STUDY ON HEAT TRANSFER CHARACTERISTICS OF SUPERCRITICAL CO_2 PRINTED CIRCUIT HEAT EXCHANGERS WITH DIFFERENT SHAPE CHANNELS

by

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Printed circuit heat exchanger is a micro-channel heat exchanger. Because of its high efficiency, high pressure and high temperature resistance, it has been widely used in photovoltaic power generation, nuclear energy and other fields. In particular, the research on the cross-section shape of heat exchanger channel has been widely concerned by researchers. In this paper, the printed circuit heat exchanger performance of semi-circular, square and trapezoidal channels with the same inlet and outlet area is compared under the pressure of 8 MPa. The heat transfer performance of the mass-flow rate in the range of 500-2000 kg/m² under three cross-section shapes was investigated. The results show that the heat transfer effect of fluid in the trapezoidal channel is obviously better than the other two channels. This is mainly because the heat exchange contact area of cold and hot fluids in the trapezoidal channel is large, resulting in an increase in heat exchange between cold and hot fluids. When the inlet velocity is the same, the Reynolds number of the fluid in the trapezoidal channel is larger. The outlet temperature of the cold fluid in the trapezoidal channel is 7.9% higher than that in the semi-circular channel and 4.1% higher than that in the rectangular channel. The outlet temperature of the hot fluid in the trapezoidal channel is 6.28% lower than that in the semi-circular interface channel and 3.4% lower than that in the square channel. The trapezoidal channel printed circuit heat exchanger has better heat transfer effect and better heat transfer performance.

Key words*: supercritical CO_2, printed circuit heat exchanger, numerical simulation, thermal hydraulic performance*

Introduction

In the past two years, due to the combined influence of various countries' requirements for *Carbon Peak* and *Carbon Neutrality* frequent extreme weather and other factors, the global energy supply and demand have been seriously unbalanced, the energy market has fluctuated sharply, and energy prices have soared, especially the European natural gas and global coal prices have repeatedly hit record highs, posing a threat to the stability of the global energy market and economic development [1]. Energy sectors around the world are working hard to find solutions and improve existing technologies to achieve more efficient and clean energy

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systems to meet the huge demand for energy. At the same time, the supercortical CO_2 (sCO_2) Brayton cycle with CO_2 as the working medium has attracted wide attention. As a kind of clean energy, CO_2 exists widely in nature. When CO_2 is near the critical point (7.38 MPa, 31 °C), its physical properties will change, its density will become lower, its compressibility is lower and it has good controllabilityz [2]. The diffusion coefficient of sCO_2 is much higher than that of conventional organic solvents, which allows it to dissolve and diffuse substances more quickly throughout the system. It is precisely because of the excellent thermodynamic properties of sCO_2 fluid that it is widely used in aerospace,heat, power generation and other fields. The physical properties of CO_2 in the supercritical region are shown in fig. 1.

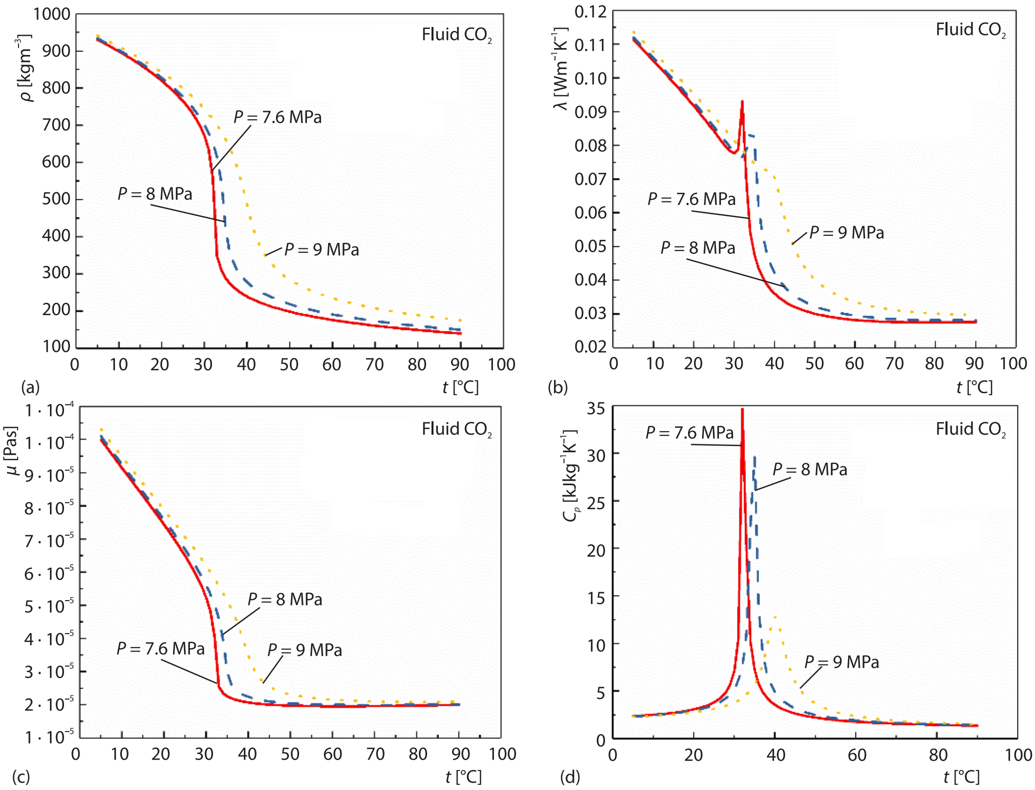

Figure 1. Thermophysical properties of sCO_2;
(a) density, (b) thermal conductivity, (c) viscosity, and (d) specific heat

Printed circuit heat exchanger (PCHE) is a new micro-channel compact heat exchanger which has attracted much attention in recent years [3]. Compared with traditional shell-and-tube heat exchangers, PCHE has higher thermal efficiency, strong specific heat exchange area (heat exchange area density up to 2500 m^2/m^3), and strong high temperature and high pressure resistance (can withstand the maximum temperature of 900 °C, can withstand the maximum pressure of 60 MPa) [4]. Therefore, the use of PCHE as a heat exchanger in the sCO_2 Brayton cycle can greatly save the footprint of its equipment. In numerical simulation, PCHE is usually arranged in a countercurrent way, and the cold and hot fluids flow in the opposite direction, which can greatly improve the heat transfer of the heat exchanger, thereby improving the local heat transfer coefficient of the entire equipment, and significantly improving the heat transfer efficiency of the entire system. The shape diagram of the PCHE is shown in fig. 2.

