Performance and Cost Analysis and Research of Air-Cooled Heat Exchanger Using Small Diameter Copper Tubes

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【Abstract】 Replacing copper tubes with aluminum tubes and using copper tubes with smaller tube diameters are the two popular trends currently to lower the cost of air conditioners. This report approaches from the perspective of using copper tubes with smaller tube diameters as a substitution. Performance comparison as well as cost analysis are conducted for the two tube types of Φ9.52mm inner-grooved copper tube and Φ5mm inner-grooved copper tube, as well as the heat exchangers using these two tube types. The research results show that: where the experimental conditions and volume flow are the same, the heat exchange coefficient within the Φ5mm inner-grooved copper tube is about 15% higher than that within the Φ9.52mm inner-grooved copper tube. Where the testing operating conditions and the windward dimensions are the same, when the Φ5mm copper tube heat exchanger has achieved a similar heat exchange amount as the Φ9.52mm copper tube heat exchanger, the copper material that can be saved is 41.8% and the aluminum foil material that can be saved is 50%.

【Keywords】 small diameter inner-grooved copper tube; fin tube heat exchanger; heat transfer performance; cost analysis

0 Preface

Copper is one of the important raw materials of the air conditioner. Even though copper deposits in China are ranked 7th in the world, the production sites are relatively dispersed. The production amount is low and it is still very far off when compared to the average international standard. 4/5 of the copper raw material required by domestic enterprises every year is imported. Copper prices remain high and this situation brings immense pressure to the cost competition among various air-conditioning enterprises. Replacing copper tubes with aluminum tubes and using copper tubes with smaller tube diameters are the two popular trends currently among air-conditioning enterprises to lower cost. Because using copper tubes with smaller diameter does not require relatively large improvements in the areas of facilities and technologies, this has become the preferred cost-lowering choice for air-conditioning enterprises currently.

This report first adopts the single tube perspective to describe the heat exchange performance and gram per meter advantages of the Φ5mm inner-grooved copper tube versus the Φ9.52mm inner-grooved copper tube. After that, the heat exchanger model is constructed. Performance and cost comparisons are done specifically for the heat exchangers using these two kinds of tube diameters. With this as a basis, the improvement methods that need to be adopted in the course of replacing the Φ9.52mm copper tube heat exchanger with the Φ5mm copper tube heat exchanger, as well as the cost advantage this replacement brings, will be set out.

1 Performance and Cost

Comparisons of Two Kinds of Inner-Grooved Copper Tubes

The inner-grooved tube is a kind of high efficiency heat exchange component. Because it possesses 2~3 times the heat exchange capability of the normal bare tube, it has received extensive attention. The high efficiency of the inner-grooved tube stimulates and promotes the development of energy saving, high efficiency and miniaturization for air-conditioning systems.

The typical inner-grooved tube tooth-type parameters are as shown in Figure 1. Of them, d is the outer diameter, δ is the tube wall thickness, h is the tooth height, β is the helix angle, γ is the tooth vertex angle and N is the tooth number. Table 1 shows the frequently used tooth-type parameters and gram per meter for the Φ9.52mm and Φ5mm inner-grooved copper tubes. It can be seen that the Φ5mm inner-grooved tube when compared to the Φ9.52mm inner-grooved tube has a substantial drop in the gram per meter.

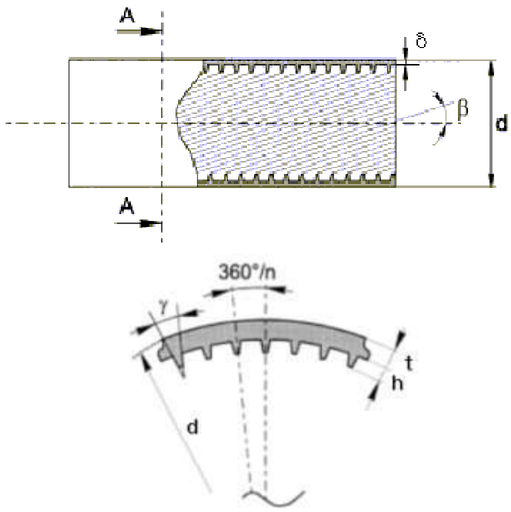

Figure 1 Schematic Diagram of Inner-Grooved Tube Structure

Table 1 Parameters for Two Kinds of Inner-Grooved Copper Tubes

Outer Diameter	Bottom Wall Thickness	Tooth Height	Tooth Vertex Angle	Helix Angle	Tooth Number	Gram Per Meter
(mm)	(mm)	(mm)	(°)	(°)		(g/m)
9.52	0.28	0.15	30	18	65	83
5	0.2	0.14	40	18	40	33

By using the single tube phase change heat exchange test bench, we tested and sorted out for the Φ9.52mm and Φ5mm copper tubes the changing situation of the local heat exchange coefficient within the tubes under different dryness conditions, as well as the changes of the average heat exchange coefficient within the tubes during different volume flow. The testing refrigerants used were all R22. The condensing temperatures were all 45°C. The inner-grooved tooth-type parameters used were the same as those in Table 1.

