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Research on flow channel layout of wing fins of PCHE heat exchanger based on SCO2

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Abstract: *Supercritical carbon dioxide Brayton cycle is a new generation of thermal energy cycle system. As an efficient heat exchange channel of printed circuit board heat exchanger, compact microchannel has important research content.In this paper, using supercritical carbon dioxide as the working medium, a non continuous staggered heat transfer fin with sinusoidal arrangement of wing type is proposed. The effects of the structural characteristics of the fin and channel on the heat transfer efficiency under different channels are analyzed and compared with the traditional broken line fin.The comparative simulation results show that under the same working conditions, the flow and heat transfer performance of the wing sinusoidal staggered heat exchange channel is better, and the pressure drop increases by about 31.14%.*

Keywords: *printed circuit board heat exchanger (PCHE), Fin structure, Supercritical carbon dioxide, Sinusoidal runner*

1. Model building

1.1 Geometric model

The schematic diagram of broken line heat exchanger is shown in Figure 1. The flow direction of cold and hot fluid is opposite, the height of flow channel is 1mm, the section is a semicircle with a radius of 1mm, and the thickness of heat exchange diaphragm is 0.6mm.The wing fin microchannel heat exchanger adopts the staggered arrangement of cold and hot fluids up and down, as shown in Figure 1. The cold and hot fluids are supercritical carbon dioxide, and the heat exchange plate is made of iron. The height of cold and hot fluid channels is 1mm. Heat exchange is carried out through fins and heat exchange diaphragms. The length of fins is 6mm, the width is 2mm, the upstream direction is oval, the tail is parabolic linear, and the distribution between fins is approximately sinusoidal. Due to the similarities between wing fins and swordfish fins, Gong Ya et al. [3] pointed out that the spacing between transverse adjacent fins is 8mm, the longitudinal distance between adjacent fins is about 6mm, and the fin inclination angle is 15°, which has better heat exchange performance. Therefore, the same fin layout is adopted in this paper, and the heat exchange diaphragm is 0.6mm thick, as shown in Figure 1. The cold and hot fluid convection is used to improve the heat transfer efficiency and structure the geometry.In this experiment, both consider the inlet and outlet effect of the fluid, and extend the non heat exchange fin area by 7mm before and after, so as to make the fluid develop fully.

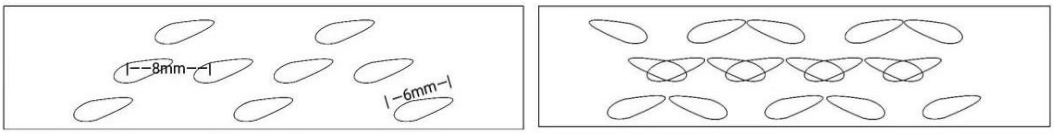

Figure 1: Staggered distribution structure of wing fins in cold and hot channels

In this paper, unstructured grids are used to calculate the equivalent diameter D of the flow channel of the irregular wing model in order to generate a reasonable size and number of grids:

$$d = \frac{4V}{A} \tag{1}$$

Where V is the total volume of flow channel and a is the total heat exchange area between fin and heat shield.Broken line type D1 = 0.0036mm, water drop type D2 = 0.0038mm.

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1.2 Boundary conditions and parameter setting

Table 1 shows the setting of boundary conditions.The ambient pressure is 10MPa; Velocity boundary conditions are set at the inlet of the cold and hot sections. The inlet velocity of the cold section is 1m / s, the temperature is 450k, the inlet velocity of the hot section is 1.5m/s, and the temperature is 750k; The pressure outlet boundary condition is adopted for the outlet of cold and hot end; The upper and lower surfaces are periodic boundaries, and the two sides of the flow channel are symmetrical boundaries.

Table 1: Boundary condition setting

position	boundary condition	numerical value
Cold section inlet	Velocity inlet boundary	0.8~1.6m/s
Hot section inlet	Velocity inlet boundary	1.0~1.8m/s
Cold and hot section outlet	Pressure outlet boundary	0MPa
Upper and lower surfaces	Periodic boundary	
Both sides of runner	Symmetric boundary	

In this paper, the real liquid carbon dioxide gas model in NIST database is used for simulation.In order to obtain better accuracy, SST K-W model is used for numerical simulation calculation. The second-order upwind discrete scheme and simple algorithm are used to couple the pressure and velocity. When the calculation residual reaches 10 ^ - 7, the calculation converges.The results of three-dimensional flow field are sorted out, and the changes of temperature and pressure drop are obtained($\Delta P / L$), Reynolds number (RE), Nusselt number (nu) and Planck number (PR).

