Numerical Simulation of Simple Heat Exchanger

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Abstract

Heat exchanger is a part of the hot fluid heat transfer to the cold fluid equipment, also known as heat exchanger. Occupies an important place in the heat exchanger in industrial production, the influencing factors of the heat exchanger performance has always been the focus of the research and development of heat exchanger design, based on the k - e can realize turbulence model and the Scalable wall function, using Fluent software for a simple tube and shell heat exchanger model has carried on the three-dimensional numerical simulation, calculates the heat exchanger in the entrance of temperature and velocity on the heat exchanger performance, the influence of calculation result accords with the theory of the actual, obtained some conclusions with reference value.

Keywords

Shell and tube heat exchanger; Numerical simulation; Fluent software; A feasible k-e turbulence model.

1. Introduction

Numerical simulation is an important means of heat exchanger research. Computational fluid dynamics (CFD) was first proposed by Patankar and Spalding in 1974 to simulate the shell flow field of shell heat exchanger without phase change [1]. However, due to the limitations of computer and computational fluid mechanics at that time, the research progress was slow. Fluent is the world's leading and widely used CFD software for fluid flow and heat transfer problems. Fluent software's thought is based on the CFD software group, from the perspective of user needs, according to various complex physical phenomena, using numerical method, and different discrete format makes the computation speed in a specific field and the stability and accuracy of the optimal combination, so as to efficiently solve various complex flow calculation problem in the field of [2].In this paper, Fluent software is used to simulate the three-dimensional flow field of heat exchanger, and certain conclusions are obtained.

2. Establishment of physical model and grid division

We used Gambit software to build the physical model. The grid is divided by the Tet/ hybird-tgrid method. By modifying the grid size to change the number of grids, 10 grids of different Numbers are divided for grid independence verification. The grid is shown in figure 1.

Set the upper left port in figure 1 to a hot fluid outlet and name the hot fluid outlet 'outlet. H', of type Pressure outlet, and the lower right port to a hot fluid inlet, which name is 'inlet. H', of type Velocity inlet. Similarly, the right outlet is set to a cold fluid outlet, and the left inlet to a cold fluid outlet, called 'outlet. C' and 'inlet. C', respectively, are of the same type as hot fluid. Finally, in order to obtain the temperature and other parameters of the heat exchange surface, the middle heat exchange surface was named 'mid' and the type was Wall. The remaining boundary is not set, the default is adiabatic surface. The flow region of cold fluid is named cold and hot fluid.

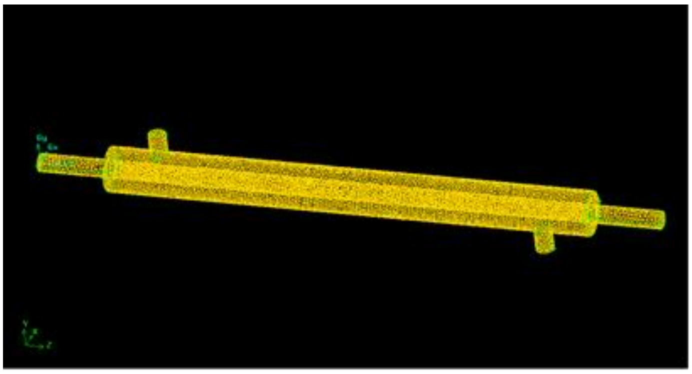

Figure 1. Grid division diagram.

3. Fluent software setup and calculation

3.1 Fluent software setup

First, since we're dealing with heat transfer, open up the energy equation. Set about turbulence in the fluid flow model, we use the Realizable k - e, Scalable Wall Functions provides model, also is to use and can realize the k - e model, and use a Scalable Wall function, choose the main reason is that the model can realize the k - e model within the boundary layer on the calculation of flow has good performance, suitable for cavity flow and the boundary layer flow [3], the study of the heat exchanger thermal dissipation is mainly boundary layer heat transfer process, within the boundary layer of fluid have larger temperature gradient, The calculation precision of boundary layer requires high, so we use this model. Scalable wall functions are also used because they provide a consistent solution for any mesh refinement, which facilitates grid-independence validation.

3.2 Calculation method and result

The SIMPLE calculation method is set to the second-order accuracy, because if the parameters of the heat exchanger change little in the calculation, the result obtained will not change significantly. Therefore, the second-order accuracy is used to obtain the result with higher accuracy and make the calculated result more reliable.

