Microgroove copper tube

Microgroove Copper Tube Heat Exchangers

Part 1 of 3

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Introduction

For energy efficient and cost effective air conditioners using natural refrigerants like R290 and R32, small diameter copper tube heat exchangers with MicroGroove™ Technology are used. The micro-grooved small diameter tube helps the development of energy saving, high efficiency and miniaturized air conditioning systems. When the diameter of the copper tube is reduced to 5mm from 7mm or 9.52mm, the cost of copper tube in heat exchanger is significantly reduced and the refrigerant charge is also reduced. The risk of fire is also reduced with flammable natural refrigerants.

Fin Design Optimization

Thermal resistance on airside of the air conditioner heat exchanger makes about 90 percent of the total thermal resistance. Hence fin design is very important to achieve optimum performance of the heat exchanger. Fins suitable for large diameter tube heat exchanger are not suitable for small diameter tube heat exchanger. So there is a need to redesign the fin for small diameter tube heat exchanger.

Optimization Process

Figure 1 shows the optimization flow-sheet for fins with the highest theoretical performance-price ratio.

As shown in *Figure 1*, optimization design includes two parts:

1. Determine the size of fin-and-tube heat exchanger of 5 mm diameter tubes (P_t/P_r, tube pitch and fin pitch).
2. Determine fin configuration of the heat exchanger.

Design the louver fins, and optimize louver angle and number of louvers based on the determined size to enhance the performance of the heat exchanger.

About the Author

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continued on page 40

continued from page 38

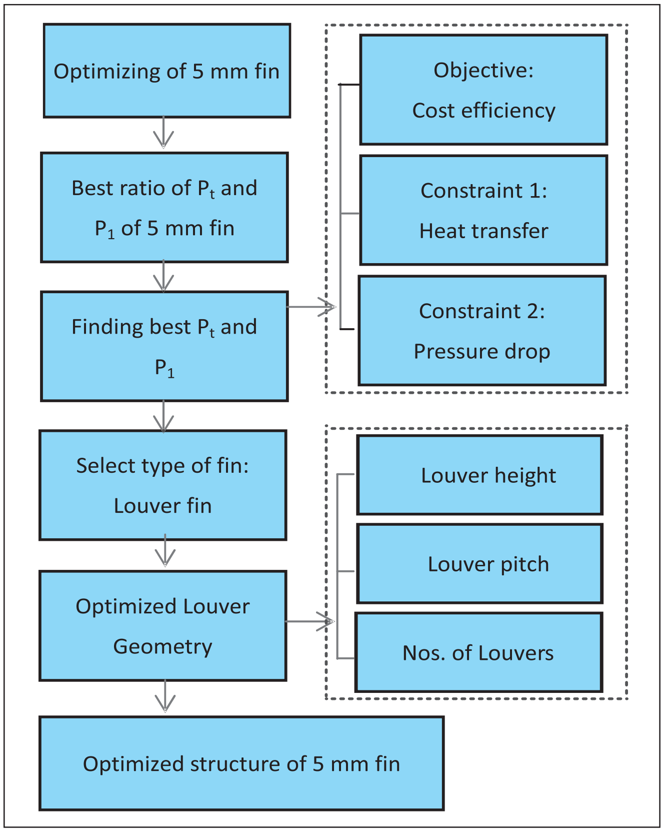


Figure 1: Optimization process for fins with theoretical optimal performance

Fin Size Optimization

Fin Design Conditions

Including indoor and outdoor sets, air velocity ranges from 0.7 to 2.0 m/s under air conditioning operation condition. Air dry bulb temperature is 27°C and wet bulb temperature is 19°C. Calculate heat transfer coefficient relatively of four different wind velocities by applying the correlations in the literature. *Table 1* shows the results.

Table 1: Heat transfer coefficient under different wind velocities on the air side

Operation condition	Wind velocity v (m/s)	Heat transfer coefficient h (W/ m².K)
1	0.7	60.7
2	1.0	66.9
3	1.5	74.7
4	2.0	80.8

According to the study, the mass-flux density of refrigerant ranges from 160kg/m².s to 270kg/m².s in current heat exchangers of 5 mm diameter tubes. Evaporating temperature is 7°C, and degree of dryness is 0.5. Calculate average heat transfer coefficient of R22 under four different mass-flux densities by the small tube correlations. *Table 2* shows the four different mass-flux densities and heat transfer coefficients relatively. If the refrigerant is R410A, R290 or R32, the absolute value of heat transfer coefficient will change, but heat transfer coefficient varies in the same way as the mass-flux density.

Table 2: Refrigerant heat transfer coefficient under different mass-flux densities

Operation condition	Mass-flux density g (kg/m².s)	Heat transfer coefficient h (W/ m².K)
1	160	4349
2	190	4991
3	230	5815
4	270	6611

Analyze Current Fin Problems

Although fin-and-tube heat exchangers of 5 mm diameter tubes have been widely used in window air conditioners, the degradation of heat exchanger performance has not been settled as the tube diameter reduces form 7 mm to 5 mm. This article will first analyze the problems of the current fins, and will then provide the prioritization scheme for fin-and-tube heat exchanger of 5 mm diameter tubes.

