Simulation study on performance of plate heat exchanger for heat pump

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Abstract: For the plate heat exchanger of heat pump system, the convection heat transfer correlation of condenser and evaporator was used to simulate the heat transfer of heat exchanger, and the experimental test of heat exchanger was carried out in the heat pump system. The numerical simulation results were compared with the experimental results. The results show that the average error between the numerical simulation results of condenser and evaporator and the experimental results are 5.75% and 1.13% respectively, which proves that the simplified hypothesis, the heat transfer model and the solution method used in the numerical simulation are reasonable for the evaporation and condensation process of plate heat exchanger for heat pump.

1. Introduction
Brazing type plate heat exchanger is made up of a series of wave superposition of sheet metal formation of the new type of high efficiency heat exchanger, heat exchange with the passage through the sheet between, compared with the traditional heat exchanger has the compact structure, low cost, high heat transfer coefficient, small dirt coefficient and a series of advantages, so in the field of refrigeration and air conditioning has a very broad market application prospect. Due to the complexity of phase transition mechanism and two-phase heat transfer, strict theoretical derivation is difficult. Compared with the flow morphology classification of two-phase flow in the tube, such as fog flow, ring flow, block flow, etc, the flow state in the plate exchange channel is more changeable and random. For in-plate fluid boiling heat transfer, it is difficult to reveal its mechanism in essence, and the research on this aspect is still in its infancy both at home and abroad [1]. The correlation formula of in-plate boiling heat transfer is mostly obtained based on working medium such as water, freon, ammonia, etc, and the error is relatively large when extended to other working medium. There are few researches on two-phase heat transfer of plate heat exchanger and no good general model has been found up to now. For the condenser model, the Tovazhnyanskiy L.L. l. formula is given [2] Wang Zhongzheng, Tianjin University [3] And the proposed formula, but there are limitations. In this paper, Zeng Weiping from Shanghai Jiao Tong University was selected [4] Hsieh and Lin model for the proposed condensation heat transfer correlation and evaporator two-phase flow heat transfer has a high fitting accuracy. By fitting the experimental data, the correlations of single-phase and two-phase heat transfer coefficients of the working medium in the evaporator and condenser are obtained, which can be applied in the simulation system and provide some reference for the simulation research of the heat
pump system.

2. Simulation Model

2.1. Physical model
In this paper, a small channel brazing plate heat exchanger is used, which is composed of herringbone corrugated metal plates superposed. The structural parameters of the plates are shown in Table 1. Two adjacent plates in the heat exchanger are combined inversely with each other, and the ripples contact with each other to form a complex flow passage section.

| Equivalent diameter of flow/mm | The cross-sectional area of the runner /m² | Flow passage volume /m³ materia | Sheet thickness /mm | Port diameter /mm |
|-------------------------------|------------------------------------------|---------------------------------|---------------------|-------------------|
| 2.5                           | 0.00015                                  | 0.0000675 AISI316               | 0.0004              | 0.06              |

2.2. Mathematical model

2.2.1. Heat exchanger model hypothesis
Heat exchange in plate condenser and evaporator involves complex three-dimensional flow of fluid. In order to simplify the simulation process and speed up the calculation, the distributed parameter model established in this paper is based on the following assumption: 1) There is no heat exchange between the heat exchanger and the outside world; 2) Assume that the flow of working medium and water between plates is a one-dimensional flow along the axial direction; 3) Assume that the gas phase and the liquid phase are in thermodynamic equilibrium, that is, the saturation temperature and pressure of the gas phase and the liquid phase are the same; 4) On the cross section of the flow direction of the working medium, the corresponding physical parameters are consistent. 5) Assume that the plate wall of the heat exchanger has no heat capacity and local resistance is not taken into account.