After repeated trial, step calculation steps can be found in 1200, almost all residual grid model can achieve a stable low value, limited to computer operation ability, we can preliminary calculation steps as 1200 steps, special problems if the higher residual, no convergence, steps can be appropriately modified calculation and calculation method. As shown in figure 2, it is a schematic diagram of calculating residuals.

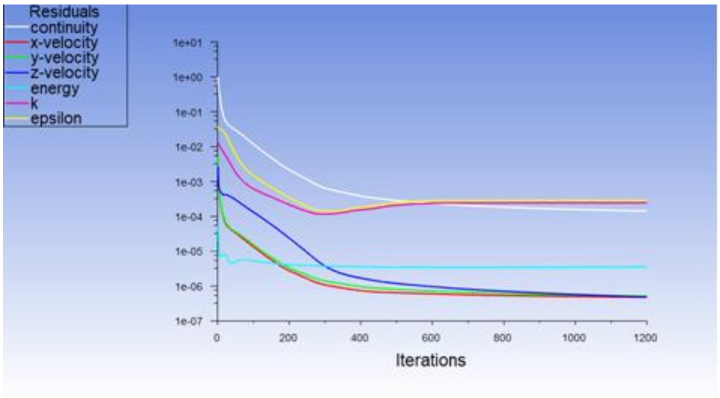

Figure 2. Schematic diagram for calculating residuals.

4. Validation of grid independence

We have obtained models with different numbers of grids by building models. For steady-state numerical simulation, it is necessary to determine the non-correlation between the number of grids used in the calculation and the results obtained by calculation, that is, to conduct grid-independence verification. In the simulation, we more focused on the heat transfer phenomenon, and heat transfer phenomena and the export of cold and hot fluid temperature and average temperature is closely related to the heat transfer surface, so we take counterflow heat exchanger, under the same boundary conditions calculated for cold and hot fluid export average temperature and heat exchange surface average temperature for the grid independence test and verify. The model with ten grids is calculated, and the results are shown in table 1.

Table 1. Calculation results under different number of grids.

Numble	Grid number	Cold fluid outlet temperature (K)	Hot fluid outlet temperature (K)	Average temperature of heat exchange surface (K)
1	7388	285.7437	358.5611	300.6039
2	16588	285.4959	358.6146	300.3805
3	36617	285.6294	358.5687	301.4363
4	80992	285.7259	358.4269	302.4313
5	97374	285.6977	358.4876	302.0197
6	138438	285.7668	358.4335	302.2555
7	196154	285.6929	358.6025	301.8468
8	315994	285.7567	358.5128	302.4955
9	532311	285.7730	358.5522	302.5464
10	953210	285.7980	358.4997	302.5136

We can see from the table 1, when the grid number from 7388 to 953210, with the increase of grid number, when the grid number reached 315994, also is the model number is 8, hot and cold fluid outlet, and the average temperature of the heat transfer surface compared with the greater the number of grid model change is very small, we can think of 315994 grid has reached or not, shall be limited to the computing power of the computer we choose 315994 grid model as our next research model of the problem.

5. Effect of inlet temperature of hot fluid on heat transfer performance of heat exchanger

The inlet velocity (flow rate) of the hot fluid, the inlet temperature of the cold fluid, and the velocity (flow rate) of the cold fluid remain unchanged, and the outlet temperature of the cold fluid and the outlet temperature of the hot fluid change with the inlet temperature of the hot fluid. The change of temperature field and velocity in heat exchanger was analyzed. Set the cold fluid inlet temperature is 283.15 K, the speed of 0.1 m/s, thermal fluid inlet velocity of 0.1 m/s, thermal fluid inlet temperature, respectively, 363.15 K, 353.15 K, 343.15 K, 333.15 K, 323.15 K, 313.15 K, 303.15 K seven values and the results obtained by studying the change of the average temperature of cold fluid outlet and the change of the average temperature of hot fluid outlet are shown in figure 3.

As can be seen from Fig. 3, as the inlet temperature of the hot fluid decreases, the outlet temperature of the cold fluid also decreases continuously and linearly. That is to say, the temperature of the hot fluid inlet is closely related to the heat transfer of the heat exchanger. At the same time, with reduced thermal fluid inlet temperature, outlet temperature of hot fluid is also declining, and is also a linear decline, suggesting that thermal fluid inlet temperature a little effects on the relative value of the outlet temperature of hot fluid, regardless of the number of thermal fluid inlet temperature for as long as is higher than that of cold fluid temperature, thermal fluid outlet temperature and inlet decreased compared to a fixed value.

