flow impeller hub and the gear box, the entity structure model is not simplified. The three-dimensional entity model of the axial-flow fire-extinguishing blower as shown in Fig. 3 (Zhang *et al*., 2009).

The air flow inside the axial-flow fire-fighting fan is seen as steady three-dimensional incompressible viscous turbulent flow. The internal flow model Reynolds number of axial-flow fire-fighting fan is: $Re = u\times d\times\rho/\mu = 0.1\times1.58\times1.2/1.8\times10\text{-}5 = 10533$, greater than the critical Reynolds number (2300), therefore gas

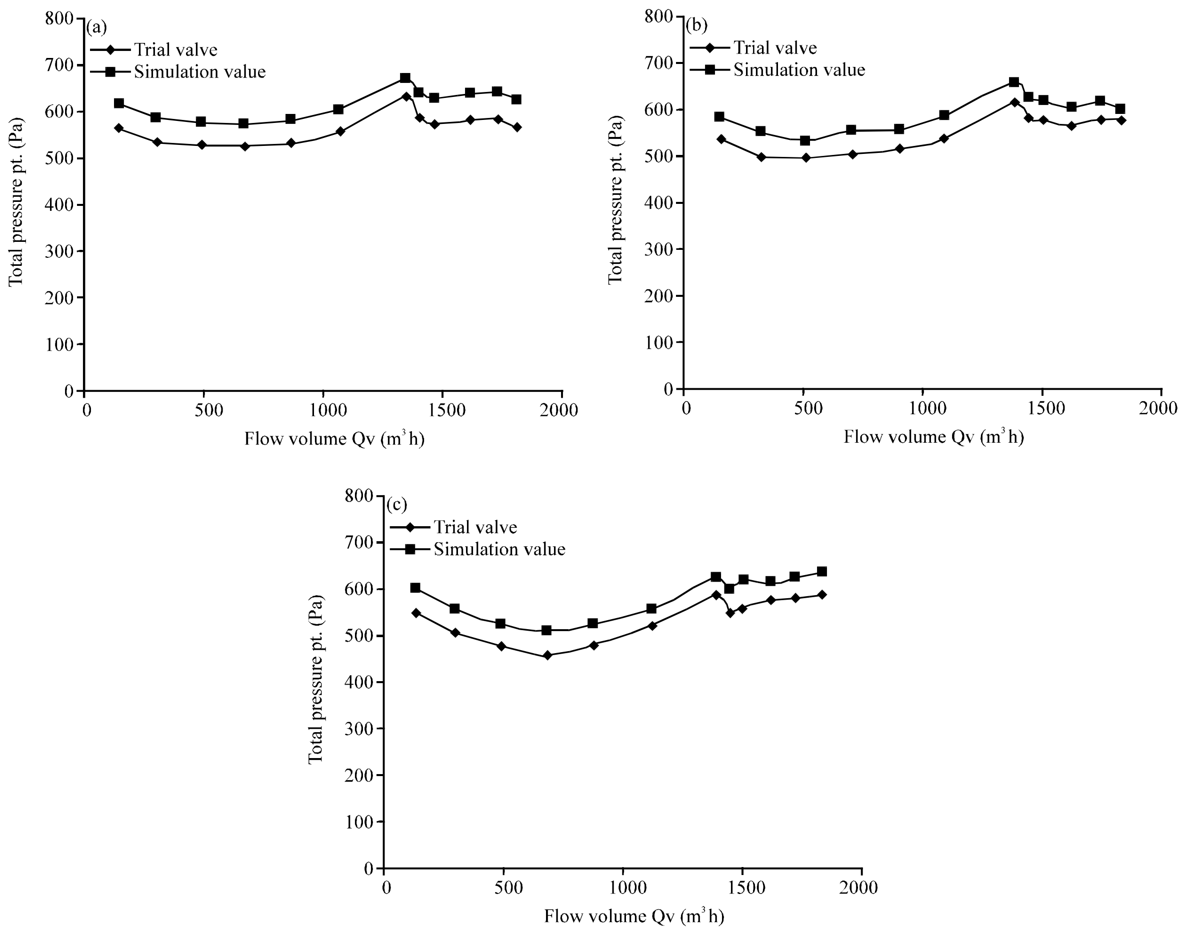

Fig. 4(a-c): Total pressure curve contrast of No.1-3 axial-flow fire-fighting fan

flow state of axial-flow fire-fighting fan is turbulence flow mainly, meets the K-ε turbulence equation. Numerical analysis can be used in the three-dimensional Reynolds-averaged N-S equations and the standard k-ε turbulence model (Yang and Cui, 2009).

