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Research paper

Cycle performance of air conditioning system based on finned tube heat exchangers with different helix angles

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HIGHLIGHTS

- Two kinds of 5 mm finned tubes with different helix angles are proposed.
- Comparisons are made between systems based on the proposed and conventional tubes.
- The cycle of the outdoor heat exchanger is adjusted.
- Material cost of the adjusted air conditioner system is proved less.

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ABSTRACT

The cycle performance of the novel 5 mm outer diameter (OD) finned tube heat exchangers (FTHX) with different helix angles (1°, 6°) were investigated as indoor unit in split air conditioning systems to be compared with those of the conventional indoor ones (5 mm and 7 mm FTHX with helix angle of 18°). Conventional T-splitter of the outdoor heat exchanger (HX) was afterward replaced by a Y-splitter and numbers of U-tubes in the two bypasses were adjusted to balance the heat exchange amount of two different bypasses. At first, experimental results showed that the 5 mm system with helix angle of 6° was superior to those 5 mm systems with helix angles of 1° and 18° but still inferior to the conventional 7 mm system, in aspects of capacity and coefficient of performance (COP) both in cooling and heating mode. But after the adjustments, performance of the 5 mm system with helix angle of 6° experienced a 1.5% and 0.7% higher capacity both in cooling and heating mode, respectively, and a 1.7% higher heating COP in spite of a 0.7% lower cooling COP. The system adopting the 5 mm tubes with the helix angle of 6° after adjustments is demonstrated that it can commendably ease material pressure and meanwhile promote the cycle performance.

1. Introduction

With the increasingly rapid development of daily life and urgent demand from human, the refrigerating industry has become more and more eye-catching. Meanwhile, rising demand for copper resources is also forecasted to drive growth in copper consumption in the upcoming years.

As necessary products in refrigerating industry, air conditioners are utterly dependent on mineral resources due to their excessive material consumption in the air conditioning system, such as joints between critical components in the heat exchanger (HX). With the drastic increase of the complexity of air conditioners, there is no doubt that this dependence on mineral resources will be aggravated [1]. For example, as the shortage risks and prices of copper resources gradually rise, cost pressure from air conditioning enterprises is increasing. To ease the contradiction between supply and demand, the miniaturization of air conditioners has also become a trend to achieve less material consumption. As the top important component of the air conditioner, the HX occupies most room of the air conditioning system. As a result, the main measure to miniaturize the air conditioner is adopting tubes with smaller diameters in the HX.

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To overcome the material problems mentioned above, microchannel HX composed of enhanced tubes with smaller diameters become popular today in the air conditioning industry [2–5]. Among them, many researchers have investigated the cycle performance of the air conditioners with harmonica-shaped tubes [6,7]. However, this kind of HX can be performed well only as evaporator at high temperature environment and would frost in the low temperature in spite of their high efficiency with less material cost and refrigerant charge than the traditional finned tubes [8–10]. In consideration of their serious frosting in the low temperature environment, harmonica-shaped tubes with smaller diameters can hardly replace the conventional tubes in the air conditioning system at present. In contrast with the HX based on the harmonica-shaped tubes, the finned tube heat exchangers (FTHX) can be performed well in both cooling and heating modes.

Nowadays, the traditional 7 mm finned tubes have been the most widely applied in the air conditioners as a result of far higher efficiency of heat exchange compared with the traditional smooth tubes [11,12]. However, more attractions have been concentrated on tubes with diameters below 7 mm [13–16], such as the 5 mm tubes which have been investigated considerably at present and are expected to replace the 7 mm in the air conditioning system to achieve less material cost. Kim et al. [17] selected vertical smooth and micro-fin tubes with the outer diameter of 5 mm to measure the evaporative heat transfer coefficient. The differences of heat transfer characteristics between the smooth and the micro-fin tubes were analyzed with respect to enhancement factor (EF) and penalty factor (PF). The average evaporation heat transfer coefficients for the micro-fin tube were approximately 111–207% higher than those for the smooth tube at the same test conditions, and the PF was increased from 106 to 123%. Cho et al. [18] measured the heat transfer coefficient data during evaporation process of carbon dioxide for 5 m long smooth and micro-fin tubes with outer diameters of 5 and 9.52 mm. They concluded that average evaporation heat transfer coefficients for a microfin tube were approximately 150–200% for 9.52 mm tube and 170–210% for 5 mm tube higher than those for the smooth tube at the same test conditions. The effect of pressure drop expressed by measured penalty factor of 1.2–1.35 was smaller than that of heat transfer enhancement. Therefore, developing the 5 mm finned tubes can reduce the usage of raw materials and meanwhile can perform well in different temperature environment. But in recent years, there have been some bottleneck problems in the process of the 5 mm tube application as well. Owing to the bigger frictional resistances of the 5 mm tube compared with the 7 mm one, the performance of the air conditioning system based on 5 mm tubes often has a certain degree of attenuation. The performance decrease principally manifests in the following two aspects. Firstly, in the indoor unit, it is easy to find the reduction of refrigeration capacity when using the 5 mm heat exchanger tube directly to replace the 7 mm one. Secondly, in the outdoor unit, replacing the conventional 7 mm tubes with 5 mm tubes will contribute to insufficient coefficient of performance (COP) or lack of heating capacity. According to the phenomena discussed above, the primary reason why the refrigerating capacity decreases when replacing the 7 mm tubes with the 5 mm is that the mass flow rate of the working fluid will be reduced as a consequence of the greater internal frictional resistance and the smaller heat exchange areas in the HX. In the meantime, the greater flow resistance will result in uneven distribution or premature evaporation of refrigerant, thus the evaporator heat transfer area is not made adequately use of. In brief, several factors included above lead to the decrease of refrigerating capacity. Therefore, it is extraordinarily crucial to solve the problems above and to promote the performance of 5 mm HX tubes simultaneously.

