CHARACTERISTICS OF A MICRO-FIN EVAPORATOR: THEORETICAL ANALYSIS AND EXPERIMENTAL VERIFICATION

by

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A theoretical analysis and experimental verification on the characteristics of a micro-fin evaporator using R290 and R717 as refrigerants were carried out. The heat capacity and heat transfer coefficient of the micro-fin evaporator were investigated under different water mass flow rate, different refrigerant mass flow rate, and different inner tube diameter of micro-fin evaporator. The simulation results of the heat transfer coefficient are fairly in good agreement with the experimental data. The results show that heat capacity and the heat transfer coefficient of the micro-fin evaporator increase with increasing logarithmic mean temperature difference, the water mass flow rate and the refrigerant mass flow rate. Heat capacity of the micro-fin evaporator for diameter 9.52 mm is higher than that of diameter 7.00 mm with using R290 as refrigerant. Heat capacity of the micro-fin evaporator with using R717 as refrigerant is higher than that of R290 as refrigerant. The results of this study can provide useful guidelines for optimal design and operation of micro-fin evaporator in its present or future applications.

Key words: *micro-fin evaporator, simulation, R290, R717, heat capacity*

Introduction

The evaporator has been widely used in the fields of energy, chemical industry, refrigeration, air conditioning and others. As an important component, the heat transfer tube affects the performance of evaporator greatly. The micro-fin tube can increase the heat transfer area and enhance fluid disturbance, change the flow speed and direction in the role of centrifugal force, and increase heat transfer coefficient finally. Therefore, many researchers have investigated the performance of micro-fin heat exchangers in the past years. Paisarn [1] studied the heat transfer and flow characteristics of the horizontal spiral-coil tube of a 8.00 mm diameter straight copper tube. Ho and Wijeysundera [2] developed a theoretical model for predicting the thermal performance of the spiral-coil heat exchanger as a cooling and dehumidifying unit. Sapali and Pradeep [3] investigated experimentally the heat transfer coefficient during condensation of HFC-134a and R-404a in a smooth (8.56 mm ID) and micro-fin tubes (8.96 mm ID). Thundil and Srikanth [4] determined the performance of shell and tube heat exchanger considering the effects of baffle inclination angle on fluid flow. Kuo and Chi [5] observed horizontal flow boiling with using R22 and R407c as refrigerants in a 9.52 mm micro-fin tube. Colombo *et al.* [6] investigated the performance of heat transfer and pressure drop of evaporation and condensation of R134a in micro-fin tubes. Shanthi *et al.* [7] reviewed the heat transfer and flow characteristics using nanofluids. Khalid [8] numerical studied the characteristics of a porous sudden expansion. Kim [9] calculated the heat transfer characteris-

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tics of R410A in 7 and 9.52 mm smooth/micro-fin tubes. Brognaux and Web [10] studied the single-phase heat transfer of micro-fin tubes.

From the literatures discussed above, it is confirmed that much work has been concentrated on the R22, R134a, and R404a *et al.* refrigerants, but there lack enough information on the optimal of micro-fin evaporator with R290 and R717 as refrigerants. In the present study, the performance of micro-fin evaporator was investigated with using R290 and R717 as refrigerants. A micro-fin evaporator simulation model was established, and the experimental data was compared with the simulation results for proving the validity of simulation model. The variations of the heat transfer coefficient with logarithmic mean temperature difference, the heat capacity with the water mass flow rate and refrigerant mass flow rate were analyzed respectively.

Mathematical model

Based on the steady distributed parameter model, the simulation model of tube-in-tube micro-fin evaporator has been developed, and the following assumptions were made to simplify the analysis [11, 12]:

– the flow of the micro-fin evaporator is steady and one dimension,
– refrigerant and water are in counter flow,
– the homogeneous model is chosen for two phase region,
– the influence of gravity and the pressure drop of overheated zone is neglected, and
– the refrigerant flow of evaporator is even.

The water heat capacity of micro-fin evaporator Q_w can be described as:

$$Q_w = m_w c_p (T_{w,\mathrm{in}} - T_{w,\mathrm{out}}) = m_w (h_{w,\mathrm{in}} - h_{w,\mathrm{out}}) \tag{1}$$

where m_w [kgs^{-1}] is the water mass flow rate, c_p [Jkg^{-1}K^{-1}] – the specific heat of water, $T_{w,\mathrm{in}}$ and $T_{w,\mathrm{out}}$ [K] are inlet and outlet water temperature of evaporator, respectively, and $h_{w,\mathrm{in}}$ and $h_{w,\mathrm{out}}$ [kJkg^{-1}] – the inlet and outlet enthalpy of water, respectively.

The refrigerant heat capacity of micro-fin evaporator Q_e is given by:

$$Q_e = m_r (h_{r,\mathrm{out}} - h_{r,\mathrm{in}}) \tag{2}$$

where m_r [kgs^{-1}] is the refrigerant mass flow rate, aand $h_{r,\mathrm{in}}$ and $h_{r,\mathrm{out}}$ [kJkg^{-1}] are the inlet and outlet enthalpy of refrigerant, respectively.