Figure 2. Schematic diagram of PCHE

The heat transfer performance of PCHE has been widely concerned. Morteza *et al.* [5] evaluated the response of the precooler by integrating integral and discontinuous ribs of different configurations and showed that the ribs enhanced the secondary swirl and helped to increase the heat transfer level in sCO_2 flow. Morteza *et al.* [6] studied the convergence of the small channels on the cold side and divergence of the small channels on the hot side under three different operating conditions of sCO_2. The results show that when the thermal performance of the precooler is improved, the flow pressure drop of CO_2 can be reduced by about 60% by small channel divergence on the hot side and small channel convergence on the cold side. Seo *et al.* [7] experimentally investigated the thermal hydraulic performance of PCHE with straight channels under laminar flow conditions. They found that the counter-flow pattern is better than the parallel-flow pattern, and the quantity of heat flux as well as pressure drop increases with larger Reynolds number.

In order to improve the PCHE performance of the airfoil, Cui *et al.* [8] proposed two new airfoils based on the NACA 0020 airfoil structure. Using sCO_2 as the working fluid, the thermal performance and strengthening mechanism of the fins were studied numerically. The results show that the overall performance of one of the new fins is better than that of the NACA 0020 fins used in PCHE. Under the selected conditions, the J-factor of the new fins is 2.97%~6.15% larger than that of the NACA 0020 fins, and the pressure drop is 0%~4.07% smaller than that of the NACA 0020 fins. Meanwhile, Aneesh *et al.* [9] studied various PCHE models, and compared with PCHE models based on sine, triangle and linear channels, trapezoidal PCHE model has the highest heat transfer and the largest pressure drop. Under the operating conditions tested, trapezoidal wave channels are expected to increase the heat transfer rate by up to 41% compared to straight channel PCHE. For sinusoidal and triangular wave channel PCHE configurations, the corresponding heat transfer advantages are expected to be 33% and 28%, respectively. Jeon *et al.* [10] proposed a novel PCHE and numerically studied its thermal properties. The results show that under the condition of constant mass-flow, the thermal performance of PCHE decreases monotonically with the increase of channel size. The spacing between channels has little effect on the thermal performance of PCHE. Based on extensive numerical studies, Kim *et al.* [11] presents a mathematical expression for predicting the thermal properties of cross, parallel, and countercurrent PCHE channels. The effects of channel size and channel length are particularly considered. Based on the total heat transfer coefficient obtained, the function expressions of PCHE efficiency and geometrical parameters, material properties and flow conditions are derived. Shin and Yoon [12] designed and manufactured a PCHE with a heat exchange power of 200 kW and evaluated its performance through nitrogen experiments.

The PCHE with different structural types usually exhibit different flow and heat transfer characteristics. Improving the PCHE heat transfer performance of different cross-sections has always been a concern. Although there are many studies on PCHE before, there are few studies on different shapes of inlet and outlet cross-sections, especially trapezoidal flow channels, when the high pressure is 8 MPa. Based on fluid simulation software, this paper introduces the modelling method and corresponding calculation process in detail by using a simplified through channel PCHE model. At the same time, the numerical simulation and performance comparison of PCHE in semi-circular, square and trapezoidal channels were carried out to study the heat transfer performance of PCHE under different inlet flow rates, so as to maximize the heat transfer coefficient and performance of PCHE.

Numerical methodology

Physical models

The straight-channel type PCHE mentioned in the literature is selected as the physical model for flow simulation. As shown in fig. 3, the model was modeled by 3-D solid modelling software. The PCHE is composed of many repeated micro-channels with the same structure. Therefore, each identical micro-channel is modeled and simulated as the basic unit in the simulation process. The specific size and model are shown in the figure. The outer bottom surface is 3.3 mm long and 3 mm wide, and the material used is 316*L* refined steel [13]. In order to ensure the investigation of the heat transfer performance of the heat exchanger under the inverted semicircular, square and long-side opposite trapezoidal channels.

Equivalent circle diameter:

$$De = 2\sqrt{\frac{A}{\pi}}$$

where De is the equivalent circle diameter, A – the area of the irregular shape, and π – the P_I for conversion keep the inlet and outlet areas of the channel approximately equal, and the pipe material is also 316*L* refined steel, and the total length of the pipe segment is L = 70 mm.

