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Experimental investigation of Al–Cu composed tube–fin heat exchangers for air conditioner

Shuangfeng Wang [a,*], Song Cheng [a], Huimin Yu [a], Zhonghao Rao [a], Zhongmin Liu [b]

[a] Key Laboratory of Enhanced Heat Transfer and Energy Conservation of the Ministry of Education, School of Chemistry and Chemical Engineering, South China University of Technology, Guangzhou 510640, China

[b] Hisense Kelon Air Conditioning Co., Ltd., Shunde 528000, China

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ABSTRACT

Al–Cu composed (ACC) tube–fin heat exchangers made through three different tube expanders (6.38, 6.40 and 6.43 mm) are investigated in air conditioner systems to evaluate their cycle performances experimentally. Aluminum and copper heat exchangers of the same kind are also adopted to make comparisons. The results show that in the aspect of performance price ratio, the ACC heat exchanger are qualified with a copper saving ratio of 71.86% and cost saving of 63% compared with the conventional copper heat exchanger. Air conditioning system adopting the ACC heat exchanger would supply 5.5% and 6.5% higher cooling and heating capacity, 5.6% and 1% higher coefficient of performance (COP) in cooling and heating mode than that of aluminum heat exchanger, meanwhile, it has negligible decline of 0.9% and 0.1% in cooling and heating capacity, 4.1% and 1.8% in COP of cooling and heating mode compared with that of copper heat exchanger. The system adopting ACC heat exchangers in this paper is proved can commendably save the copper and reduce the material cost of the heat exchangers, and meanwhile guarantee the cycle performance.

1. Introduction

The existence of abundant mineral resources promises a country to experience a sustained and rapid development of national economy. And in the past few decades, an exponential growth in demand for a great quantity of minerals has occurred due to the rapid economic development and increasing complexity of products. Furthermore, there will be an undisputed exacerbation of this situation that the coming metals should meet the requirements of not only sufficient numbers but also higher quality with better accessibility, as a result of the upturn living standards and scientific progresses in the future.

Being an energy critical element as an essential guarantee for economic advances which depend seriously on electric energy, copper plays a significant role due to its particular conductive characteristics in our daily life as everyone knows [1]. There have been heavy demands all the time in fields rely heavily on the use of copper. However, the sustainability of copper supply emerges to be severe that copper is regarded as a scare mineral resource with only 60 years of expected availability at current production levels [2]. Over the last five decades, global refined copper usage has increased by approximately 300% [3], and even worse, the quality of globally discovered copper deposits has been proved to deteriorate [4]. This situation has been most evident in developing countries such as China [5]. As the biggest producer and consumer of copper in the world, China is also facing a severe depletion of copper resources [6]. China has a growth rate of 15% in copper consumption per year since 1999, and in 2009, refined copper production in China exceeded 4 million tons, finally making China the greatest customer of refined copper in the world. Studies show that the output, import and consumption of refined copper in China in 2009 are 4.05, 3.18 and 5.75 million tons, respectively. The Chinese have found the copper reserves of 64.1 million tons by 2010, of which there are 13.78 million tons untapped, and the untapped copper resources are mainly low grade and difficult mining. Although China is rich in the countrywide reserves of copper, however, to make it worse, the quantity per capita is less than half the figure per capita worldwide [7,8].

Despite the serious situation on copper sustainability, many industries are notwithstanding dependent on it, especially in indoor air conditioning industry. The heat exchangers composing air-conditioners are mainly made of copper at present. The consumption of copper in air conditioning industry per year is 0.85 billion kg, which occupies almost 21% of gross cooper requirement in China [9]. To reduce the copper usage in air conditioning industry, an increasing number of air conditioner manufacturers have started to use aluminum as a substitute to product the heat exchangers due to its high thermal conductivity, abundant

* Corresponding author. Tel.: +86 020 22236929.
E-mail address: sfwang@scut.edu.cn (S. Wang).

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resources and lower price (lower by one third of the copper price) [10,11].

Many researchers have already focused their studies on aluminum heat exchangers, which can be mainly categorized into four types according to shape and material of the heat exchangers tubes: harmonica-shaped tube of alloyed aluminum, harmonica-shaped tube of pure aluminum, round tube of alloyed aluminum and round tube of pure aluminum. Air conditioners in the market these days are mainly made of alloyed aluminum heat exchangers because that heat exchangers of alloyed aluminum tubes operate better than the pure ones in aspect of corrosion resisting [12]. And numerous researches have been achieved on the performance of alloyed aluminum heat exchangers (both the harmonica-shaped tube fin type and ground tube fin type). The characteristics of conventional finned-tube (ground tube) heat exchangers refrigerator systems in air conditioner and heat pump have been investigated by many researchers [13,14]. Lin et al. [9] experimentally test the performance of four different heat exchangers made of ground aluminum pipe, their results showed that the N type internal screw thread aluminum pipe has the best function and can meet the demand of the refrigeration performance. Aluminum heat exchangers can perform normally both in cooling and heating mode, the electrochemical corrosion between copper pipe and aluminum fins can be avoided by adopting the aluminum tubes. When operating the heating mode under the low outdoor temperature in winter, the outdoor unit running as evaporators is harder to frost compared with the harmonica-shaped tube fin type due to its lower wind drag. There is no doubt that frosting could cause a serious dropping of capacity [15]. However, the EER of the air conditioners of aluminum heat-exchangers is still far less than that of the same kind heat-exchangers made of copper pipe despite these advantages, as a result of their heat conductivity coefficient diversity (aluminum is nearly half of copper).