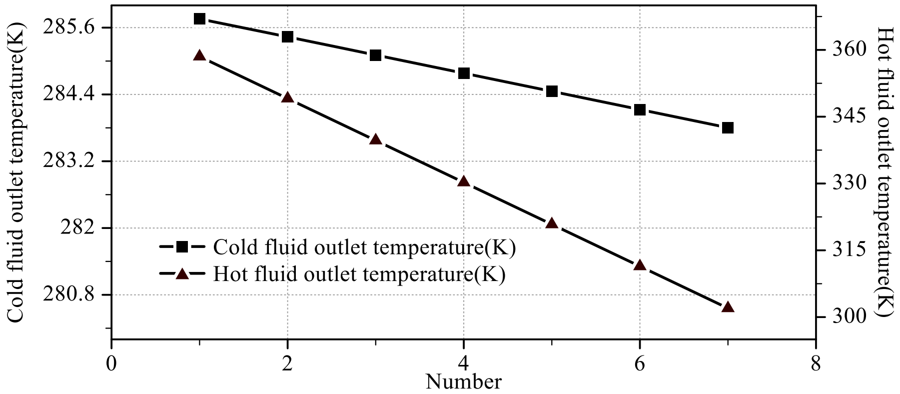

Figure 3. The change of the average temperature of the cold fluid outlet and the hot fluid outlet.

6. Effect of inlet velocity of hot fluid on heat transfer performance of heat exchanger

Hot fluid inlet temperature, cold fluid inlet temperature and velocity of flow remains the same, given thermal fluid pressure loss of the import and export with the change of the thermal fluid inlet velocity , set the cold fluid inlet temperature is 283.15 K, the rate of 0.1 m/s, thermal fluid inlet temperature is set to 363.15 K, thermal fluid inlet velocity was set to 0.02 m/s, 0.04 m/s, 0.06 m/s, 0.08 m/s, 0.1 m/s, 0.15 m/s, 0.2 m/s seven values, the thermal fluid pressure loss of the import and export. The pressure loss at the inlet and outlet of the hot fluid varies with the inlet velocity of the hot fluid, as shown in figure 4. Note that the outlet pressure of the hot fluid is 0Pa, so the total pressure loss is the total pressure at the inlet.

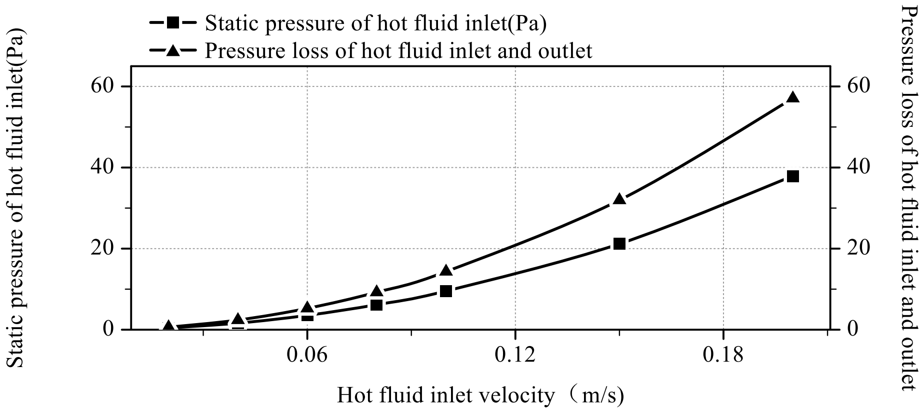

Figure 4. The change of inlet and outlet pressure loss of hot fluid.

As can be seen from Fig. 4, with the increase of inlet velocity of the hot fluid, the dynamic pressure of the hot fluid inlet keeps increasing, which is consistent with the expression of Bernoulli equation (1) of the ideal fluid. The total pressure is composed of hydrostatic pressure and dynamic pressure.

$$p+\frac{1}{2}\rho v^2+\rho gh=C \tag{1}$$

At the same time, we can find that, with the increase of the flow rate, the pressure loss of the whole heat exchanger increases continuously, and the rate of increase increases continuously. It can be found that the relationship between the pressure loss of the flow inlet and outlet and the flow rate is approximately quadratic. The pressure difference at the inlet and outlet of the fluid represents the loss in the flow area, that is to say, the flow loss and the flow velocity should also be quadratic, so the result obtained by our calculation is consistent with the expression of flow loss and local loss in Darcy Weisbach formula (2) and (3) [4].