The heat balance equation of evaporator is defined:

$$Q_w = \varepsilon Q_e \tag{3}$$

where ε is the leakage heat coefficient and it is among 0.92 and 1.0.

The paper have chosen five two-phase region heat transfer correlations of evaporator for estimating the heat transfer coefficient, and those correlations are Rin Yun correlation, Koyama correlation, Cavallini correlation, Thome correlation, and Gungor-Winterton correlation, respectively [13]. The simulation results of Gungor-Winterton correlation are the most agreement with the experimental data in all tested cases, and its relative error is not more than 5% [13]. So, the Gungor-Winterton correlation as the suitable correlation was recommended in this paper. The detail formulas of heat transfer coefficient and pressure drop can referred to literature [13].

A simulation model of micro-fin evaporator is developed based on REFPROP software version 8.0 and Engineering Equation Solver (EES) software.

Validation of the simulation

The validation of simulation model is carried out for micro-fin evaporator using R290. The diameter of inner tube is 9.52 mm, its wall thickness is 0.3 mm, the θ equals to 22°, the γ equals 16°, the δ is 0.3 mm, the number of micro-fin is 60, and its design heat capacity is equals to 4.5 kW, and the inlet and outlet water temperature are designed 12 °C and 7 °C, respectively. The schematic diagram and photograph of the micro-fin tube used in the evaporator are shown in fig. 1.

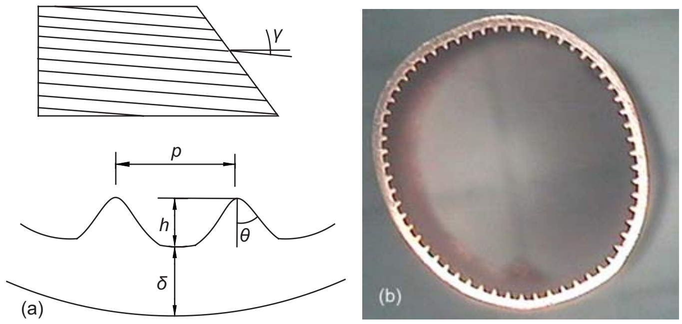

Figure 1. Schematic diagram and photograph of micro-fin tube; (a) Schematic diagram of the micro-fin tube; (b) photograph of cross-section

Figure 2 gives the variation of the heat transfer coefficient with logarithmic mean temperature difference of micro-fin evaporator. As seen in fig. 2, the simulated performance results are fairly in good agreement with the experimental data and the deviation is found within 5% [13].

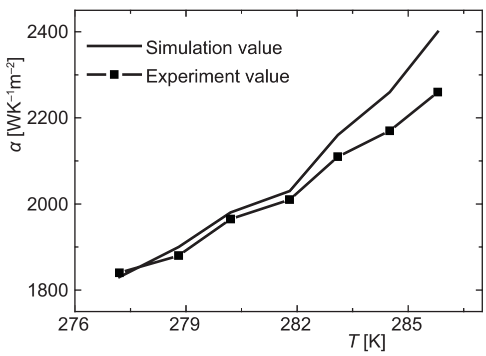

Figure 2. Variation of heat transfer coefficient with the logarithmic mean temperature difference

Results and discussion

Based on the simulation model, the performance of the micro-fin evaporator was analyzed using R290 and R717 as refrigerants. The inlet water temperature is kept at 285 K during the test. Figure 3 depicts the effect of the refrigerant mass flow rate on heat transfer coefficient of micro-fin evaporator using R290 as refrigerant. It can be found that the heat transfer coefficient of the evaporator increases with the refrigerant mass flow rate increasing from fig. 3.

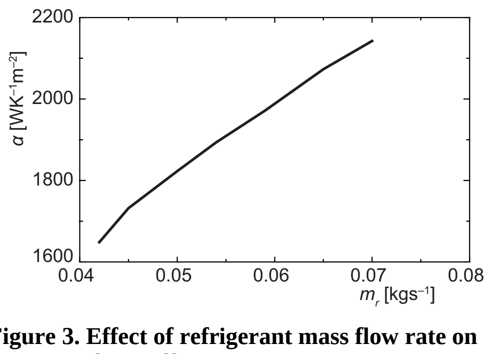

Figure 3. Effect of refrigerant mass flow rate on heat transfer coefficient (T_e = 283 K)

Figure 4 shows the effect of water mass flow rate of micro-fin evaporator on heat transfer coefficient for R290. It is noted, from fig. 4, that the heat transfer coefficient increases with the water mass flow rate increasing. At the given conditions, an increase of the water mass flow rate with 0.01 kg/s, results in an increase of the heat transfer coefficient by about 10%.

Figure 5 depicts the variations of the heat capacity of micro-fin evaporator with water mass flow rate using R290 as refrigerant when the evaporator temperature equals 283 K.