To handle the coefficient decline, micro-channel heat exchangers made of harmonica-shaped aluminum tube are getting popular today, which are widely used in automotive air conditioning systems. Many studies have investigated the performances of micro-channel heat exchangers [16,17], it is eye-catching because of the higher efficiency with less material cost and refrigerant charge than the conventional finned-tube heat exchanger. However, it can only be good performed as an evaporator at high temperature environment, and it would severe frost in low temperature environment as an evaporator (heating conditions in winter). Many studies showed that the operating capacity would undoubtedly experience significant reductions when the frosting of micro-channel heat exchangers occurred [18–20]. Therefore, the micro-channel heat exchangers can hardly popularize in domestic air conditioners which need to operate heating condition in winter or other low temperature circumstances despite its high efficiency. Although finned-tube heat exchangers made of aluminum can function well in both heating and cooling conditions, it is still mismatching considering its lower capacity and efficiency than copper finned-tube heat exchangers.

To find heat exchangers with the less copper usage which can also perform well in both heating and cooling conditions with high COP, Al–Cu composed tubes (ACC tubes) are chosen as a solution in this paper owing to its unique structure. And in this study, the working performance of ACC tube–fin heat exchangers are authoritatively experimentally detected, the thermophysical property of Al–Cu composed tubes is tested at first, then the Al–Cu composed tube–fin heat exchangers is studied both individually and in an air conditioning system. The performance of the air conditioners based on copper and aluminum tube–fin heat exchangers of equal size are also studied as comparison under the same conditions. This paper could provide convincible information for application of the ACC tube–fin heat exchangers in air conditioners.

2. Analysis of ACC tubes

ACC tube, of which the internal copper layer and the external alloyed aluminum layer combine with each other in a metallurgical bonding way between atoms as Fig. 1 presents, can simultaneously utilize the good heat absorptivity of copper and heat dissipation of aluminum. Additionally, the fins surrounding the ACC tube will not electrochemical react with the tube because it is contacted to the external alloyed aluminum layer, not the copper of the traditional heat exchangers. Furthermore, progresses can also be achieved by using ACC tubes in reducing costs of air conditioners and easing the shortage of copper resources. And the weight of heat exchangers is also decreased. The dimension parameters of ACC tubes are presented in Table 1.

2.1. Ratio analysis of copper and aluminum

It is important to recognize the degree of the copper saved, so three ACC tubes of 4–8 cm are weighed after stoving, the weight are recorded as T1, then the ACC tubes are put into sodium hydroxide solution (mass fraction of 10 ± 5%) to completely react off the aluminum layer, the weight of remnants after stoving are recorded as T2. The copper ratio of the ACC tubes can be deduced by following equation:

$$\text{Copper ratio} = T2/T1 \times 100\% \quad (1)$$

Results presented in Table 2 state that the copper ratio is only 28.14% of the total tube weight on average, which is amazing compared with the conventional copper heat exchanger.

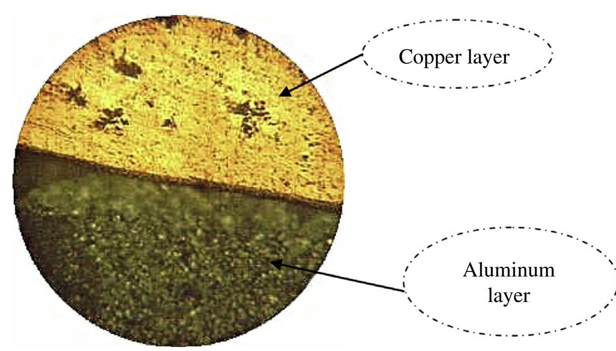

Fig. 1. The profile view of ACC tube.

Table 1
The dimension parameters of ACC tubes.

Parameters	Value
Outside diameter (mm)	7 ± 0.05
Tooth height (mm)	0.08 ± 0.02
Total thickness (mm)	0.48 ± 0.03
Apex angle (°)	60° ± 5°
Helix angle (°)	18° ± 0.02
Number of teeth	65

Table 2
Copper and aluminum ratio of ACC tube.

Sample	1	2	3	Average value (%)
Copper ratio	27.82%	27.95%	28.67%	28.14
Aluminum ratio	Remnant value			71.86