Application of Small Diameter Inner-Grooved Copper Tubes in Air-Conditioning Systems

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【Abstract】 On the basis of comparing the characteristics of heat exchange and fluid pressure drop for the Φ5mm inner-grooved copper tube and the Φ7mm inner-grooved copper tube, the features of residential air-conditioning using Φ5mm inner-grooved copper tubes, as well as the corresponding measures adopted, are introduced. The performance testing shows that when using the Φ5mm inner-grooved copper tube, the copper usage in the evaporator is lowered by more than 43%. The cost is also reduced by around 40%; further, the cooling capacity , EER, and air volume are all increased.

【Keywords】 small diameter copper tube; inner-grooved copper tube; heat exchanger

0 Preface

With the rapid development of the economy, the market capacity for air-conditioning has been gradually expanding. The requirements for air-conditioning quality have also been gradually increasing. Copper tubes play a very important role in the air conditioner. The technology requirements of copper tubes similarly get more demanding. Particularly for the copper tubes in the heat exchanger, the requirements are even higher. Therefore, it has become even more important to utilize the copper tubes to better satisfy the requirements of the air-conditioning industry. For the copper tube manufacturing industry, the development trend has been widely acknowledged to be the pursuit of low cost, high efficiency and high quality.

There is data to show that copper resources in China are relatively scarce and that the copper material is mainly imported. However, our country is a big consumer of copper resources. The annual consumption for just air-conditioning alone is already quite considerable. The annual production of air conditioners in the market in 2009 was around 81.53 million units. Calculating based on each unit using an average of 6~8kg of copper, the total copper consumption was around 4.9~6.5×10^5tons. Based on the existing market price for copper at 55000RMB/ton, it comes up to be as high as RMB 26.9 billion~35.7billion. Calculating based on the annual domestic copper demand of 3.8 million tons currently, copper use for air-conditioning takes up 12.6%~16.8%. Reducing copper consumption for the air conditioner thus has important significance for reducing the overall copper consumption for our country. At the same time, this also benefits the development of air conditioner miniaturization which lowers air conditioner manufacturing cost and raises product competitiveness for enterprises.

The heat exchanger is a core component of the air conditioner. It has a key effect on the performance and cost control of the air conditioner. In order to reduce copper consumption and enhance heat exchange, small diameter inner-grooved copper tubes would be used in air conditioners for households. Pertaining to the problem of pressure drop increasing, modifications have been made to the inner groove of the small diameter copper tube. Relevant experiments have also been conducted; at the same time, adjustments have been made to relevant technologies too. Experiments have shown that it is feasible to replace the Φ7mm inner-grooved copper tube used in the air conditioner for households with the new type

Φ5mm small diameter inner-grooved copper tube.

1 Performance Comparison and Analysis of Two Kinds of Inner-Grooved Copper Tubes

The heat exchange methods of the heat exchanger include three kinds of basic methods: conduction, convection and radiation. The copper tube in the heat exchanger provides the conduction heat exchange effect which is the most direct method of heat exchange. The heat exchange performance of the copper tube itself can directly affect the heat exchange effect of the air conditioner. At the same time, the copper tube itself also contributes to the looping effect of the refrigeration system. Based on requirements, copper tubes have to be bent into different kinds of shapes and connected together through methods of flaring and welding. The important effects contributed by the copper tubes in the air conditioner cannot be overemphasized. Therefore, the requirements for the copper tube in areas such as geometric dimensions, welding performance, processing performance and reliability are very high.

1.1 Structural Characteristics of Φ5mm Inner-Grooved Copper Tube

The research[1] for the characteristics of heat exchange and pressure drop shows that pertaining to the oil-containing refrigerant flowing and boiling within the small diameter heat exchanging tube, the refrigerant flow pressure drop within the Φ5mm enhanced tube is larger than that within the Φ7mm enhanced tube by 10%~30%. That is, the energy loss when the refrigerant is flowing within the tube is increased by 10%~30%.

From the perspective of the heat exchange theory, increasing the contact length is of great help to increasing the evaporation heat transfer coefficient within the tube. It increases the fluid retention area and is of great help to increasing the condensation heat transfer coefficient within the tube. Therefore, to improve the heat exchange efficiency of the copper tube, consideration is mainly given to areas such as how the tooth height can be increased, how the width of the tooth bottom can be increased and how the tooth vertex angle can be reduced.