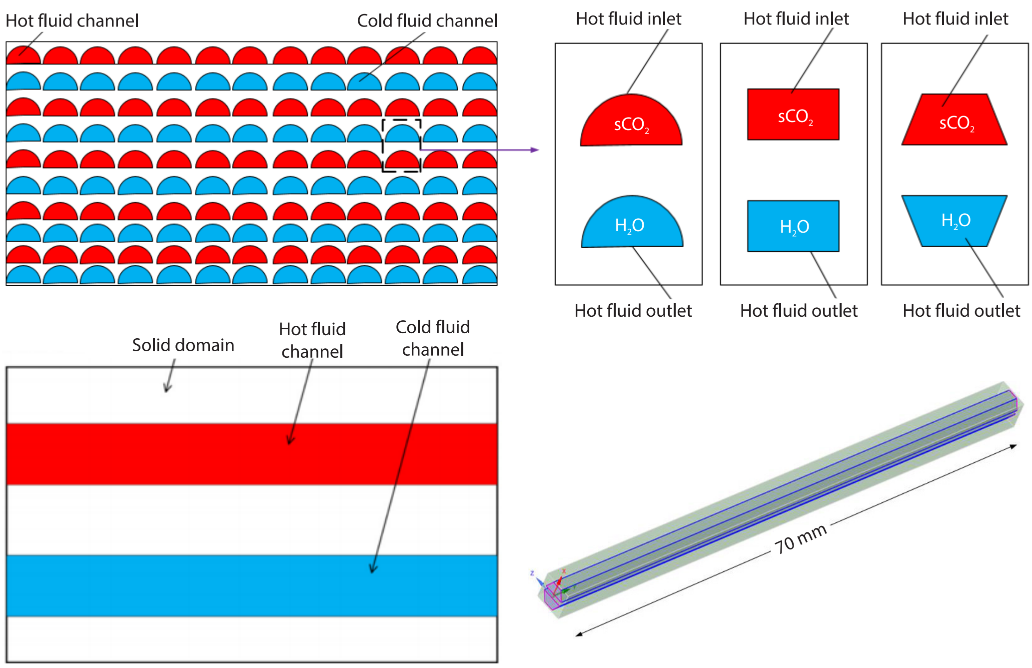

Figure 3. Different channel geometries for PCHE

The heat transfer working medium is sCO_2 and H_2O, and the heat transfer is carried out in the upper and lower channels, respectively [14]. The calculated physical model is horizontal placement, without considering the influence of gravity conditions on the heat transfer condition [15]. The channel parameters of the heat exchanger are shown in tab. 1.

Table 1. Dimensions of the studied channels

Letter	Implication	Dimension
S	Width of the rectangular channel	0.94 mm
W	Length of the rectangular channel	2.00 mm
D	Depth of the trapezoid channel	1.04 mm
B	Bottom width	2.40 mm
C	Width of channel slope	3.30 mm

In order to reduce the complexity of the entire model and facilitate numerical simulation with Fluent, the following assumptions are made for the entire heat exchanger:
– There is no heat exchange between the outer wall of PCHE and the external environment and
– ignore the influence of the outer tube wall thickness on the entire heat exchange system [16].

Numerical model

In order to evaluate the thermal performance of PCHE under different inlet and outlet shapes, many mathematical physics equations need to be used to solve the numerical simulation, and the equations selected should correspond to the appropriate models [17]. The equations used in this paper include energy equation, momentum equation, continuity equation, turbulent kinetic energy equation [18]. The details are as follows.

The continuity equation:

$$\frac{\partial}{\partial X_i}(\rho u)+\frac{\partial \rho}{\partial t}=0 \tag{1}$$

where ρ is the density and u – the velocity vector.

The momentum equation:

$$\frac{\partial}{\partial x_j}\left(\rho u_i u_j\right)+\frac{\partial \rho}{\partial x_i}=\rho \mathrm{g}_i+\frac{\partial}{\partial x_j}\left[\left(\mu+\mu_t\right)\frac{u_i}{x_j}\right] \tag{2}$$

where ρ is the pressure and μ and μ_t are molecular viscosity and turbulent viscosity, respectively

The energy equation:

$$\frac{\left(\rho E_0\right)}{\partial t}+\frac{\partial\left(\rho u_i u_j\right)}{\partial x_i}=\rho u_i F_i-\frac{\partial q_i}{\partial x_i}+\frac{\partial}{\partial x_j}\left(u_i T_{ij}\right) \tag{3}$$

where E_0 is the total internal energy.

Turbulent kinetic energy, k, equation:

$$\frac{\partial}{\partial x_j}\left(\rho u_j k\right)=\frac{\partial}{\partial x_j}\left[\left(u+\frac{u_i}{\sigma k}\right)\frac{\partial k}{\partial x_j}\right]+u_i\frac{\partial u_i}{\partial x_j}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)-\rho\varepsilon \tag{4}$$

Boundary conditions and calculation methods

The numerical t software was used to calculate and solve the PCHE, and the physical parameters of sCO_2 were obtained by the inquiring physical parameters software. Regardless of the influence of gravity, the interface wall between solid and fluid of the heat exchanger is set under the condition of no slip, and the working pressure is set to 8 MPa, which can ensure that CO_2 can always be in a supercritical state under this pressure [19]. The CO_2 Reynolds number Re > 8000 is calculated during the working process, showing a turbulent state. The model is calculated by SST, k-ω model. The turbulence calculation model has the characteristics of accurate calculation results and high precision. The flow in the computational fluid region is considered to be 3-D, stable, and uncompressible [20]. When the iterative residuals of all the governing equations are less than 10^{-6}, the numerical calculation is considered to have reached the standard of convergence [21].

The SIMPLEC algorithm was used for the pressure and velocity coupling curves, PRESTIO was selected as the pressure interpolation format, momentum, energy, turbulent kinetic energy and turbulent dissipation rate were all adopted as the second-order upwind format [22]. After referring to relevant papers, the inlet channel of supercritical CO_2 is set as the mass inflow port, and the outlet is set as the pressure outlet.

Validation and grid independence

The meshing of sCO_2 PCHE is divided by ICEM in Ansys Workbench platform. In order to improve the calculation accuracy of the whole meshing, the boundary-layer mesh needs to be encrypted, and the mesh density at the boundary is finer than that in other places. At the same time, the y+ values of the inner and outer walls of the inner tube involved in coupled heat transfer are set to be less than 0.6. In order to achieve an effective balance between computational cost and simulation accuracy, a variety of computational grids are constructed for analysis. PCHE local grid division and independence verification for semi-circular and square cross-section channels are shown in fig. 4.