2.2.2. Basic equation of heat exchanger model
The heat transfer equation between water and refrigerant is:

\[ Q_c = K \cdot A \cdot \Delta t_m \]  

Where, the logarithmic mean temperature difference in heat transfer process is (take the condenser as an example):

\[ \Delta t_m = \frac{1}{\frac{1}{\Delta t_{w}} + \frac{1}{\Delta t_{r}}} \]

The calculation formula of the total heat transfer coefficient \( K \) of the heat exchanger is:

\[ K = \frac{1}{\frac{1}{\Delta t_{w}} + \frac{1}{\Delta t_{r}}} \]  

Water side heat transfer coefficient correlation formula:

\[ Nu = 0.2319 Re^{0.74229} Pr^{n} \left( \frac{\mu_r}{\mu_w} \right)^{0.14} \]

N is the undetermined coefficient. When heating the fluid, \( n=0.4 \); when cooling the fluid, \( n=0.3 \). In this formula \( Nu \) is the nusschert number

\[ Nu = \frac{a l}{\lambda} \]  

\[ Re = \frac{u l}{v} \]  

\[ Pr = \frac{v}{a} \]
In these formula, \( l \) is the upsilon's fixed size, \( \lambda \) is the thermal conductivity, \( u \) is the fluid flow rate, \( \upsilon \) is the upsilon, \( \mu \) is the kinetic viscosity, \( \alpha \) is the thermal diffusion rate.

The velocity of the working medium in a single channel:

\[
u = \frac{M}{\rho S n}
\]

In this formula, \( M \) represents the mass flow rate of the working medium, \( S \) represents the area of the cross section of the flow channel, and \( n \) represents the number of channels. Thermal parameters such as thermal conductivity can be checked from Refprop9.0.

For heat transfer of single-phase working medium, its basic correlation is:

\[
Nu = C Re^0 Pr^{0.3} \left( \frac{\mu}{\mu_w} \right)^{0.14}
\]

In this formula, \( C \) and \( P \) are undetermined coefficients, regression fitting can be carried out through experimental data.

Two-phase flow heat transfer correlation of heat exchanger:

\[
Nu = C_1 Re^{c_2 Pr c_3 \left( 1 - \frac{x}{\bar{x}} \right)} \left( \frac{\mu}{\mu_w} \right)^{0.14}
\]

Type in the \( C_1 \), \( C_2 \), \( C_3 \), \( C_4 \)s the undetermined coefficient, and regression fitting can be carried out through experimental data.

The two-phase heat transfer model for evaporator selected in this section is Hsieh and Lin model[5], the model correlation is as follows:

\[
Nu = a_1 Re^{a_2 Pr^{a_3 Bo} \left( \frac{\mu}{\mu_w} \right)^{0.14}}
\]

Type in \( a_1 \), \( a_2 \), \( a_3 \)s the undetermined coefficient, and regression fitting can be carried out through experimental data. Where \( Bo \) is the boiling number.

\[
Bo = \frac{q}{G l}
\]

Where \( q \) is the heat flux, \( G \) is the mass flux and \( l \) is the latent heat.

2.3. Calculation process

The iteration calculation block diagram of the heat exchanger is shown in Figure 1:
3. Model Validation

Figure 1 and Figure 2 are the comparison of measured heat exchange data and simulation results of plate heat exchanger. After analysis, it can be seen that the error between measured data and simulated data is within 10%. The specific data are as follows: when R417 and NC004 (R134a: R1234ze(E): R32 = 40:30:30%) are used for the condenser, the average error is 1.13% and 5.75 respectively. When R417 and NC004 are used for evaporator, the average error is 3.59% and 6.33 respectively, which can meet the requirements of practical analysis.

4. Conclusion

In this paper, the application of brazed plate condenser and evaporator in the heat pump system was studied, a one-dimensional steady-state distribution parameter model was established, and the condensation and evaporator characteristics of R417 and NC004 in the plate heat exchanger were calculated respectively under the same working condition. The model was verified through experiments, and the following conclusions were obtained:

1) The one-dimensional steady-state distribution parameter model of the small-channel brazing plate condenser is of good accuracy when the condensing heat transfer correlation model of Zeng Weiping and the two-phase flow heat transfer model of the evaporator, Hsieh and Lin, are selected. The simulation results are verified by effective R417 and NC004 experimental points. The results show that the average heat exchange error of the simulation model is 4.2%, which can be used to guide
the design and selection of the small channel brazing plate condenser and evaporator heat pump system.

2) The heat pump experimental system adopts the small channel brazed plate condenser and evaporator. This model can analyze the thermal performance of different refrigerants and simulate the system performance changes at different operating temperatures, so as to reduce the number of experiments and improve the working efficiency.

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