

Geometric parameters optimization of low resistance T-junction with guide vanes in HVAC system

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Abstract. In recent years, with the increasing energy consumption and carbon emissions, people are paying more and more attention to related measures for energy conservation and emission reduction. As an important conveying component of the HVAC system, the pipe network system plays the function of distributing the fluid medium. However, a large part of the resistance loss is often generated during this transportation process, and the local pressure loss caused by local resistance components (e.g., T-junction) accounts for a large part of the total pressure drop. In this work, the influence of different guide vane positions on the resistance of the T-junction is analyzed. The internal flow field distribution and resistance characteristics of the T-junction are explored by numerical calculation method. The total energy dissipation and resistance reduction rate of the traditional T-junction and the novel T-junction with a guide vane are compared under different flow ratios. The resistance reduction rate of the optimized T-junction with a guide vane is 21.5%. The insertion of guide vanes can reduce the flow resistance and total energy loss of T-junction.

1. Introduction

Energy is an essential resource for human survival and development. With the exploitation and utilization of energy by human beings, people are paying more and more attention to carbon emissions and energy utilization[1-3]. Globally, building energy consumption accounts for about 40% of the world's total annual energy consumption[4]. In the heating pipeline, the local resistance accounts for a large part of the total energy loss. Due to its wide application and significant energy consumption in transportation, heating pipe network system has received increasing attention for energy saving[5, 6]. Therefore, it is important to take scientific measures to reduce the resistance of local components.

Inserting guide vanes at reasonable positions of local components can effectively reduce the local resistance loss of components. Ziganshin[7] inserts a vertical baffle vane at the centre of the confluence tee by numerical simulation method; the results show that the tee with baffle vanes has a good drag reduction effect. In the process of fluid flowing through the elbow, the secondary vortex motion is accompanied by flow separation. This flow separation and flow vortex can be reduced by installing one or more vanes in the elbow[8]. Luo[9] analyzed the effect of reducing flow separation by adding guide vanes in the elbow, compared the flow field distribution of three vanes with different radial positions,

and investigated the mechanism of reducing drag loss. Prabhu[10] has experimentally investigated the effect of a single guide vane and multiple guide vanes on the pressure drop of a smooth square channel, and the results show that 90° multiple guide vanes can reduce the total pressure drop by 40%. Most of the previous research has been on the insertion of guide vanes in 90° and 180° elbows, with less research on the reduction of resistance and internal flow in the T-junction. Therefore, it is necessary to explore the effect of inserting guide vanes at reasonable positions of the T-junction on the flow resistance.

In this work, the influence of different guide vane positions on the resistance of the T-junction is analyzed. The internal flow field distribution and resistance characteristics of the T-junction are explored by numerical calculation method. The total energy loss and resistance reduction effect under different flow ratios are analyzed.

2. Methodology

2.1 Physical model

The research object is a confluent T-junction with a circular cross section, as shown in **Fig. 1**. The diameter of the main pipe of the T-junction is $D_1 = 100\text{ mm}$, and the diameter of the branch pipe is $D_2 = 80\text{ mm}$. To ensure

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that upstream and downstream flows are fully developed, and the length of each pipe segment is set to $30D_1$, $30D_1$, and $30D_2$, respectively[11].

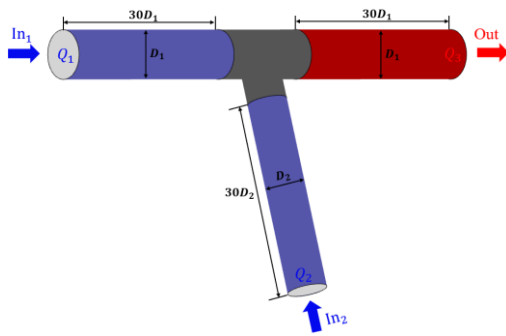


Fig. 1. Schematic diagram of the T-junction.

At this time, the local resistances of the two flow directions of the T-junction are as follows:

The flow direction of In₁ to Out:

$$\Delta P_1 = P_{in1} - P_{out} - (P'_{in1} - P'_{out}) \quad (1)$$

The flow direction of In₂ to Out:

$$\Delta P_2 = P_{in2} - P_{out} - (P'_{in2} - P'_{out}) \quad (2)$$

where ΔP_2 denotes the local resistance; $P_{in2} - P_{out}$ and $P'_{in2} - P'_{out}$ refer to represent the total pressure and on-way resistance losses, respectively.