Computing grid, boundary conditions and parameter settings: For the convenience of CFD analysis, the gird mesh of the overall flow way inside the axial-flow fire-fighting fan is needed. Meshing method uses the whole 3D mesh, from the axial-flow cylinder inlet, taking the axial-flow fan, internal flow channel, the axial-flow impeller and jet duct as a whole grid, the all flow area is divided into the two representative and main regions: the rotor of axial-flow impeller and stator of circular duct and conical duct, the relative rotation exists between the two parts. Using hexahedral 3D unit structured grid form. The numerical calculation method uses the simple algorithm of the finite volume method for solving the discrete equations. According to the ideal incompressible gas and Newton fluid, considering viscosity, the internal flow field of axial-flow fire-fighting fan is assumed to be viscous steady flow (Xu *et al*., 2006; Li and Zhang, 2008).

For the boundary conditions, the inlet section of the axial-flow fire-fighting fan adopts free import, the environmental standard atmospheric pressure is taken as inlet boundary conditions, the outlet section is the flow boundary condition. The inner wall is a stationary wall, it is handled with no slip, adiabatic wall condition. The designed speed of axial-flow fan is 7000 r min^{-1} in the simulation condition. The designed total pressure is the total pressure of maximum efficiency operating point, designed flow volume is the flow volume of maximum efficiency operating point.

COMPARISON AND ANALYSIS OF AERODYNAMIC EXPERIMENT AND NUMERICAL RESULTS

The comparison of experimental and numerical simulation results: Figure 4 and 5 is the trial valve and

