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Analysis and Research on Flow Characteristics of Hot Water Pipeline System

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Abstract. Based on the CFD numerical simulation method, a pipe model was established to study the internal flow characteristics of two different specifications of hot water pipe system, and the related information of the flow field was obtained, such as the internal pressure, flow velocity and flow rate. The results showed that the smoother the pipeline transition was, the smaller the velocity uniformity coefficient would be, and the higher flow field uniformity means the smaller pressure and velocity fluctuations. Therefore, the pipeline vibration will be smaller, and the flow characteristics are greatly improved.

1 INTRODUCTION

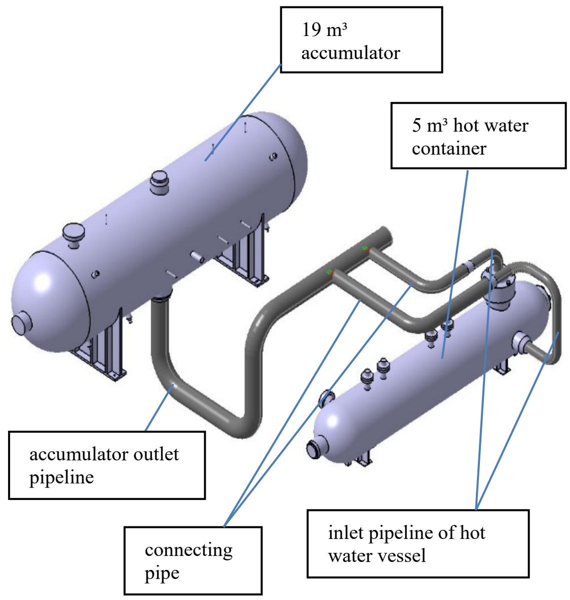
Hot water pipeline system is widely used in energy, shipping, petrochemical, machinery and other industries. As for the power system, it serves as the bridge and link to connect the boiler, heat accumulator, heat exchanger and other equipment. The unreasonable pipeline design and layout will lead to the loss of the pipeline resistance. Too large resistance fails to ensure the smooth medium flow, while too small resistance will make the medium flow too large. And the large flow rate will bring pipeline vibration, affecting the safety and reliability of the system. At the same time, in the large-scale pipe network, the number of pipelines is large, add to the various specifications, and the complex layout. The layout and direction of the pipe network have great limitations due to the limited space. Therefore, the design of the pipe network should not only meet the requirements of completing the pipeline system layout in the limited space, but also ensure that all equipment parameters can meet the requirements of stable operation.

In this paper, we do research on the flow characteristics of the valve test system, which is designed for the operation performance test and discharge test of the pressurizer safety valve. We analyze two different pipe combinations to improve the flow characteristics, and propose the optimization scheme of pipe system combination.

2 STRUCTURE PRINCIPLE AND PERFORMANCE PARAMETERS

2.1. Structure principle

The hot water test circuit is mainly composed of heat (19 m^3) accumulator, hot water container (5 m^3), valve, pipeline and accessories, as shown in Figure 1.



1. 19 m³ accumulator
2. 5 m³ hot water container
3. accumulator outlet pipeline
4. connecting pipe
5. inlet pipeline of hot water vessel

Figure 1. Structure diagram of hot water pipeline system

2.2 Performance Parameters

Parameters of Hot Water Pipeline System (Table 1):

Table 1. Parameters of hot water pipeline

Name	Numerical value
accumulator volume	19 m³
volume of hot water container	5 m³

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maximum test pressure (MPa)	20
temperature range (℃)	333~343
medium	Saturated water / super cooled water
accumulator outlet pipeline connecting line inlet pipeline of hot water vessel	φ406 × 25 φ273 × 34/ φ 325 × 40 φ 273 × 34

This paper compares and analyzes the two connecting pipe specifications from 19 m^3 heat storage device to 5 m^3 water vessel pipeline system. The specific system pipeline combination is as follows:

(1)Plan A:

Accumulator outlet pipeline φ 406 × 25
Connecting line φ 273 × 34
Inlet pipeline of hot water vessel φ 273 × 34

(2)Plan B:

Accumulator outlet pipeline φ 406 × 25
Connecting line φ 325 × 40
Inlet pipeline of hot water vessel φ 273 × 34

3 Numerical Simulation

3.1. Governing equation

In this paper, the mature standard model is used for numerical simulation. The continuity equation, momentum conservation equation, turbulent kinetic energy k equation and dissipative energy equation constitute the governing equations.