To decrease the performance reduction when using 5 mm finned tubes, many institutes concentrated their attention on the study concerning the internal spiral-grooved tubes. K. Aroonrat et al. [19] investigated heat transfer and flow characteristics of water flowing through horizontal internal spiral-grooved tubes. Their test tubes consisted of one smooth tube, one straight grooved tube, and four grooved tubes with different pitches. The results showed that the thermal enhancement factor obtained from groove tubes was about 1.4–2.2 for a pitch of 0.5 in.; 1.1–1.3 for pitches of 8, 10, and 12 in., respectively; and 0.8 to 0.9 for a straight groove. M.A. Akhavan-Behabadi et al. [20] carried out an experiment to study the heat transfer characteristics during the evaporation of R-134a inside a single helical microfin tube with different tube inclination angles. The results demonstrated that the tube inclination angle affected the boiling heat-transfer coefficient in a significant manner. Ding et al. [21] studied two-phase frictional data for R410A-oil mixture flow boiling in an internal spiral grooved microfin tube with outside diameter of 5 mm. In their investigations included above, although the performance of HX made of internal spiral-grooved tubes has been promoted to a certain extent, it is still lower than that of the conventional 7 finned tubes.

To further overcome the obstacle of lower performance for HX with internal thread, this paper first considers reducing the internal frictional resistance of the 5 mm internal spiral-grooved tubes through adjusting the parameters of internal thread. Then HX composed of the 5 mm tubes with the internal thread of different helix angles are designed. The performance of the air conditioners based on different internal spiral-grooved tubes and the conventional finned tubes diameters of 7 mm and 5 mm are meanwhile studied as comparisons. Afterwards, the outdoor cycle is adjusted to make sure that two bypasses in the outdoor air conditioning system exchange heat uniformly. This paper can provide authentic information for the development of the new enhanced 5 mm tubes applied in air conditioning systems.

2. Experimental system

2.1. Design of the 5 mm enhanced copper tubes

As is shown in Table 1, structural parameters of 5 mm evaluated tube 1, 5 mm evaluated tube 2, the conventional 5 mm and 7 mm tubes are displayed, respectively. Apex angles and helix angles are reduced compared with those of conventional tubes in the experiments, making the internal flow resistance of the HX tubes smaller. From Table 1, it can be seen that helix angles of the 5 mm evaluated-tube 1 and the 5 mm evaluated-tube 2 are 1° and 6°, respectively, which are far less than the traditional 5 mm 18° and the 7 mm 18°. As to addendum angle, the values of two evaluated-tubes are also far smaller than those of the traditional 5 mm and 7 mm ones.

Table 1
Structural parameters of different copper tubes.

Parameters	Value			
Tube	1	2	3	4
Outer diameter (mm)	5.05 ± 0.05	5.05 ± 0.05	5.05 ± 0.03	7.00 ± 0.03
Inner diameter (mm)	4.37 ± 0.03	4.37 ± 0.03	4.37 ± 0.03	6.30 ± 0.03
Bottom wall thickness (mm)	0.20 ± 0.03	0.20 ± 0.03	0.20 ± 0.03	0.25 ± 0.03
Tooth height (mm)	0.14 ± 0.02	0.14 ± 0.02	0.14 ± 0.02	0.10 ± 0.02
Addendum angle (°)	20° ± 10°	20° ± 10°	40° ± 5°	40° ± 5°
Helix Angle (°)	1° ± 2°	6° ± 2°	18° ± 3°	16° ± 2°
Article thread number (N)	40	40	40	65
Weight per meter (g/m)	34.5 ± 2	34.5 ± 2	34.5 ± 2	52.6 ± 2

1 : 5 mm evaluated tube 12 : 5 mm evaluated tube 2.
3 : 5 mm conventional tube 4 : 7 mm conventional tube.

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