$$h_f = \lambda \frac{l}{d} \frac{v^2}{2g} \tag{2}$$

$$h_j = \zeta \frac{v^2}{2g} \tag{3}$$

7. Effect of inlet temperature of cold fluid on heat transfer performance of heat exchanger

The inlet velocity of hot fluid, inlet temperature of hot fluid and inlet velocity of cold fluid remain unchanged. The inlet temperature of the hot fluid was set as 363.15k with a velocity of 0.1m/s, and the inlet velocity of the cold fluid was set as 0.1m/s. The inlet temperature of the cold fluid was set as 283.15k, 293.15k, 303.15k, 313.15k, 323.15k, 333.15k and 343.15k, respectively, to study the temperature difference between the inlet and outlet of the cold fluid and the outlet temperature of the hot fluid. The temperature difference between the inlet and outlet of the cold fluid is shown in figure 5.

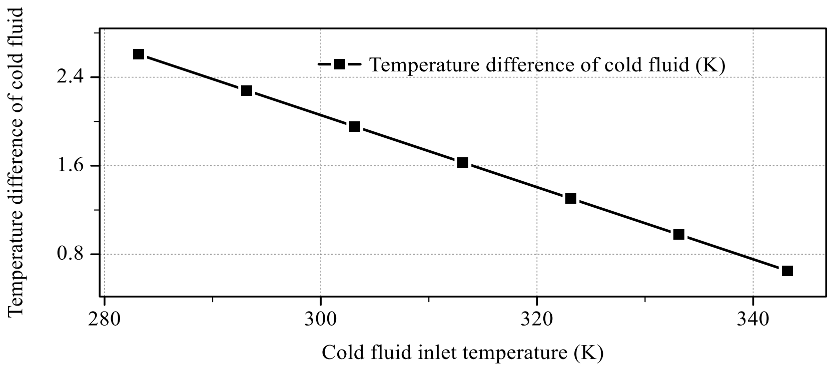

Figure 5. Variation of mean temperature difference between inlet and outlet of cold fluid.

As can be seen from Fig. 5, the temperature difference between the inlet and outlet of the cold fluid keeps decreasing with the increase of the temperature of the cold fluid. This is because with the increase of the temperature of the cold fluid, the logarithmic average temperature difference between the cold fluid and the hot fluid keeps decreasing, leading to the decrease of the heat gain of the cold fluid and the decrease of the temperature difference between the inlet and outlet of the cold fluid.

The average temperature of hot fluid outlet is shown in figure 6.

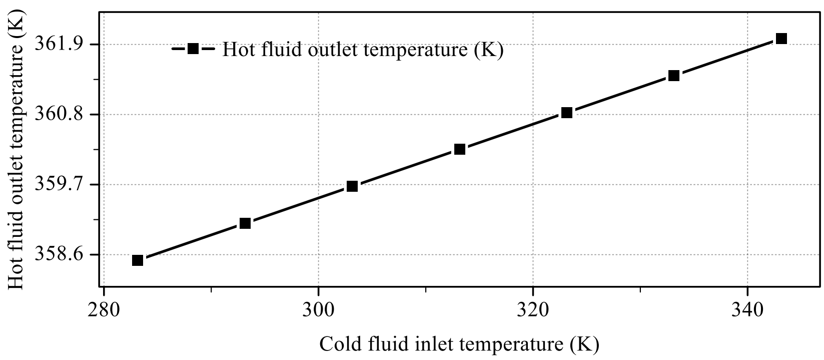

Figure 6. Change in average temperature of hot fluid outlet.

As can be seen from Fig. 6, with the continuous rise of the inlet temperature of the cold fluid, the average temperature of the outlet of the hot fluid also keeps rising, which is also the deterioration of heat exchange caused by the decrease of the average temperature difference.

8. Effect of inlet velocity of cold fluid on heat transfer performance of heat exchanger

The inlet velocity of hot fluid, inlet temperature of hot fluid and inlet temperature of cold fluid remain unchanged. The inlet temperature of the hot fluid was set as 363.15k with a velocity of 0.1m/s, the inlet temperature of the cold fluid was set as 283.15k, and the inlet velocity of the cold fluid was set as 0.02m/s, 0.04m/s, 0.06m/s, 0.08m/s, 0.1m/s, 0.15m/s and 0.2m/s, respectively. The average temperature of cold fluid outlet and average temperature of hot fluid outlet are shown in figure 7.