Continuity equation:

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_i}(\rho u_i)=0 \quad (1)$$

Momentum conservation equation (N-S equation) formula:

$$\rho\frac{du}{dt}=\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}-\frac{2}{3}\delta_{ij}\frac{\partial u_i}{\partial x_j}\right)\right]+\frac{\partial}{\partial x_j}\left(-\overline{u_i'u_j'}\right) \quad (2)$$

The transport equations of turbulent kinetic energy k and turbulent energy dissipation rate of standard $k\sim\varepsilon$ turbulence model can be expressed as follows:

$$\frac{\partial(\rho k)}{\partial t}+\frac{(\partial\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_i}\left[\left(\mu+\frac{\mu_t}{\delta_k}\right)\frac{\partial k}{\partial x_j}\right]+P-\rho\varepsilon \quad (3)$$

$$\frac{(\partial\rho\varepsilon)}{\partial t}+\frac{(\partial\rho\varepsilon u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\mu+\frac{\mu_t}{\sigma_Z}\frac{\partial\varepsilon}{\partial x_j}+\frac{\varepsilon}{k}\left(C_{\varepsilon1}P+\rho C_{\varepsilon2}\varepsilon\right) \quad (4)$$

In the formula

u_i —Velocity component along direction i, i=1, 2, 3

μ — Kinematic viscosity coefficient of medium

u_t — Eddy viscosity coefficient

δ_k — Prandtl number corresponding to turbulent kinetic energy k

δ_ε — Prandtl number corresponding to turbulent dissipation rate ε

P— Generation term of turbulent kinetic energy

$$P=\mu_t\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)\frac{\partial u_i}{\partial x_j} \quad (5)$$

where:

$$\mu_t=C_\mu\rho\frac{k^2}{\varepsilon} \quad (6)$$

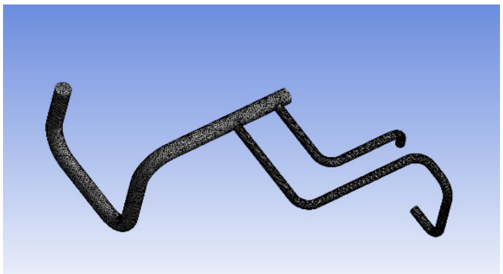
Empirical constants in model k-ε(Table 2).

Table 2. Coefficients in k-ε model

$C_{\varepsilon1}$	$C_{\varepsilon2}$	C_μ	δ_k	δ_ε
1.44	1.92	0.09	1.0	1.3

3.2 Establishment of flow channel model and grid division

According to the specific structural parameters, CATIA software is used to establish the three-dimensional model of the pipeline system, and the internal flow path model is generated by introducing the reverse modeling of the hydraulic software. The flow model is introduced into ANSYS ICEM CFD for mesh division (Figure 2). The numerical calculation grid is divided by tetrahedron or hybrid grid. We generate more accurate calculation results through the local encryption at the corner of convection channel, and then perform the grid independence test.



a) Plan A

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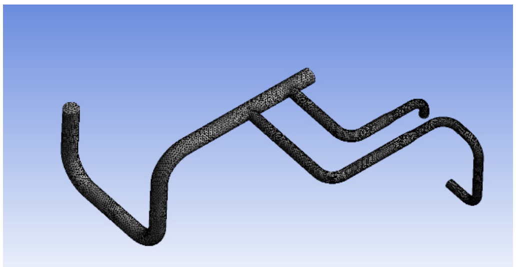