Therefore, the local resistance coefficients in the two directions can be expressed as:

$$\zeta_1 = \frac{\Delta P_1}{0.5\rho v_m^2} \quad (3)$$

$$\zeta_2 = \frac{\Delta P_2}{0.5\rho v_m^2} \quad (4)$$

where v_m is the average velocity of the outlet.

The sum of the local resistance of the two flow directions constitutes the local resistance of the T-junction. Considering the local resistance coefficients in both directions alone is relatively complex, it is advantageous to compare the performance of both T-junctions in terms of total energy loss. The total energy loss coefficient (K) is expressed as

$$K = \frac{Q_1}{Q_3} \zeta_1 + \frac{Q_2}{Q_3} \zeta_2 \quad (5)$$

The resistance reduction rate η is expressed as

$$\eta = \frac{K_{tra} - K_{nov}}{K_{tra}} \quad (6)$$

where η is the resistance reduction rate, K_{tra} and K_{nov} are the total energy loss coefficients of the traditional T-junction without a guide vane and the novel T-junction with a guide vane, respectively.

2.2 Numerical simulation

ANSYS Fluent 19.0 is used to calculate the flow field of the T-junction. The fluid is single-phase incompressible water, ignoring the heat exchange of the fluid, and the physical properties are constant.

2.2.1 Verification of turbulence models

The two inlets of the T-junction are defined as velocity inlets, and the outlet is set as a pressure outlet, and the gauge total pressure is 0 Pa. The wall boundary is a nonslip boundary condition, and the absolute roughness of the stainless steel pipe[12] is set to 0.04 mm.

The choice of turbulence model has a great influence on the numerical results. Generally, the turbulence models used to calculate the flow of the T-junction include the realizable $k-\varepsilon$ model, standard $k-\varepsilon$ model, RNG $k-\omega$ model, SST $k-\omega$ model, and RSM[13]. The experimental data[14] of the radial velocity distribution have verified numerical results, as shown in **Fig. 2**. The mean bias error values of the turbulence models are 1.7%, 5.2%, 3.3%, 3.2%, and 5.4%. Based on the above calculation results, we select the realizable $k-\varepsilon$ as the numerical model in the present work.

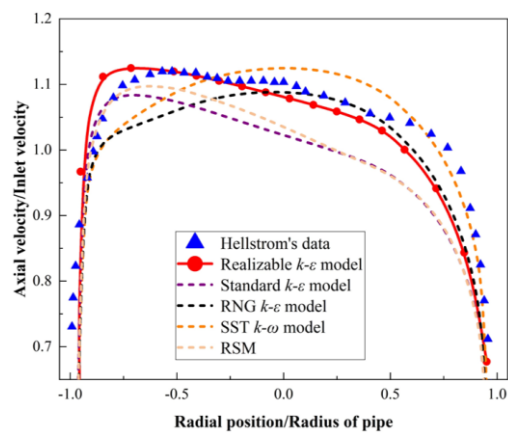


Fig. 2. Comparison of experimental[14] and numerical simulation results for the radial velocity distribution.

2.2.2 Validating grid independence

The mesh quality has a large influence on the numerical results, but too many grids will greatly reduce the computational efficiency. In this study, a hybrid method of structured and unstructured grids is used for grid division, as shown in **Fig. 3**. Computational results for six different grid systems are compared. The number of cells in the six grids is 0.12 million, 0.32 million, 0.60 million, 1.30 million, 1.90 million, and 2.40 million, respectively.

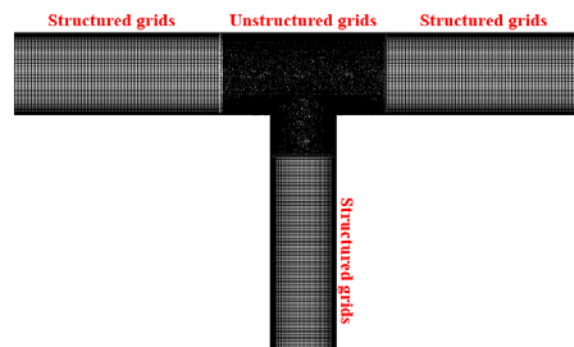


Fig. 3. Schematic diagram of grid division.