In order to reduce the pressure drop, the liquid membrane is made thinner to raise the heat conduction efficiency. Improvements have also been made to the Φ5mm inner-grooved copper tube:

(1) The vertex angle of the inner-grooved tooth has been adjusted from 25° to 18°. The tooth height has been lowered from 0.18mm to 0.14mm to make the tooth more tapered. This will strengthen the disturbance between the grooved-tooth and the refrigerant, as well as increase the shear between the grooved-tooth and the liquid membrane. In doing so, the refrigerant liquid membrane of the tube wall will become thin. At the same time, a larger width will be obtained for the groove bottom, the flow resistance of the refrigerant will be reduced and the heat exchange situation within the tube will be enhanced;

(2) Reducing the tube diameter causes the pressure resistance performance of the tube passage to be strengthened. For this, the wall thickness of the Φ5mm copper tube can be adjusted from 0.25mm to 0.20mm. Without reducing the pressure resistance of the evaporator, the copper consumption is effectively cut back.

1.2 Heat Transfer Coefficient Comparison Within Tube

The comparison of the heat exchange coefficient within the improved new type small diameter inner-grooved copper tube and the Φ7mm inner-grooved copper tube is as shown in Figure 1. It can be seen that when the two kinds of inner-grooved copper tubes with different specifications are used in the evaporator, the heat exchange coefficient within each tube is practically the same (evaporation temperature of 7.5°C). Typically, the performance difference for the air-conditioning evaporator is the same as one-tenth the heat exchange coefficient within the tube. Therefore from this, it can be deduced that when using these two kinds of copper tubes in the evaporator, any differences can be ignored.

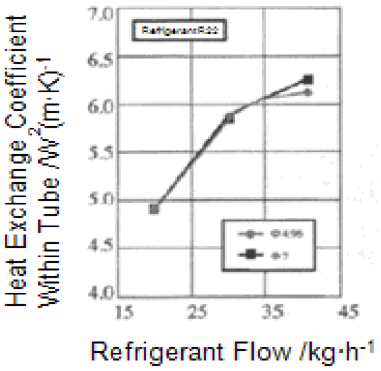


Figure 1 Heat Transfer Coefficient

Comparison Within Tube

1.3 Pressure Loss Comparison Within Tube

Figure 2 shows the comparison of the pressure drop within tube between the new type small diameter inner-grooved copper tube and the Φ7mm inner-grooved copper tube. It can be seen that the pressure loss within the new type small diameter inner-grooved copper tube is about 10%~12% higher.

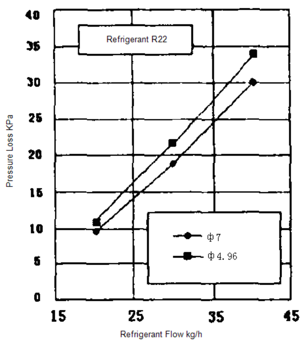


Figure 2 Comparison of Pressure Loss

Within Two Kinds of Copper Tubes

1.4 Comparison of Heat Transfer Coefficient Outside Tube

Using the Φ5mm tube can effectively reduce the block effect of the tube row, decrease the heat transfer blind zone at the leeward side outside the tube, and raise the side heat transfer performance outside the tube. At the same time, the spacing increase between tube rows is beneficial to the discharge of condensate which then causes the pressure drop loss of the heat exchanger to be reduced[2].

Taking into account the processing technologies and substitutability, when using the Φ5 tube in the evaporator, a structure the same as that of the Φ7 tube is used. The tube row arrangement remains unchanged. When comparing the single tube heat exchange performance of the Φ5 tube with the Φ7 tube, they are basically similar. However, the pressure loss within tube for the former is about 10%~12% higher; because the air volume is increased and the side heat transfer performance outside the tube is raised, the overall heat exchange performance of the heat exchanger is basically similar.

1.5 Mechanical Properties and Pressure Resistance

For the copper tubes used in the air-conditioning system, not only must their heat exchange performance be considered, their mechanical performance must also be satisfactory. That is, the copper tubes should have sufficient strength and toughness. The necessary technological properties of the 5mm copper tube in the course of applying and processing, such as the plasticity and formability when the copper tube is undergoing bending and flaring, are almost the same as in the case of the 7mm copper tube. But because the wall thickness is reduced, the requirements for the 5mm during welding and flaring are higher.

The pressure resistance property and burst performance of the copper tube are not part of the standard copper tube requirements for air-conditioning heat exchange. The reason is that the working pressure of the air-conditioning refrigeration installation is not high. However after using the HFCs type refrigerants, because the pressure of the air-conditioning refrigeration installation that uses the new type refrigerant is raised by about 50%, the pressure resistance property of the copper tube should then be considered. Through experiments, it was found that the pressure resistance property of the 5mm copper tube is good even though its tube diameter is small. The pressure resistance performance of the 0.20mm wall thickness copper tube is comparable to that of the 0.25mm wall thickness 7mm copper tube. Both are able to withstand pressure of above 2MPa and so satisfy usage requirements.