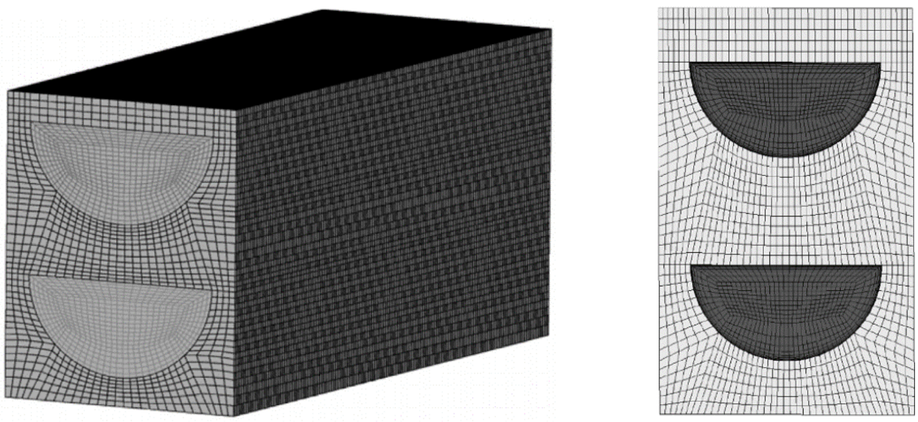

Figure 4. Mesh structure used in this paper

When the trapezoidal, square and semicircular cross-section channel models are meshed, seven different meshes are divided by adding boundary-layer and other methods. A trapezoidal channel is taken as an example to verify its grid independence. When the number of grids is 1408104, the temperature of the hot end outlet changes little. Considering the problems such as time and accuracy in the calculation process, and on the premise of fully considering the computing efficiency and computation amount, the grid model 1408104 was finally selected for subsequent simulation work, and the other two PCHE models of cross-section channels were verified by referring to this method. In the final selection, the number of grids for the semi-circular section channel was 1283694, while the number of grids for the square section was 1028618. The grid independent verification of trapezoidal cross-section channels is shown in fig. 5.

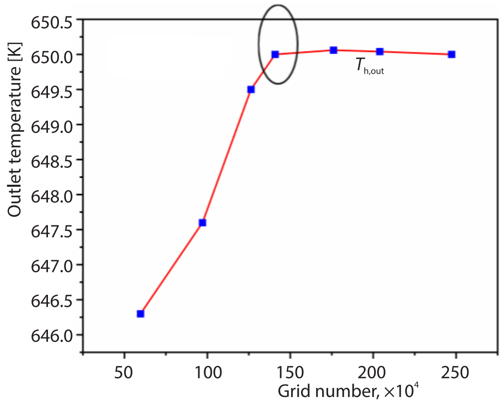

Figure 5. Grid independence verification

In order to verify the validity of the established model, the corresponding physical model is established according to the proportion of PCHE in [23], and the working conditions used in the experiment are simulated. The simulation results are compared with the experimental results. It can be seen from the fig. 6 that the local heat transfer curve simulated by FLUENT is basically consistent with the experimental data line, with the maximum error maintained at about 8.7% and the average error at about 4.6%, which is within the allowable range. Therefore, it can be considered that the model can correctly reflect the heat transfer situation of PCHE, and the model is considered effective.

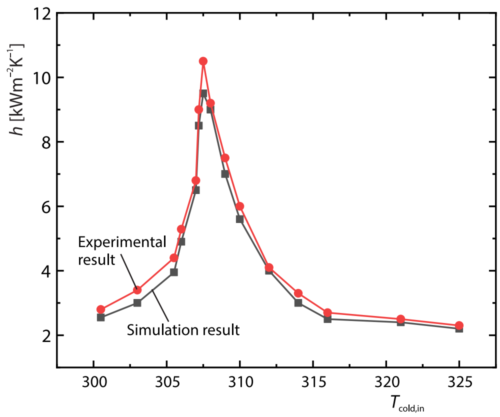

Figure 6. Comparison of experimental and simulation result

Data processing methods

The thermal conductivity of PCHE in this paper is obtained by weighted average of volume:

$$\lambda_f = \frac{1}{V}\int \lambda \mathrm{d}V = \frac{1}{V}\sum_{i=1}^{1} \lambda_i \left|V_i\right| \tag{5}$$

where V is the unit mesh volume and λ – the unit mesh thermal conductivity.

In the simulation project, the average temperature of sCO_2 fluid is taken as the qualitative temperature required by the calculation process to calculate:

$$\mathrm{Re} = \frac{\rho u D_h}{\mu}$$
$$\mathrm{Nu} = \frac{h D_h}{\eta \lambda_f} \tag{6}$$

where Re is the Reynolds number, D_h – the hydraulic diameter of the hexagonal channel, ρ – the fluid density, μ – the dynamic viscosity, u – the mass-average fluid velocity, h – the average heat transfer coefficient, and λ_f – the thermal conductivity of fluid.

The CO_2 average heat transfer coefficient:

$$h = \frac{q_w}{T_w - T_b} \tag{7}$$

where q_w and T_w are the average heat flux density of the wall area and the solid-flow interface temperature, respectively, A – the internal surface area of the interface, and T_b – the average body temperature.

The evaluation formula:

$$PEC = \frac{\dfrac{\text{Nu}}{\text{Nu}_0}}{\dfrac{f}{f_0}} \tag{8}$$

where Nu_0 is the Nusser number of the reference flow channel and f_0 – the resistance coefficient of the reference flow channel.

Results and discussion

Flow and heat transfer performance of trapezoidal channels at high temperature

In order to explore the heat exchange performance of PCHE under trapezoid channel, this paper explores the influence of G = 500 kgm²/s, G = 1000 kgm²/s, and G = 2000 kgm²/s inlet mass-flow rate on the heat exchange performance of heat exchangers based on the comparison of inlet and outlet heat exchangers with different cross-sections.

Figure 7 shows the schematic diagram of fluid density along the Y-direction in the trapezoidal PCHE channel when the hot runner and cold runner inlet flows are different.