Fig. 4 shows the pressure distribution in the central section of the T-junction at different grid numbers. With

the increasing number of meshes, until 1.90 million, the pressure of the central section of the tee no longer changes. Therefore, a grid system of 1.90 million is chosen for the numerical calculations in this paper.

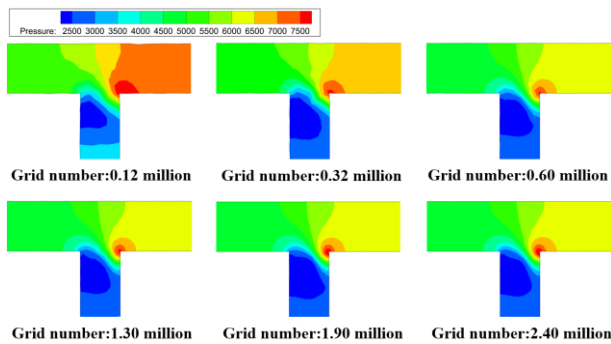


Fig. 4. Pressure distribution of the T-junction with different grid numbers.

3. Results

3.1 Geometric parameters optimization of the guide vane in the T-junction

A low-resistance T-junction can be achieved by optimizing the geometric parameters of the guide vane in the T-junction. The diameters of the main, straight and branch pipes are 100 mm, 100 mm and 80 mm, respectively. To make this study more relevant to practical engineering applications, the specific dimensions of the T-junction refer to the ASME standard [15]. And the velocity inlets 1 and 2 are 2.1m/s and 1.4m/s, and the pressure outlet is 0 Pa.

The position of the guide vane has a significant effect on the resistance distribution of the T-junction. To obtain a low-resistance T-junction with a guide vane, there are three parameters to optimize the position of the guide vane. As shown in **Fig. 5** and **6**, the parameter a was first optimized, and 7 different a are compared. The results show that when $a=0.25D_1$, there is a smaller total energy loss coefficient, and the resistance reduction rate is 11.5%. Then the parameter b is optimized, and the comparison of 7 different b shows that when $b=0.385D_1$, it has a good resistance reduction rate. Finally, from the calculation results of 7 different c , when $c=1.1D_2$, it has the optimal resistance reduction effect, and the resistance reduction rate is 21.5%.

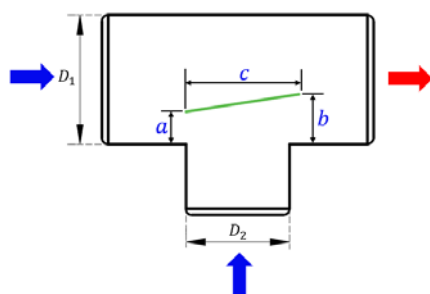


Fig. 5. Schematic diagram of the position parameters of the guide vane in the T-junction.

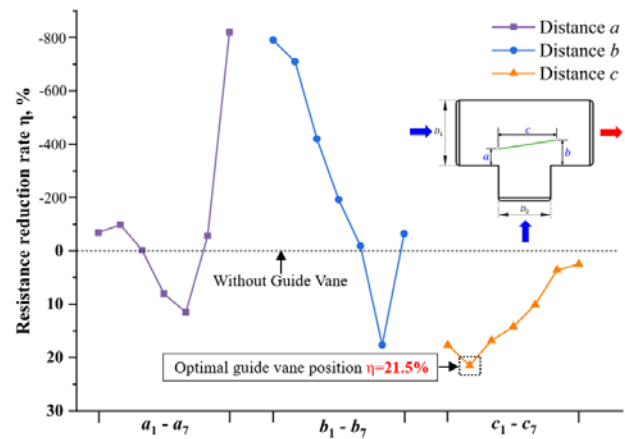


Fig. 6. Geometric parameters optimization of the guide vane in the T-junction.

3.2 Effectiveness of the resistance reduction using various flow ratios

Generally, the inlet and outlet flow ratio is a conventional parameter that affects the internal resistance distribution of the T-junction. The resistance reduction effectiveness of inserting optimal guide vane in the T-junction is analyzed under different flow ratios. As shown in **Fig. 7**, under different flow ratios, the novel T-junction with a guide vane has a good resistance reduction effect. Only when $Q_2/Q_3=0.5$, the phenomenon of increased resistance occur, which is because the flow rate on the side of the branch pipe is too high, which causes the velocity to be so large that it exceeds the reasonable flow distribution range. The optimal resistance reduction rate occurs when $Q_2/Q_3=0.3$, and the resistance reduction rate is 21.5%.