Figure 2 describes the situation of the local heat exchange coefficient within the two kinds of inner-grooved copper tubes changing according to the dryness of the refrigerant. From the figure, it can be seen that: as the dryness of the refrigerant increases, the local heat exchange coefficient of the refrigerant within the tube presents a rising trend. Within the entire dryness change scope, compared to the Φ9.52mm inner-grooved copper tube, the local heat exchange coefficient within the Φ5mm inner-grooved copper tube is higher by 10-15%.

Figure 3 describes the situation of the average heat exchange coefficient within the two kinds of inner-grooved copper tubes changing according to the volume flow of the refrigerant. From the figure, it can be seen that: as the volume flow of the refrigerant increases, the average heat exchange coefficient of the refrigerant in the entire two-phase region also presents a rising trend. Within the entire flow change scope, compared to the Φ9.52mm inner-grooved copper tube, the average heat exchange coefficient within the Φ5mm inner-grooved copper tube is correspondingly higher by 10-15% too.

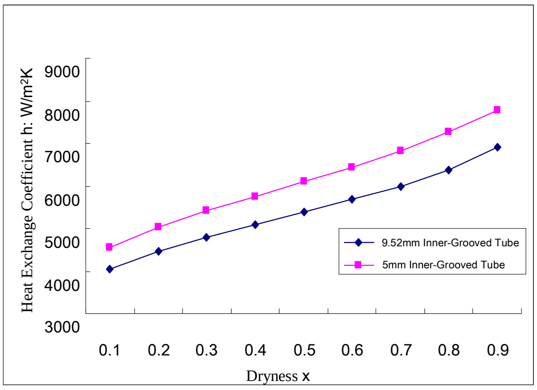

Figure 2 Local Heat Exchange Coefficients of Φ9.52 and Φ5 Copper Tubes During Different Dryness

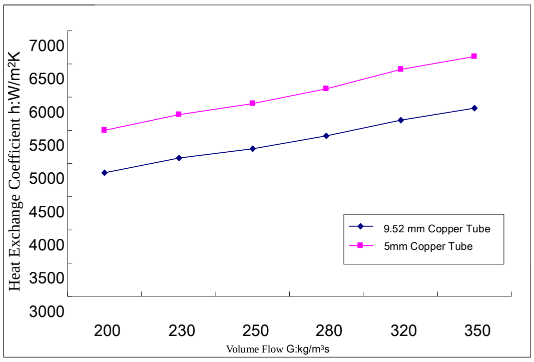

Figure 3 Average Heat Exchange Coefficients of Φ9.52 and Φ5 Copper Tubes During Different Volume Flow

2 Constructing and Checking Heat Exchanger Model

This section uses the finite volume method as basis to partition the nodes for the fin tube heat exchanger core body model. A one-dimensional steady-state distribution parameter model[1] was constructed. The control equations are as below:

Mass conservation equation:

$$\frac{d}{dz}\rho u = 0 \tag{1}$$

Momentum conservation equation:

$$\frac{d}{dz}\rho u^2 = -\frac{dp}{dz} - \frac{\tau_w s}{A_r} \tag{2}$$

Energy conservation equation:

$$\frac{d}{dz}\rho u h = -\left(\frac{\pi D}{A_r}\right) q_w \tag{3}$$

Of the above, A_r, τ_w, s and q_w are the tube passage cross-sectional area, shear stress, surface heat exchange area within the tube and heat flow respectively.

The calculation correlation equation within the tube comes from a reference document[2]. The air-side correlation equation comes from another reference document[3].

It must be made clear that: the heat exchange amount calculations for this model use the effectiveness-number of transfer units method. Because the refrigerant needs to flow through the over-hot zone, two-phase zone and over-cold zone from entry to exit, calculations must be done by handling it as two kinds of situations – the single-phase zone and the two-phase zone. The air side was under a dry operating condition from the beginning and it is calculated as per a single-phase model.

The bare tube heat exchanger calculation of this model is checked against the CoilDesigner software developed by the University of Maryland. The inner-grooved tube heat exchanger model is also compared against the heat exchanger laboratory test results. The heat exchange deviations are all within 5%. This proves that the current model is definitely effective.

3 Performance and Cost Comparisons of Heat Exchangers

Below, the two kinds of Φ9.52mm and Φ5mm inner-grooved copper tube heat exchangers are used as examples to describe the cost advantage a heat exchanger with a small tube diameter has when the heat exchange performance of the two are close.