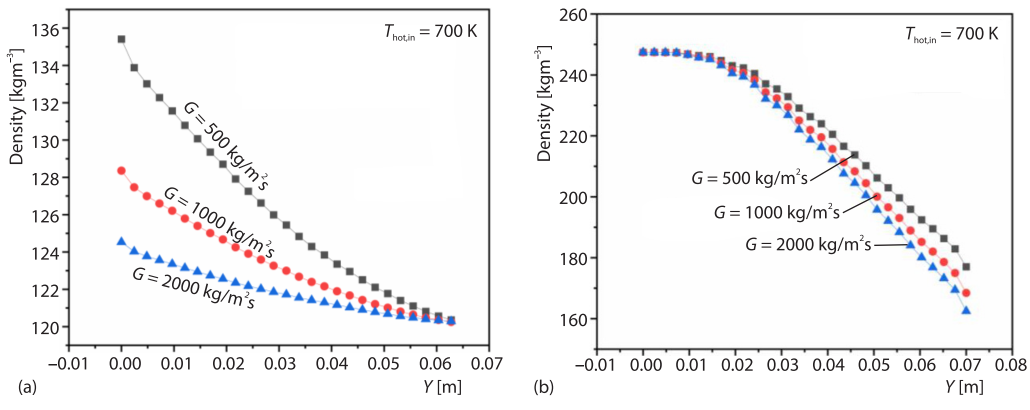

Figure 7. The fluid density in the hot and cold channels changes along the *Y*-direction; (a) hot channel and (b) cold channel

In the process of heat transfer, the density of cold fluid and hot fluid of heat exchanger decreases, and the fluid density changes greatly. The density of the fluid decreases with the increase of the flow rate, and the difference of the density of the cold fluid is greater than that of the hot fluid. This is mainly because when water is heated, the thermal motion of the molecules is intensified, and the spacing between the molecules becomes larger, resulting in a larger reduction in density.

Figure 8 shows the change of turbulent kinetic energy of the hot and cold channel along the heat transfer direction of the heat exchanger during the trapezoidal PCHE channel heat transfer. The relationship between the turbulent kinetic energy and the inlet mass-flow rate is discussed. When the mass-flow rate is small, the turbulent kinetic energy of the hot fluid channel gradually decreases along the *Y*-direction and has little change in the whole heat transfer process. With the increase of mass-flow, the turbulent kinetic energy of hot fluid increases rapidly and decreases with the *Y*-direction, which is mainly caused by the increase of inlet mass-flow. The turbulent flow of sCO_2 is very strong. Under the action of eddy current, the particles in the fluid will collide and mix violently, speeding up the heat transfer rate inside the material. At the same time, the turbulence will also transfer heat from the high temperature region the low temperature region, so as to achieve a balanced distribution of heat. However, the turbulent kinetic energy in the cold fluid channel decreases first and then increases, which is basically not affected by mass-flow.

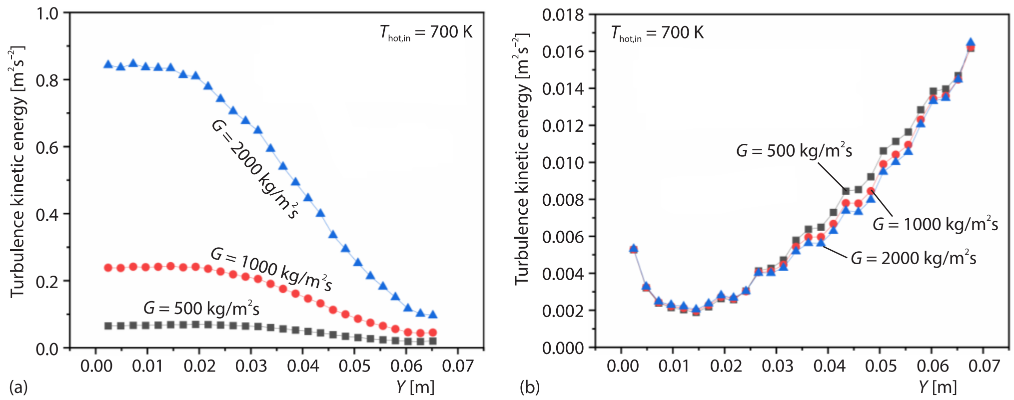

Figure 8. The turbulence kinetic energy in the hot and cold channels changes along the *Y*-direction; (a) hot channel and (b) cold channel

Influence of different cross-section channels on heat transfer performance of PCHE

The setting of operating parameters and boundary conditions plays a key role in the simulation ensure that the flow and velocity set at the inlet and outlet are consistent across the PCHE of different shapes and diameters. The heat exchange wall of the two channels is 1.5 mm, and the wall thickness of the channel is 3 mm. The simulation work is carried out under the determined working parameters, and the temperature situation along the pipe-line direction is analyzed after the end.

Figure 9 shows the temperature variation of hot flow and cold flow in different types of channels along the *Y*-direction. The hot fluid inlet temperature is 700 K, and the cold fluid inlet temperature is 330 K. As can be seen from the figure, when heat is transferred along the pipe direction, the temperature of the cold fluid gradually increases, while the temperature of sCO_2 gradually decreases. At the same time, the average temperature and flow rate of the fluid in the heat transfer process were calculated, as shown in tab. 2. It can be seen from the scatter diagram in the figure that the heat transfer of cold and hot fluids in PCHE with different flow channels is more adequate in trapezoidal flow channels, and the temperature has a certain linear relationship with the pipe length along the *Y*-direction. It can be seen from the figure that the PCHE heat transfer effect of cold and hot fluid in trapezoidal cross-section channel is obviously better than that of rectangular tube and semi-circular tube channel.