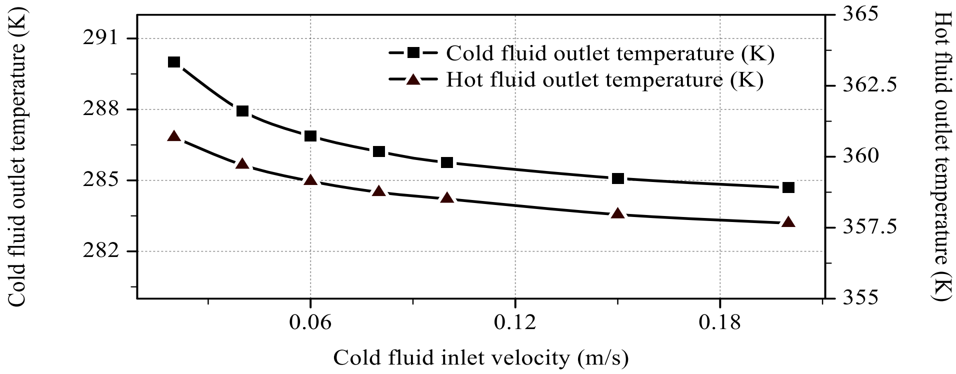

Figure 7. The change of average temperature of cold fluid outlet and hot fluid outlet.

As can be seen from Fig. 7, as the inlet velocity of the cold fluid increases, the outlet temperature of the cold fluid keeps dropping, which indicates that the longer the cold fluid stays in the pipe, the more heat it will get. However, the temperature of the hot fluid outlet keeps dropping, and the heat dissipation of the hot fluid keeps decreasing. However, when the flow rate increases to a certain value, the outlet temperature of the cold fluid will approach to the inlet temperature, and the outlet temperature of the hot fluid will also approach to a certain value. At this time, the flow process of the cold fluid is approximate to isothermal flow, which is favorable for improving the cooling degree of the hot fluid, but unfavorable for heating the cold fluid.

9. The performance difference between counterflow heat exchanger and downstream heat exchanger

The performance of heat exchanger is mainly determined by heat exchange, which can be calculated by heat transfer equation (4).

$$\Phi = Ak\Delta t_m \tag{4}$$

We can find that in the same heat exchanger, the greater the average temperature difference, the greater the heat exchange. The accurate average temperature difference should be calculated by formula (5).

$$\Delta t_m = \frac{1}{A}\int_0^A \Delta t dA \tag{5}$$

After simplification, equation (5) can be simplified to equation (6) as follows, so as to facilitate our calculation.

$$\Delta t_m = \frac{\Delta t_{\max} - \Delta t_{\min}}{\ln \frac{\Delta t_{\max}}{\Delta t_{\min}}} \tag{6}$$

In formula (6), $\Delta t_{\max}$ and $\Delta t_{\min}$ are the big and small in the end difference of heat exchanger [5].

From the above analysis, we can compare the average temperature difference between the counterflow heat exchanger and the downstream heat exchanger to compare the performance differences between the two types of heat exchanger. The physical model of the downstream heat exchanger can be obtained by exchanging the hot fluid outlet and inlet of the counterflow heat exchanger with other boundary conditions unchanged. The calculated results are shown in the following table.

Table 2. The difference between countercurrent heat exchanger and downstream heat exchanger.

Heat exchanger form	Cold fluid inlet temperature (K)	Cold fluid outlet temperature (K)	Hot fluid inlet temperature (K)	Hot fluid outlet temperature (K)	Average temperature difference (K)
Counterflow heat exchanger	283.1500	285.7567	363.1500	358.5128	76.3736
Downstream heat exchanger	283.1500	285.7632	363.1500	358.4828	76.3019

It can be seen that the counterflow heat exchanger has better heat transfer performance than the downstream heat exchanger.

10. Conclusion

Through the analysis of the above problems, obtained certain result, but there are still some problems, first of all, is limited to the size of the heat exchanger, the heat exchanger in heat are relatively small, and change the boundary conditions of heat exchanger for the influence of the velocity field and temperature field of the whole heat exchanger is not big, the center line of the pipeline fluid temperature change is very small. However, the results still accord with the actual physical laws, so the research results of these problems are still of some reference value to the study of practical problems.

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