In the calculations, the two types of Φ9.52mm inner-grooved copper tube and Φ5mm inner-grooved copper tube heat exchangers are calculated using the same entry parameters as per Table 2. See Table 3 for the structural parameters of the Φ9.52mm inner-grooved copper tube heat exchanger. See Table 4 for the structural parameters of the Φ5mm inner-grooved copper tube heat exchanger. The various manifold layouts are as shown in Figure 4.

The calculation results show that after adjusting the tube number and tube spacing (spacing in the T-direction and spacing in the N-direction), the Φ5mm inner-grooved copper tube heat exchanger can reach almost the same heat exchange performance as that of the Φ9.52mm inner-grooved copper tube heat exchanger: for the Φ9.52mm inner-grooved copper tube heat exchanger, the heat exchange amount is 3670W and the supercooling temperature is 10°C; for the Φ5mm inner-grooved copper tube heat exchanger, the heat exchange amount is 3637W and the supercooling temperature is 7°C.

From the perspective of cost analysis, the Φ9.52mm copper tube heat exchanger uses 12 copper tubes and 6 U tubes. The total weight is 537.7g. The Φ5mm copper tube heat exchanger uses 18 copper tubes and 9 U tubes. The total weight is 312.9g. The copper tube usage amount is reduced by 41.8%. The T-direction spacing of the heat exchanging tubes in the Φ5mm copper tube heat exchanger is half the T-direction spacing of the heat exchanging tubes in the Φ9.52mm copper tube heat exchanger. The length and height are the same for both kinds of heat exchangers. Therefore, the aluminum foil usage amount for the Φ5mm copper tube heat exchanger is reduced by half.

Table 2 Calculated Operating Condition

Parameters for Heat Exchanger

Parameter	Value	Unit
Air Inlet Dry-Bulb Temperature	35	℃
Air Inlet Wet-Bulb Temperature	24	℃
Air Inlet Air Speed	1.5	m/s
Atmospheric Pressure	101.3	kPa
Refrigerant Type	R22	-
Refrigerant Inlet Flow	0.022	kg/s
Refrigerant Inlet Temperature	75	℃
Refrigerant Inlet Pressure	2530	kPa

Table 3 Structural Parameters

for Φ9.52mm Heat Exchanger

Parameter	Symbol	Value	Unit
Heat Exchanger Length	L	500	mm
Heat Exchanger Height	H	306	mm
Heat Exchanger T-Direction Spacing	S1	22	mm
Heat Exchanger N-Direction Spacing	S2	25.4	mm
Fin Type		Louvered Window	-
Fin Thickness	δ_f	0.105	mm
Fin Spacing	Ft	1.2	mm

Table 4 Structural Parameters

for Φ5mm Heat Exchanger

Parameter	Symbol	Value	Unit
Heat Exchanger Length	L	500	mm
Heat Exchanger Height	H	306	mm
Heat Exchanger T-Direction Spacing	S1	11	mm
Heat Exchanger N-Direction Spacing	S2	17	mm
Fin Type		Louvered	-

		Window	
Fin Thickness	δ_f	0.105	mm
Fin Spacing	Ft	1.2	mm

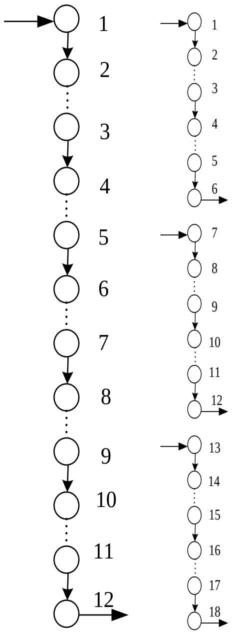

Figure 4 Flow Chart for Φ9.52mm and Φ5mm

Inner-Grooved Copper Tube Heat Exchangers

4 Conclusion

For this report, research was first conducted for the single tube performance and cost of the two kinds of Φ9.52mm and Φ5mm inner-grooved copper tubes. After that, the steady-state distribution parameter model for the tube fin heat exchanger was constructed. Research was then carried out regarding the performance and cost of the tube fin heat exchangers that use the two abovementioned kinds of different diameter inner-grooved copper tubes. The conclusion obtained is as below:

(1) Under the same testing conditions, the heat exchange coefficient within the Φ5mm inner-grooved copper tube is around 15% higher than that within the Φ9.52mm inner-grooved copper tube. The material cost is thus greatly reduced;

(2) For the same dimensions and under the same operating conditions, the Φ5mm inner-grooved copper tube heat exchanger can achieve almost the same heat exchange performance as the Φ9.52mm inner-grooved copper tube heat exchanger. The copper tube usage amount can also be reduced by 41.8%. The aluminum foil cost is reduced by around 50%.

(3) While keeping the windward cross-sectional dimensions unchanged, through adjusting the refrigerant manifold and tube spacing, as well as structural parameters like the fin spacing, the heat exchanger with small tube diameter can obtain the same performance as the copper tube heat exchanger with big tube diameter.

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