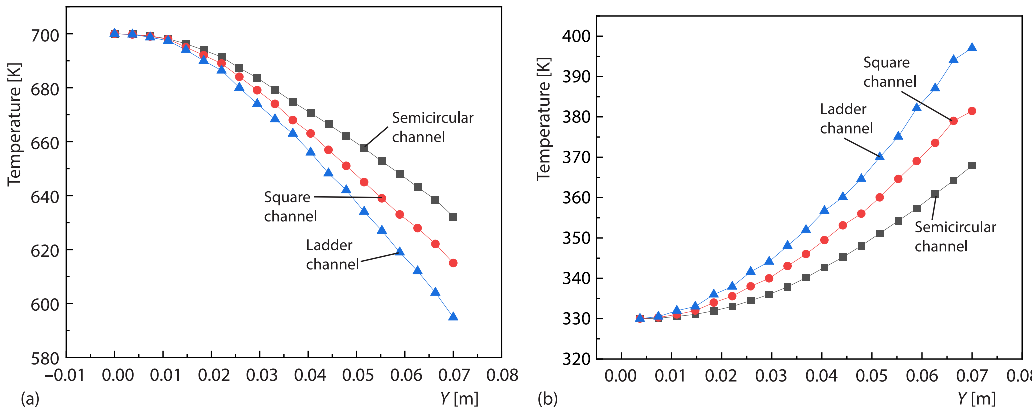

Figure 9. The temperature of cold and hot fluids in different channels varies along the *Y*-direction; (a) hot channel and (b)cold channel

Table 2. Three channel characteristics

Channel type	Hot fluid outlet temperature [K]	Average flow rate of fluid outlet [ms^{-1}]	Cold fluid outlet temperature [K]	Reynolds number
Semicircular	632.26	3.53	367.95	8733
Square	615.01	3.96	381.45	12102
Ladder	594.89	4.49	397.07	14257

Through the comparison of trapezoidal channel, rectangular channel and semi-circular channel, it is found that the heat transfer effect of fluid in trapezoidal channel is obviously better than that of other two shapes. This is mainly because the trapezoidal channel structure is relatively complex, showing a special structure of wide at the top and narrow at the bottom, and the fluid-flow shows a turbulent state, and the fluid disorder degree increases. At the same time, the direction of cold and hot fluid-flow is opposite, the friction resistance in the trapezoidal channel is larger, and the contact time between the fluid surfaces is increased, resulting in an increase in the heat exchange between the cold and hot fluids. Compared with the other two channels, the trapezoid heat transfer area also has obvious advantages. The outlet temperature of trapezoidal cold fluid is 7.9% higher than that of semicircular channel and 4.1% higher than that of rectangular channel, while the outlet temperature of hot fluid is 6.28% lower than that of semicircular interface channel and 3.4% lower than that of square channel, which also confirms the better PCHE heat transfer effect of trapezoidal channel.

Comparison of multi-channel PCHE performance parameters

The influence of Reynolds number on the heat transfer performance of PCHE is also discussed and the calculated results are compared. The calculation of Reynolds number involves mass-flow parameters, and the influence of mass-flow changes under various conditions is studied under certain inlet temperature and operating pressure. Various qualitative and quantitative results are presented and discussed in detail. The observed phenomena can be understood by comparing the simulation results under different shaped cross-sections.

Figure 10 show the temperature changes in the PCHE along the flow direction under the trapezoidal and semicircular cross-section channels. First, the inlet temperature of the hot

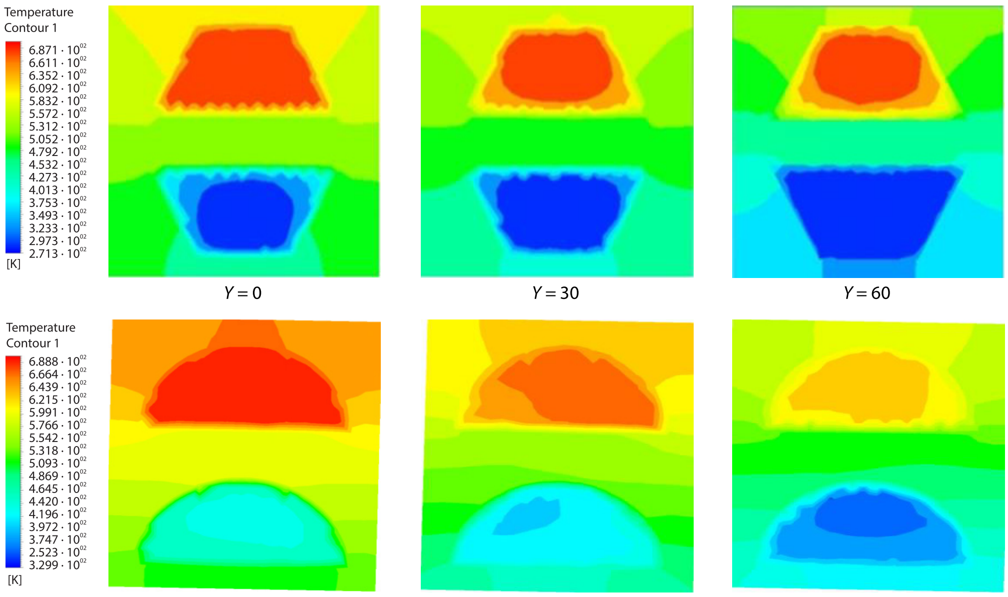

Figure 10. Temperature distribution of trapezoidal and semicircular channels at different positions

fluid is set to 700 K, and the inlet temperature of the cold fluid is set to 330 K. In order to ensure that the CO_2 pressure is always kept in a supercritical state, the pressure is set to 8 MPa. With the mass-flow rate G = 500 kgm^2/s, under the same conditions, the Reynolds number of the semi-circular channel, the square channel and the long-side trapezoid channel are calculated to be 8747, 12109, and 14257. On the basis of these results, the influence on the heat transfer performance of PCHE was explored. In order to increase the contact time of the cold and hot fluids, the cold and hot fluids flow countercurrent. Along the direction of the cold fluid-flow, the temperature of the cold fluid water gradually increases, while the temperature of the hot fluid sCO_2 gradually decreases. Compared with the other two cross-section channels, Reynolds number in the trapezoidal tube is larger, the fluid is in a turbulent state, and the boundary-layer of heat transfer in the flow is destroyed, which increases the heat transfer and leads to a lower outlet temperature for the hot fluid in the trapezoidal channel. The temperature display at different positions of the trapezoidal channel is shown in fig. 11.