2. Result analysis

2.1 Grid calculation results

In this paper, ICEM is used to divide the grid. The number of boundary layers is 4 and the growth rate is 1.1. The grid sensitivity is compared. When the number of grids is about 3 million, high-quality unstructured grids can be generated. The grid division results of broken line heat exchanger and wing fin heat exchanger are shown in Fig. 2 (a) and Fig. 2 (b), and the grid quality is 0.873.

Figure 2 (a): Wing type grid division

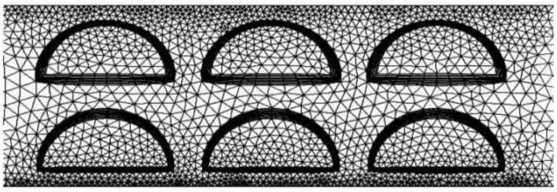

Figure 2 (b): Broken line grid division

2.2 Analysis of calculation results

1) Heat transfer analysis

Under the same cold and hot fluid temperature, the temperature field nephogram of broken line type and wing type is compared. The results are shown in Fig. 3. It is obvious that the heat exchange of the two methods are mainly concentrated at the inlet, but the effective heat exchange area of wing type is more than that of broken line type pipe, which can obtain greater heat exchange power. Select the middle channel to sort out the data of temperature changes of the two, as shown in Fig. 4, There is no significant difference in the change of temperature difference, but the average temperature distribution in the sinusoidal whole area is more uniform, which is conducive to reducing the damage of solid materials and prolonging the service life of heat exchanger.

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Figure 3: Temperature distribution cloud diagram of broken line channel

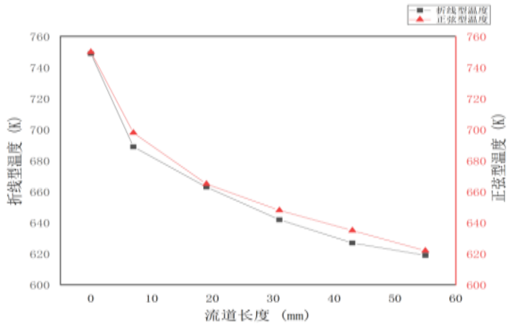

Figure 4: Variation of temperature with channel length

2) Pressure drop analysis

Taking this working condition as an example, the pressure nephogram and velocity nephogram of both are shown in figures 5 (a) and 5 (b). It can be seen that in the broken line heat exchange pipe, the pressure is mostly concentrated in the middle pipe, while in the pipe with sinusoidal wing fins, the pressure reduction direction is distributed with the fin arrangement direction, the pressure decreases evenly and the pressure drop is obvious, Because the cold and hot pipes adopt convective staggered distribution, the pressure on both sides of the heat exchange surface can be effectively uniform.

Compared with the direct flow of fluid, the sinusoidal flow produces fluid fluctuation with the fins, which will produce large flow resistance at the peak. The narrow tail of wing fins can effectively reduce the velocity and negative pressure gradient while unifying the fluid flow, and avoid the reflux and vortex at the bend. Compared with the broken line channel, the turbulence will increase with the increase of mass flow, and the local heat transfer and pressure drop will increase significantly, which will improve the heat transfer performance of the heat exchanger.

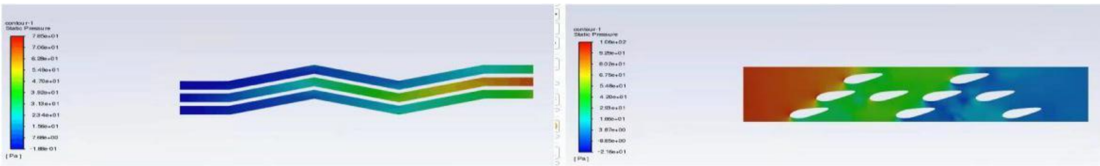

Figure 5 (a): Cloud diagram of pressure distribution

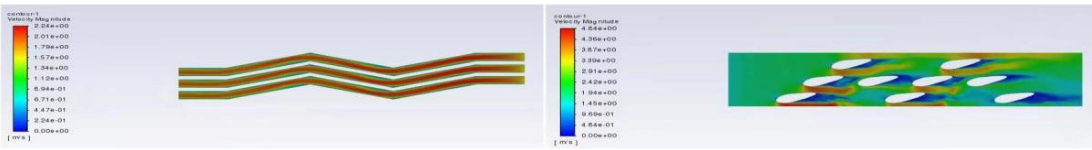

Figure 5 (b): Cloud diagram of velocity distribution

3) Parameter calculation and analysis

The calculation formulas of parameters re, Nu and PR are as follows:

$$\mathrm{Re} = \rho v d/\mu; \qquad \mathrm{Nu} = hd/k; \qquad \mathrm{Pr} = \mu C_p/k \tag{2}$$