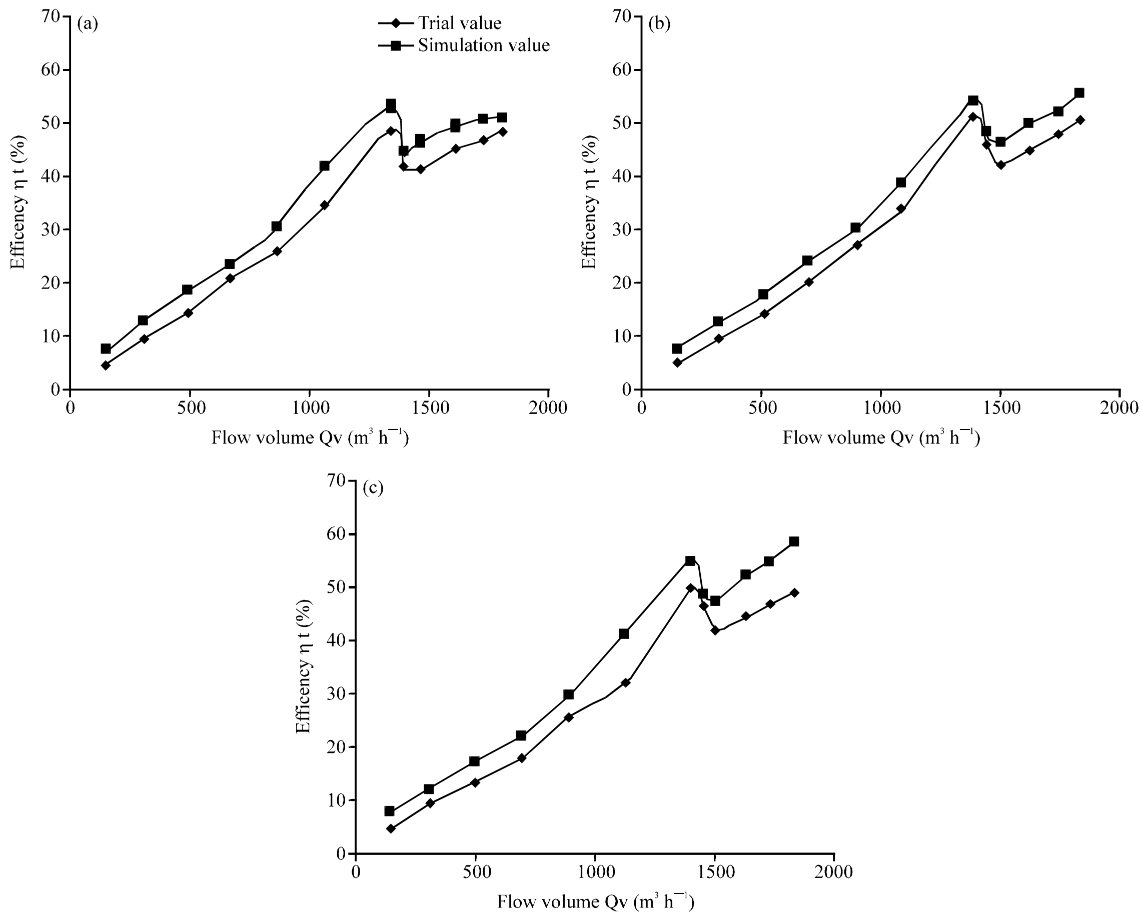

Fig. 5(a-c):Efficiency curve contrast of No.1-3 axial-flow fire-fighting fan

simulation valve contrast diagram of efficiency curve and the total pressure curve of the No.1~3 axial-flow fire-fighting fan from up to bottom. We can see that, in the neighborhood of the best working situation point, the trial valve and simulation valve match together better, it has the best simulation effect. It shows that numerical simulation has a good effect on reflecting the aerodynamic performance of axial-flow impeller, the total pressure simulation valve is higher than the trial valve. In the work condition of high-flow, because the enlargement of flow-field complication, it causes to simulation value and trial value have a certain margin, but the relative error is still smaller than 15%, it belongs to the scope of normal error. Seeing from error results, it is believable that the simulation result of internal flow-field in the axial-flow fire-fighting fan by CFD numerical simulation.

Structure simplification of axial-flow fire-fighting fan during the numerical simulation causes to simulation valve is higher than trial valve, the calculation model of axial-flow fire-fighting fan is tended to idealize, meanwhile,the outward appearance of the grid model is even. But the actual grid of axial-flow fire-fighting fan is cut with the thin sheet iron, the outer surface is uneven. There will be the leakage phenomenon occurrence at the weld of the conical jet tube. Numerical simulation process also reduces the actual flow loss in simulation calculation, it also shows that the numerical simulation needs improving in the actual axial-flow fire-fighting fan operation.

Aerodynamic performance analysis: By comparing the aerodynamic performance parameters of best efficiency point about 3 kinds of axial-flow impeller, it is shown that the aerodynamic performance of 3 kinds of axial-flow fire-fighting fan meet the requirement of national standard about portable pneumatic extinguisher, only the total pressure efficiency is slightly lower (Chu *et al*., 2010). The different blade angle of axial-flow fire-fighting fan have a significant effect on the aerodynamic performance of axial-flow fire-fighting fan. Blade angle is larger, the export flow volume of fire-fighting fan is more. With the increasing of the blade angle, the total pressure of

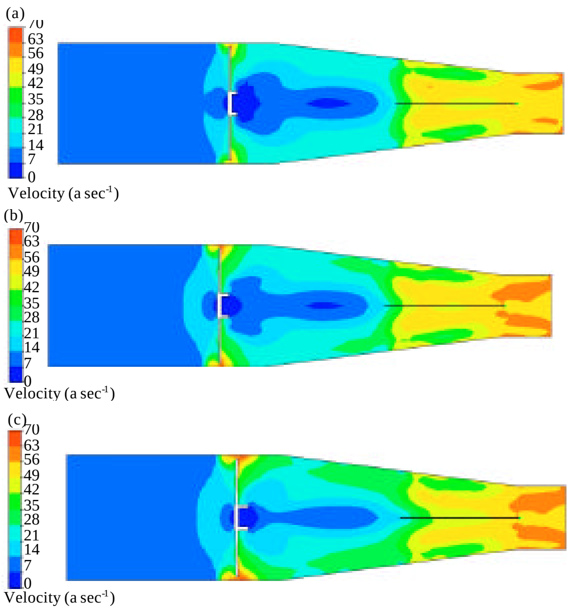

Fig. 6(a-c): Velocity distribution cloud picture of No.1-3 axial-flow fire-fighting fan center vertical section