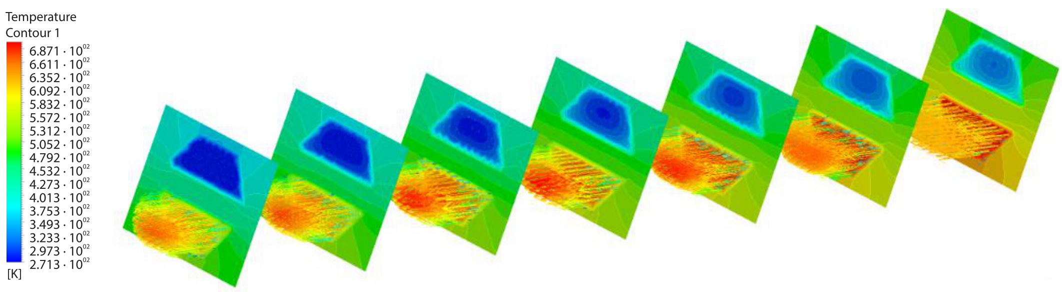

Figure 11. Temperature distribution of trapezoidal channel along axial direction

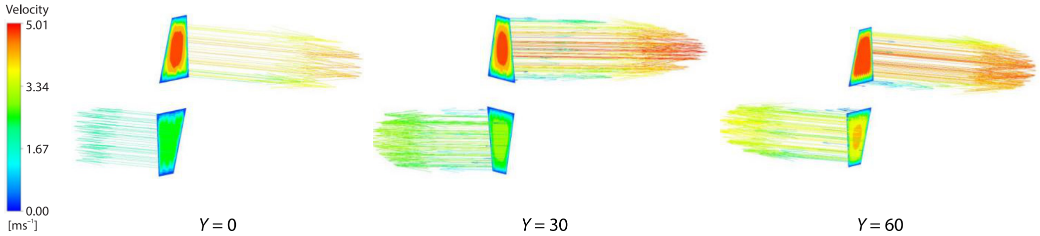

Figure 12. Trapezoidal channel velocity vector flow diagram

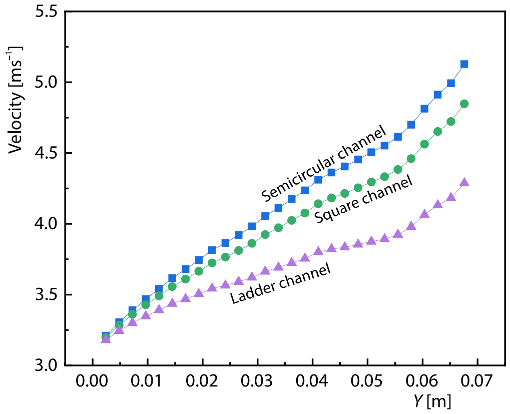

Figure 13. Diagram of fluid-flow velocity at different positions in the channel

Figure 12 shows the schematic diagram of the local flow field of sCO_2 in the trapezoidal channel PCHE. The speed of fluid-flow can be determined by the color depth of the flow line. The temperature of the cold fluid gradually increases along the direction of flow, and the more intense the thermal movement between molecules, the lower the viscosity of water. Under the same conditions, the viscosity of the fluid is lower, and the resistance to the movement of the same speed is also smaller, resulting in an increase in the flow of the fluid. In order to facilitate judging the average velocity of fluid-flow in the three channels, fig. 13 is added for exploration. When the fluid-flows in the trapezoidal channel, the Reynolds number is large, the turbulent kinetic energy in the channel is strong, and the degree of

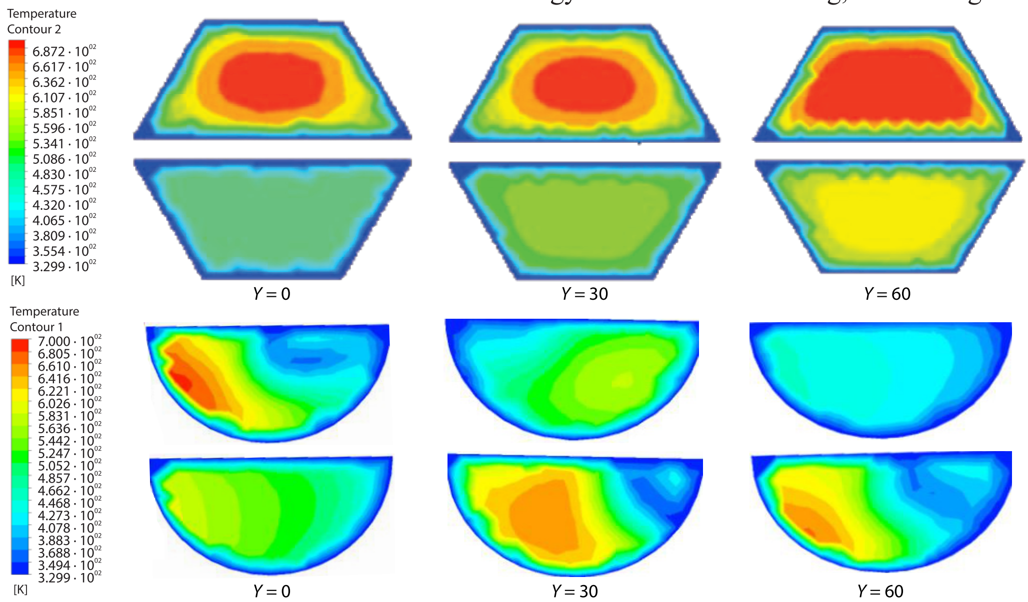

Figure 14. The velocity distribution of trapezoidal and semicircular channels at different positions

fluid disturbance is large, resulting in the flow velocity of the fluid in the trapezoidal channel under the same conditions is smaller than that of the semicircular channel and the square channel. The flow velocity diagram of fluid at different positions in the channel is shown in fig. 13.