Where: ρIs the fluid density; μ Is hydrodynamic viscosity; V is the fluid flow velocity; H is the heat transfer coefficient between fluid and wall;K is the thermal conductivity and the specific heat capacity of the fluid at a given pressure.Calculate and sort out the Reynolds number, Nusselt number and Planck number of fold type and wing type. The changes of Nusselt number and Planck number of the two heat

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exchangers with Reynolds number are shown in Fig. 6 (a) and Fig. 6 (b) respectively.

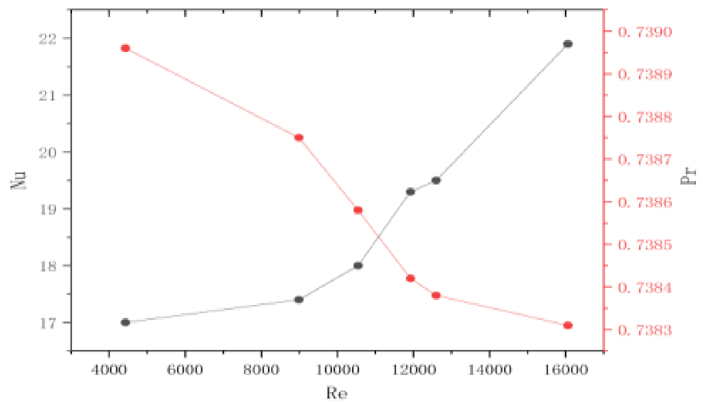

Figure 6 (a): variation of broken line Nu and PR with re

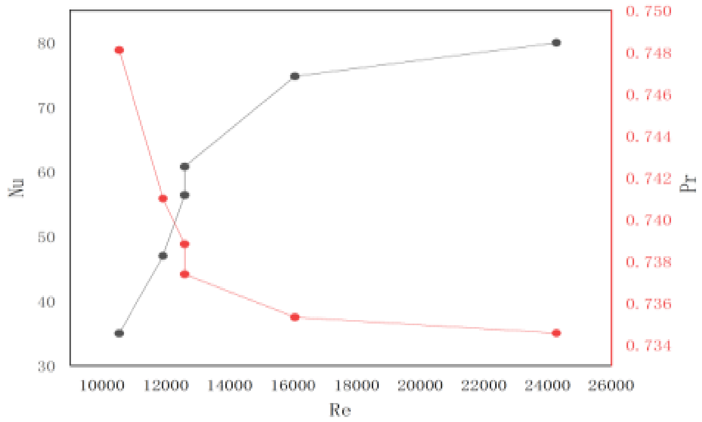

Figure 6 (b): variation of wing Nu and PR with re

With the increase of Reynolds number, the Planck number (PR) of folding line and wing gradually decreases and tends to be flat, and the Nusselt number (nu) decreases.

With Reynolds number. The smooth transition of the heat exchange surface of the streamline profile of the wing fin reduces the friction coefficient, which is consistent with the experimental results. The results in the figure show that there is a negative correlation with the Reynolds number, and the pressure drop decreases. However, the excessive bending angle of the broken line causes the friction coefficient to be significantly higher than that of the slow streamline channel, therefore, wing fins can significantly reduce pressure drop loss while maintaining good heat transfer performance.

At the same Reynolds number, the Nusselt number of the wing sinusoidal flow channel is significantly higher than that of the folded line, indicating that its heat transfer performance has more advantages. It can also be seen from Fig. 6 that the pressure drop loss increases by about 31.14%, and the growth of Reynolds number is slower than that of the folded line, which proves that its flow and heat transfer performance is better.

3. Conclusion

Based on the existing wing fins, a new arrangement method of channel fins is proposed in this paper. For the broken line heat exchanger under the same conditions, it has better heat transfer performance.

1) The sinusoidal uneven arrangement of fins can effectively improve the pressure drop, and the staggered flow mode of fins and channels can have better heat transfer capacity under the same pressure drop.

2) Too dense fin arrangement is not conducive to the uniform and full development of the channel and is prone to turbulence. The rapidly reduced channel will significantly enhance the local pressure of the channel and reduce the heat transfer capacity.

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3) Under the same conditions, the wing sinusoidal channel can reduce the pressure drop loss of broken line pipe PCHE by about 31.14%, and ensure the heat transfer performance.

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