b) Plan B

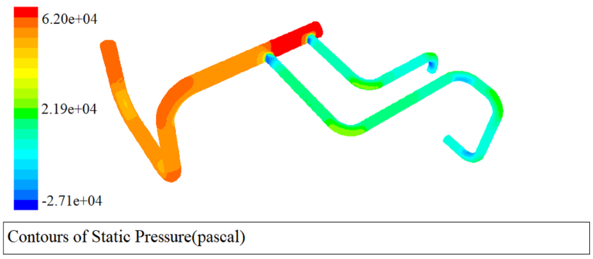
Figure 2. Grid model of pipeline system

Combined with the actual working conditions of hot water pipeline system, the internal flow model under typical conditions is established. The closed equations are composed of three-dimensional incompressible Reynolds time average equations and k-ε turbulence model to solve the internal flow field of the pipeline system. The fluid medium is water, and the temperature change is not considered in the solution process. The outlet of the heat accumulator is set as the boundary condition of the velocity inlet, the velocity is 6.484m/s, the inlet 1 and 2 of the hot water vessel are set as the boundary conditions of the pressure outlet of 0MPa, and the pipeline wall should be set as the adiabatic and slip free boundary condition, then we can simulate and analyze the three-dimensional flow field.

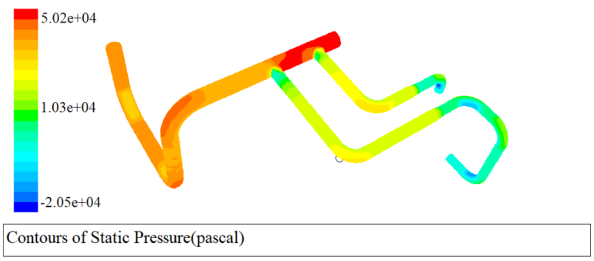
4 Study on Internal Flow Characteristics

4.1 Pressure Field Distribution

In Figure 3, it shows the combined pressure cloud diagram of different pipe specifications. The figures indicate that the pressure gradient of Plan A changes greatly with uneven pressure distribution, and the maximum pressure appears at the end of the pipeline. While the pressure gradient of Plan B changes little, its pressure fluctuation has a smooth transition and the distribution is relatively uniform.



a) Plan A

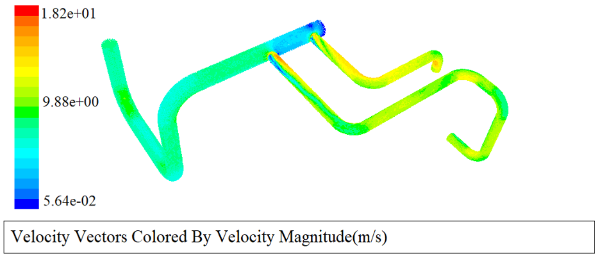


b) Plan B

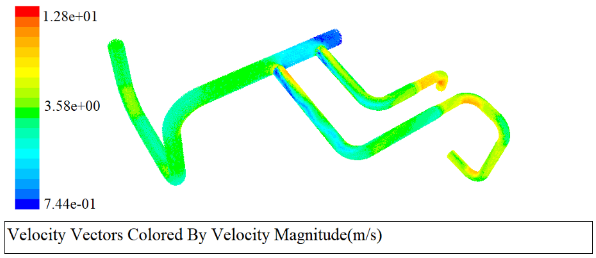
Figure 3. Pressure nephogram of different pipeline specifications

4.2 Velocity field distribution

After studying the velocity field distribution of different pipe combinations, we have obtained the velocity distribution nephogram, as shown in Figure 4. According to the figures, the velocity of Plan A is high and the velocity gradient changes greatly. The maximum velocity appears at the junction between the outlet pipe of the heat exchanger and the connecting pipe, causing certain scour to the pipeline. We can see gradual changes in Plan B, and the velocity distribution is uniform and tends to be stable.



a) Plan A



b) Plan B

Figure 4. Velocity nephogram of different pipeline specifications

5 Conclusion

(1) Compared with Plan A, Plan B is more optimized by using the φ325×40 connecting pipeline, and the change of pressure gradient and velocity gradient is more stable.

(2) The more stable the pipeline combination transition, the higher the uniformity of flow field, the smaller the pressure and velocity fluctuations, and the smaller the pipeline vibration, the flow characteristics will be greatly improved.

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