Figure 14 shows the changes of flow velocity in the PCHE along the flow direction under the trapezoidal channel and semi-circular channel. The temperature of the cold fluid gradually increases along the flow direction, and the more intense the thermal movement between molecules, the lower the viscosity of water. Under the same conditions, the viscosity of the fluid is low, and the resistance to the movement of the same speed is also small, resulting in an increase in the flow rate of the fluid. When the fluid-flows in the trapezoidal channel, the Reynolds number is larger and the degree of fluid disturbance is larger, resulting in the flow velocity of the fluid under the same conditions is smaller than that in the semicircular channel.

Influence of PEC comprehensive heat transfer evaluation index on PCHE

At the same time, the influence of different section shapes on the comprehensive performance (PEC) of PCHE under the same working conditions is calculated. The semicircular section channel is taken as the reference. The influence of the section shape of the flow channel on PEC is shown in the figure below. By establishing a comprehensive performance evaluation index PEC combined with the flow velocity of hot fluid in the flow channel, the relationship between flow velocity and PEC can be obtained to evaluate the performance of PCHE heat exchangers with different section shapes. From the fig. 15, we can see that with the increase of flow velocity in different flow channels, the PEC of three channels with different sections is greater than 1. The trapezoidal channel has the largest PEC and the semicircular channel has the smallest PEC. There is little difference between the trapezoidal channel and the square channel. Therefore, the trapezoidal channel PCHE has the best heat transfer performance.

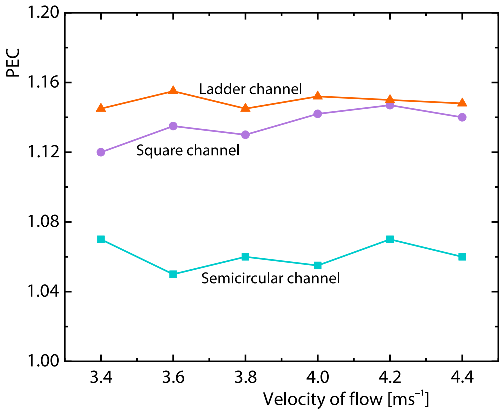

Figure 15. Influence of different section shapes on PEC

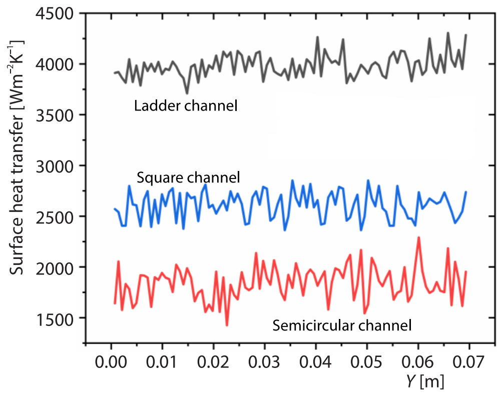

Figure 16. Distribution of surface heat transfer coefficient along the *Y*-direction

The change of surface heat transfer coefficient of different cross-section runner outlet

Figure 16 shows the variation of the surface heat transfer coefficient of PCHE along the length direction of the pipe in different cross-sections. Heat transfer coefficient is one of the important indexes to evaluate the performance of heat exchangers, which is of great significance to engineering design and equipment selection. It is affected by a variety of factors. In this paper, the method of control variables is used. As can be seen from the figure, the heat transfer coefficient of the trapezoidal channel is higher than that of the other two channels. The heat transfer coefficient of the trapezoidal channel is concentrated in the range of 4000 W/m^{2}K, while that of the other two structural channels is lower than this value. Therefore, at a certain temperature difference, the more heat is transferred per unit time. Because the trapezoidal structural channel is more complex, the heat transfer area and Reynolds number are larger under the same conditions, resulting in a larger heat transfer coefficient. The results show that the trapezoidal channel has better heat transfer performance than the other two channels.

Conclusions

The PCHE is a compact plate heat exchanger widely used in heat, power generation, nuclear energy and other fields. It is widely praised for its advantages of high temperature and high pressure. In this paper, PCHE simulation and performance evaluation are carried out on the inlet and outlet channels with different shapes and sections of straight channels. The main conclusions are as follows.

- With the increase of mass-flow, the turbulent kinetic energy of the hot fluid in the trapezoidal channel PCHE increases rapidly along the flow direction. However, the turbulent kinetic energy of the cold fluid in the channel decreases first and then increases, and the range of change is small.
- The temperature change in the trapezoidal channel PCHE is approximately linearly related to the direction of hot fluid-flow, and the heat transfer effect is significantly better than that of the rectangular tube and the semicircular tube channels. The exit temperature of the trapezoidal cold fluid is 7.9% higher than that of the semicircular channel and 4.1% higher than that of the rectangular channel, while the exit temperature of the hot fluid is 6.28% lower than that of the semicircular interface channel and 3.4% lower than that of the square channel.
- With the increase of flow velocity in different flow channels, the PEC of three channels with different sections is greater than 1. A trapezoidal channel has the largest PEC, while a semicircular channel has the smallest PEC. There is little difference between trapezoidal channel and square channel PEC. Therefore, the trapezoidal channel PCHE has the best heat transfer performance.
- Compared with the traditional channel, the trapezoidal channel has the highest heat transfer coefficient, followed by the square channel, and the semi-circular channel has the lowest heat transfer coefficient.

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Nomenclature

A – heat transfer area, [m^2]
C_p – specific heat capacity, [Jkg^{-1}K^{-}1]
E_0 – total internal energy, [J]
f – friction factor
h – heat transfer coefficient, [Wm^{-2}K^{-1}]
Nu – Nusselt number
Re – Reynolds number

Greek symbols

λ – thermal conductivity, [Wm^{-1}K^{-1}]
μ – dynamic viscosity, [kgm^{-1}s^{-1}]
ρ – density, [kgm^{-3}]

Acronyms

HTF – heat transfer fluid
PCHE – printed circuit heat exchanger
sCO_2 – supercritical carbon dioxide

Subscripts

0 – baseline
c – cold channel
h – hot channel
in – inlet

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