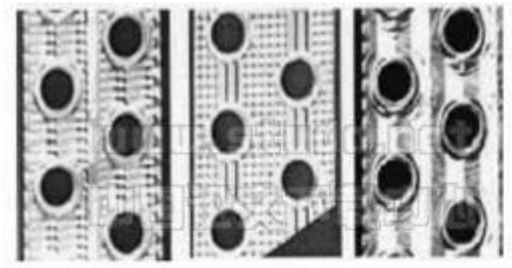
2 Corresponding Technical Measures for Using New Type Small Diameter Inner-Grooved Copper Tube

While using the new type small diameter inner-grooved copper tube to save copper material, several problems in the areas of techniques and technologies will also crop up at the same time. To resolve these problems and further raise the heat exchange performance of the heat exchanger, a series of corresponding measures have been adopted.

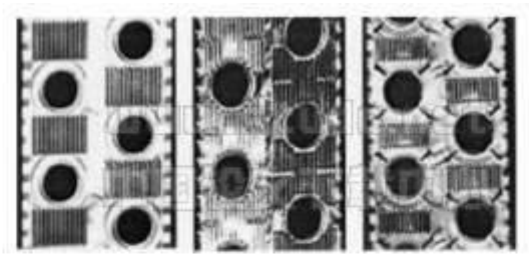
2.1 Application of New Type High Efficiency Fin

Using the new type Φ5mm inner-grooved copper tube causes the heat exchange area of the evaporator to be reduced by 20%. To raise the heat exchange efficiency of the evaporator, the new type high efficiency fin has been adopted. The said fin originates from leading louvered window fin technologies both local and abroad. It includes many separated parallel fins to guide air to flow between every pair of adjacent fins. The fin incorporates a grid-type structure. The grid can make the air flow become turbulent; the structure of fins on two opposite sides sticking out alternately strengthens the temperature boundary layer effect and causes the pressure drop to be reduced to the lowest extent. The combined effect of both areas causes the heat exchange performance to be higher than that of the normal fin by 1.5 times.

Because the evaporator fin temperature gradually rises along the air inlet direction of the air conditioner, at the windward side of the fin, because the fin temperature is relatively low, the heat exchange effect is relatively poor compared to the other positions. The impact on wind resistance is similar when compared to the other positions. Therefore, the fin width can be appropriately reduced from 12.7mm to 10.8mm which effectively saves material. At the same time, this also raises the air flow speed and increases the side heat transfer performance outside the tube.



(a) (b) (c)



(d) (e) (f)

Figure 3 Several Kinds of Fin Forms

(a) Fin Used for This Example; (b) Corrugated Board Arc-Shaped Louvered Window; (c) Small Fin Belt Rectangular Louvered Window Type; (d) Wrinkled Board in T-Direction; (e) Point-Shaped Wrinkled Board; (f) Triangular Corrugated Board

2.2 Flow Path Optimization

Research[3] has shown that the heat exchange performance for the small tube diameter is relatively good. However, it easily forms an annular flow and causes the pressure drop within the tube to increase. The flow path of the heat exchanger should be optimized. Where possible, the non-uniformity of heat transfer caused by a complicated manifold arrangement should be avoided. The optimal tube group connection method should be adopted to allow the heat exchanger to have a uniform heat exchange and fluidity. This will achieve a relatively high heat exchange amount.

For this, a two-path method is used in the experiment for the front half of the evaporator with relatively more refrigerant in fluid state. This fully exploits the feature of the heat exchange effect becoming better as the refrigerant flow speed increases; for the back half of the evaporator with relatively more refrigerant in gaseous state, the path number is increased and the four-branch method is adopted. This effectively reduces the pressure drop of the refrigerant within the tube.

2.3 Problems Existing in Copper Tube Processing Process and Their Analysis

In the manufacturing process of the copper tubes for air conditioners, quality problems[4] arising from areas such as facilities, technologies and raw material performance do occur occasionally. The Φ5mm inner-grooved tube is chosen and higher requirements[5] are made of copper tube processing in areas such as expanding and welding. The frequently seen problems during the copper tube processing process and their reasons for occurring are summed up in Table 1.