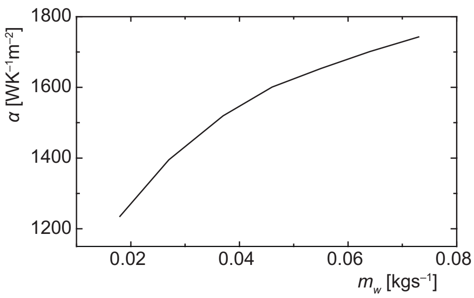

Figure 4. Effect of water mass flow rate on heat transfer coefficient (T_e = 283 K)

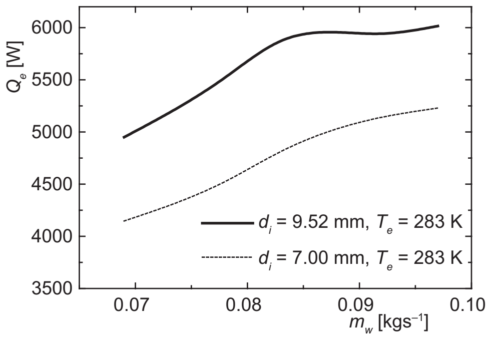

Figure 5. Effect of water mass flow rate on heat capacity of micro-fin evaporator for R290

As shown in fig. 5, it can be clearly seen that heat capacity increase with water mass flow rate increasing. Across the whole range of water mass flow rate, the characteristic of inner tube (diameter 9.52 mm) is the same as that of diameter 7.00 mm, and the heat capacity of the micro-fin evaporator for diameter 9.52 mm is higher than that of diameter 7.00 mm. Contrary to the results of the diameter 7.00 mm, the diameter 9.52 mm results in an increase of the heat capacity of evaporator by 20% averagely, and the maximum increase reach to 25% or so.

Figure 6(a) shows the effect of water mass flow rate on heat capacity of micro-fin evaporator for the diameter 9.52 mm with using R290 and R717 as refrigerant respectively. It can be noticed that, the heat capacity of micro-fin evaporator increases with the water mass flow rate increasing for R290. The same trend of variation is observed for R717 from fig. 6(a). Any increase in water mass flow rate leads to increase in heat transfer coefficient of the evaporator as shown in figs. 3 and 4. Between the two refrigerants selected, across the whole range of water mass flow rate, the heat capacity using R717 as refrigerant is higher than that of using R717 as refrigerant at the same operating conditions. At the given water mass flow rate, the heat capacity of R717 as refrigerant is about more than 10% that of R290 as refrigerant, and the maximum heat capacities are up to 15% higher.

Figure 6(b) depicts the variation of water mass flow rate with heat capacity of micro-fin evaporator for the diameter 7.00 mm with using R290 and R717 as refrigerant, respectively. As seen in fig. 6(b), the heat capacity with using R717 as refrigerant is higher than that of using R290 as refrigerant at the same water mass flow rate, and the heat capacity of R717 as refrigerant is about more than 15% that of R290 as refrigerant, and the maximum heat capacities are up to 19% higher.

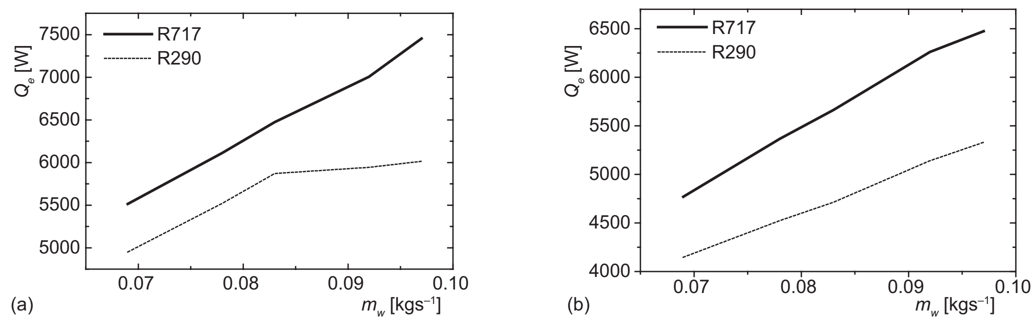

Figure 6. Effect of water mass flow rate on heat capacity of micro-fin evaporator (T_e = 283K); (a) diameter of inner tube is 9.52 mm; (b) diameter of inner tube is 7.00 mm

Conclusions

A simulation model for micro-fin evaporator using R290 as refrigerant was developed based on the REFPROP software version 8.0 and EES software in this paper. The simulated results are fairly in good agreement with experimental data, and the variation of water mass flow rate and refrigerant mass flow rate with the heat transfer coefficient and heat capacity of micro-fin evaporator are studied. The results can be summarized as follows.

- The heat transfer coefficient and heat capacity of micro-fin evaporator increase with water mass flow rate and refrigerant mass flow rate increasing with using R290 and R717 as refrigerants.
- The heat capacity of the micro-fin evaporator for diameter 9.52 mm is higher than that of diameter 7.00 mm with using R290 as refrigerant. The heat capacity of using R717 as refrigerant is higher than that of R290 as refrigerant, and the maximum heat capacity is up to 19% higher.

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