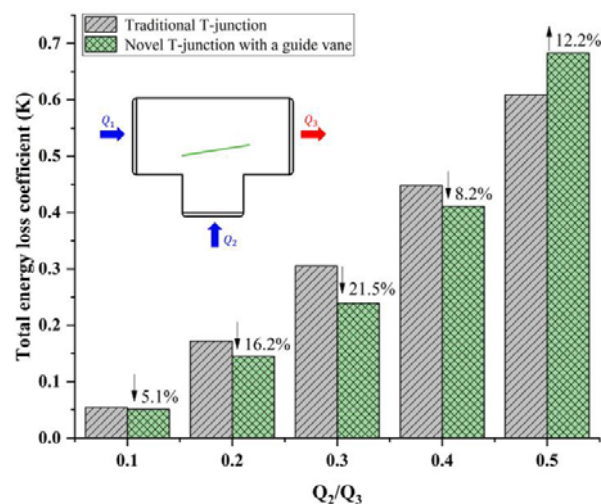


Fig. 7. Total energy loss coefficient and resistance reduction rate with various flow ratios.

3.3 Flow field analysis

By analyzing the internal flow field of the T-junction, areas of high resistance field can be identified. When the fluid enters the pipeline from the two inlets, the two fluids

converge at the T-junction. Velocity stratification is obvious at the T-junction, and the fluid close to the upper wall shows a high flow velocity; the fluid close to the lower wall shows a lower flow velocity, and there is an obvious flow vortex. As shown in Fig. 8, the flow field distribution of the traditional T-junction and the novel T-junction with a guide vane are compared. From the internal flow field of the traditional T-junction, it can be seen that there is a large flow vortex in the red marked area. Whereas for a T-junction with a guide vane, there is a small area of vortex in this marked area. The smaller the vortex area, the smaller the energy loss here, that is, the T-junction with a guide vane has the characteristics of low resistance and low energy loss.

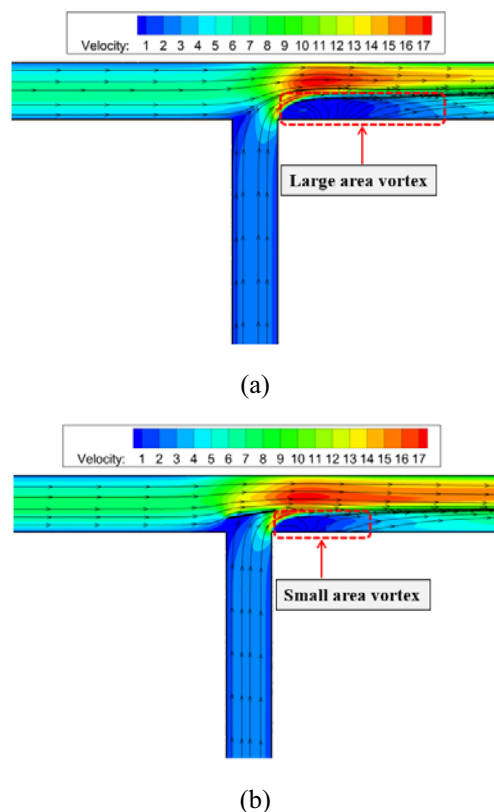


Fig. 8. Flow distribution in the T-junction: (a) traditional T-junction; (b) novel T-junction with a guide vane.

4. Conclusions

In this work, the influence of different guide vane positions on the resistance of the T-junction is analyzed. The internal flow field distribution and resistance characteristics of the T-junction are explored by CFD numerical calculation method. The validity of the numerical model and the independence of the mesh are verified separately. And analyzed the total energy loss and resistance reduction effect under different flow ratios. The conclusions are summarized as follows:

Inserting the guide vane at a reasonable position of the tee can reduce the flow resistance. By comparing 21 different guide vane positions, the guide vane position with the optimal resistance reduction effect is obtained, and the resistance reduction rate is 21.5%.

The total energy dissipation and resistance reduction

rate of the traditional T-junction and the novel T-junction with a guide vane are compared under different flow ratios. The optimal resistance reduction rate occurs when $Q_2/Q_3=0.3$, and the resistance reduction rate is 21.5%.

At the downstream side near the lower sidewall of the T-junction, the novel T-junction with a guide vane has a smaller flow vortex, indicating that the insertion of guide vanes can reduce the flow resistance and total energy loss.

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