Table 2 Frequently Seen Problems in Copper Tube Processing Process and Reason Analysis

No.	Frequently Seen Problem	Analysis of Main Reason
1	Surface oxidation within and outside tube	① The tube head is not sealed properly, resulting in oxygen entering the tube; ② The climate is damp and hot; ③ Not timely cooling the copper tube after annealing; ④ Too much environmental moisture during the transportation process
2	Inner wrinkling phenomenon arising when making copper tubes into U-shaped tubes	① Core head position too front; ② Copper tube extensibility lower than 40%; ③ Insufficient degree of finish for core head; ④ Insufficient oil sprayed when bending tubes
3	Cracking at the bent point when bending copper tubes	① Core head position too front; ② Copper tube extensibility lower than 40%; ③ Insufficient degree of finish for core head; ④Insufficient oil sprayed when bending tubes
4	Cracking during	① Flare head damaged due to

	copper tube flaring	abrasion; ② Cut surface unsatisfactory; ③ Center missed when flaring flare head; ④ Copper tube defects in N-direction
5	Uneven shrinkage ratio during flaring	① Uneven copper tube wall thickness; ② Core head damaged due to abrasion; ③ Mixing flare heads of different specifications together for use; ④ Surface oxidation within copper tube
6	Cracking of flaring	① Enlarged mouth core head position shifted; ② Large deviation of copper tube dimensions (uneven total wall thickness, large outer diameter deviation, etc.); ③ Severe wire defects or straight line-shaped sand eyes on inner or outer copper tube surfaces; ④ Incision not round when cutting U-shaped tubes
7	Inner copper tube leakage	① Severe internal defects; ② Deviations at defect detection point and ink spraying position; ③ Defect detection ineffective or accidental hit on logo; ④ Impurities within tube
8	High leakage rate at bent head welding position	① Improper welding technology; ② Too much residual oil on inner copper tube surface; ③ Inappropriate choice of tube bending oil; ④ Improper solder composition

3 Analysis and Comparison of Performance for Entire Machine

3.1 Application in R22 System

Table 2 shows the testing results of using evaporators in a 1P system that uses R22 that have been processed using different copper tubes. It can be seen that in practical application, the various performance indexes when using the new type Φ5mm inner-grooved tube heat exchanger are all superior to those when using the Φ7mm inner-grooved tube heat exchanger.

Table 3 Capability Testing Data for

Applying Heat Exchangers Using

Two Kinds of Copper Tubes in R22 System

Test Item	Normal Φ7 Evaporator	Φ4.96 Tube Evaporator Using New Type Fin
Cooling Capacity (W)	2495	2529
Power Consumption (W)	828	831
Energy Efficiency Ratio (W/W)	3.01	3.04
Air Volume (m3/h)	490.9	518.7
Refrigerant charge (g)	650	590

3.2 Application in R410A System

According to the "Montreal Protocol for the Protection of the Ozone Layer" and the "Kyoto Protocol", phasing out the R22 is already a foregone conclusion. The R410A is being used increasingly in air-conditioning systems. Some experimental research has also been conducted regarding using the 5mm copper tube in systems that use the R410A refrigerant.

Because the working pressure of the R410A is high, and its fluidity is good, the system performance is not sensitive to the effect of pressure drop loss. Therefore when looping, the flow speed of the refrigerant can be even larger. Using the small diameter copper tube and a multi-manifold design provides even more obvious advantages for the R410A system.

Table 4 Capability Testing Data for

Applying Heat Exchangers Using

Two Kinds of Copper Tubes in R410A System

Test Item	Normal Φ7 Evaporator	Φ4.96 Tube Evaporator Using New Type Fin
Cooling Capacity (W)	2487	2536
Power Consumption (W)	843	845
Energy Efficiency Ratio (W/W)	2.95	3.0
Air Volume (m3/h)	487	510
Refrigerant charge (g)	1100	890

4 Conclusion

(1) Using the new type 5mm inner-grooved evaporator has obvious advantages in the areas of lowering material consumption and raising performance when compared to the traditional 7mm

inner-grooved copper tube evaporator. This substantially increases the market competitiveness of the product.

(2) Research has shown that when applying the 5mm copper tube in a system that uses the R22 refrigerant, adopting a reasonable design can lower a relatively high pressure drop within the tube. Processing problems such as its flaring and welding can also be resolved through adjustments in technologies.

(3) Research has shown that applying the 5mm copper tube in a system that uses the R410A refrigerant has even more obvious advantages.

(4) Because using the small diameter copper tube can significantly reduce the system perfusion amount, this is very beneficial to both the economy of the system and its environmental protection performance.

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