Table 2: Comparison of aerodynamic performanceparameters of different blade angle axial-flow fire-fighting fan

Parameters	No.1	No.2	No.3
Flow volume Qv (m3/h)	1343.500	1385.700	1400.30
Total pressure Pt (Pa)	628.690	614.620	584.61
Power N (kw)	0.484	0.467	0.45
Efficiency βt (%)	48.370	50.620	50.44

axial-flow fire-fighting fan reduces correspondingly, power reduces and efficiency improves (Fu *et al*., 2009).

Velocity flow field contours: Figure 6 is internal velocity distribution cloud picture of No.1-3 axial-flow fire-fighting fan center vertical profile from top to bottom (unit: m sec^{-1}).As can be seen from the chart, internal velocity field of No.1, No.2 and No.3 even-leaf axial-flow fire-fighting fan is symmetrical about center axis approximately. Velocity in the outlet hub of axial-flow impeller is small, gas velocity at the top of the impeller blade is greater than that of the blade root. At the same time it also shows that the power distribution of the axial-flow impeller.

At the designed condition, the center speed axial-flow impeller is low, the gas flow speed increases along the flow channel, flow speed nearing conical jet duct increases significantly, the outlet velocity reaches at the maximum in the conical jet flow duct, this is mainly because the air acceleration effect caused by the jet flow. The outlet flow velocity is larger than the inlet flow velocity, this is because airflow is pushed and pressurized by the inner wall of axial-flow blade. Closing to the wall at the exit, due to the viscous function force between airflow and wall, flow velocity decreases rapidly (Song, 2008).

The number of leaves is more, the outlet speed of conical jet duct increases, the circumferential velocity at the tip of axial-flow impeller is more greater. The impeller blade angle of No.3 axial-flow fire-fighting fan is most largest, the low-velocity zone is most smallest, airflow velocity into grid plate is most highest, the outlet flow speed is maximum through rectification of grid plate. The blade number of axial-flow fire-fighting fan have a little effect on the internal flow-field, the blade angle of axial-flow fire-fighting fan have a great effect on the internal flow-field. As the blade angle increasing, the working capacity of axial-flow impeller is strengthening. With the installation angle of impeller blade increasing, the airflow volume is increasing.

CONCLUSION

- According to aerodynamic performance test about the different blade angles (30°, 34°, 38 °) of axial-flow fire-fighting fan composed of 3 kinds of axial-flow impeller, the aerodynamic performance parameters and aerodynamic performance curves of 3 kinds of axial-flow fire-fighting fan are obtained. The test results show that the airflow volume of No.3 axial-flow fire-fighting fan which axial-flow impeller blade number is 6, the blade angle is 38°is closest to the designed flow volume, up to 1400.3 m 3 h,the total pressure is 584.61Pa, power is 0.45kW, the efficiency is 50.44%, aerodynamic performance is good, it basically meet the aerodynamic performance needs of fire-fighting fan, the best choice applied in the axial-flow pneumatic extinguisher is that impeller blade number is 6 and the blade angle is 38°
- Based on the Reynolds averaged N-S equations and the standard k-ε model, the internal flow-field of axial-flow fire-fighting fan is simulated numerically. The calculation results show that: in the designed flow conditions, the hub outlet recirculation area of No. 3 axial-flow fire-fighting fan which axial-flow impeller blade number Z = 6, the blade angle is 38° is smaller, power consumption is smaller. The inner velocity vector distribution of conical jet duct is larger and more intensive, the jet outlet velocity is larger, the airflow volume is larger, the numerical simulation results are basically consistent with performance test results, it shows that the numerical method is correct and feasible. The calculation

results provide the reference basis for the design of axial-flow fire-fighting fan inner airflow and axial-flow impeller.

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