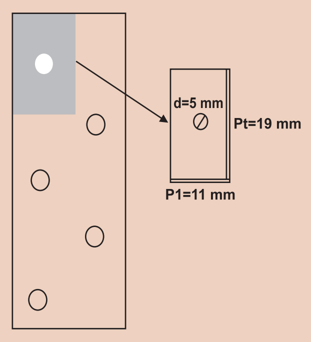


Figure 2: Fin configuration with $P_t \times P_l = 19 \times 11$ mm

According to the study, the fin size of fin-and-tube heat exchangers of 5 mm diameter tubes currently used in window air conditioners is $P_t \times P_l = 19 \times 11$ mm,

where P_t is fin length, and
P_l is fin width.

Figure 2 shows the unit configuration of plain fin.

Heat transfer performance can be evaluated by fin temperature distribution and fin efficiency.

Analyze Fin Temperature Distribution of Current Fins

Under free convection condition, fin temperature distribution can be known by solving the heat conducting differential equation of plain fin:

$$\frac{d^2 t}{dx^2} + \frac{\phi}{\lambda} = 0 \tag{1}$$

$$\phi = (P dx) h (t - t_e) \tag{2}$$

where x is the distance from the fin root,
t is fin temperature,
t_e is environment temperature,
λ is fin heat transfer coefficient,
h is fin film coefficient of heat transfer, and
P is the boundary circumference of heat transfer part.

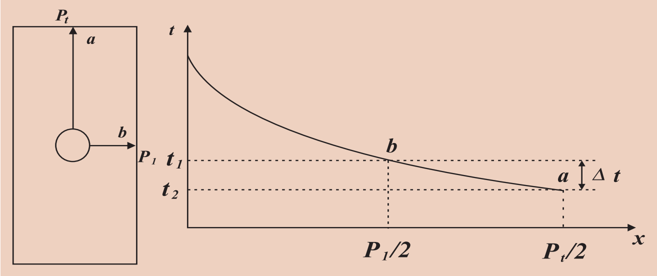


Figure 3: Fin temperature distribution in the direction of P_t and P_l

continued on page 42

continued from page 40

Figure 3 shows fin temperature distribution in the direction of P_t and P_l according to Equation (1) and (2).

The temperatures of point a and b on the boundary tend to be the same with regard to ideal fins with the best heat transfer performance.

Figure 3 shows that the boundary temperature in the direction of Pl is higher than that in the direction of Pt for the current fin-and-tube heat exchangers with 5 mm diameter tubes, because fin width is small. It shows that heat conduction in the direction of P_l is not complete. As a result, heat transfer performance is not good.

Louver Configuration Design Optimization

Louver Design

Reducing the thermal resistance on the air side is an effective way to enhance the heat transfer performance. The radiator of louver fin can cut down the development of boundary layer on the air side, decrease the thickness of boundary layer, and enhance the heat transfer performance. Meanwhile, dry condition and wet cooling condition operate alternately in most heat exchangers used in air conditioners. The properties of heat transfer and resistance of different fin type heat exchangers differ greatly under the wet cooling condition from those under the dry condition. Comparing a louver fin with hydrophilic coating with a plain fin, the increase in heat transfer performance is higher than the increase in pressure drop, according to the study. Louver fin with hydrophilic coating has good comprehensive performance.

Figure 4 shows louver configuration. $\theta = \arctan \dfrac{L_h}{L_p}$ means louver angle,

where L_h is fin height,

and L_p is fin projected length.

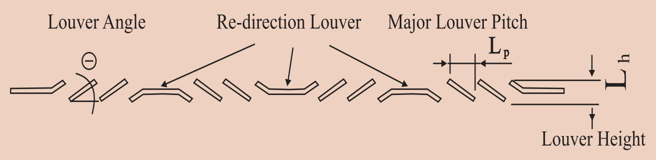


Figure 4: Louver configuration

Optimization of Louver Configuration

As shown in *Figure 4*, the main structural parameters of the louver fin with determined size are fin height (L_h), fin projected length (L_p), louver angle (θ) and number of louvers (n). Louver angle (ϑ) and number of louvers (n) are independent variables, while fin height (L_h) and fin projected length (L_p) are determined by the two independent variables. Therefore, the influence on heat transfer performance can be discussed with louver angle (ϑ) and louver number (n).

Determine Louver Angle (ϑ)

Variation trend of heat transfer efficient can be calculated as louver angle (ϑ) varies according to the correlations under constant pressure drop (12 Pa) and determined size of $P_t \times P_l$=18×15 mm.

Figure 5 shows the variation trend of fin heat transfer efficient with determined size as louver angle (ϑ) varies according to the calculation result.

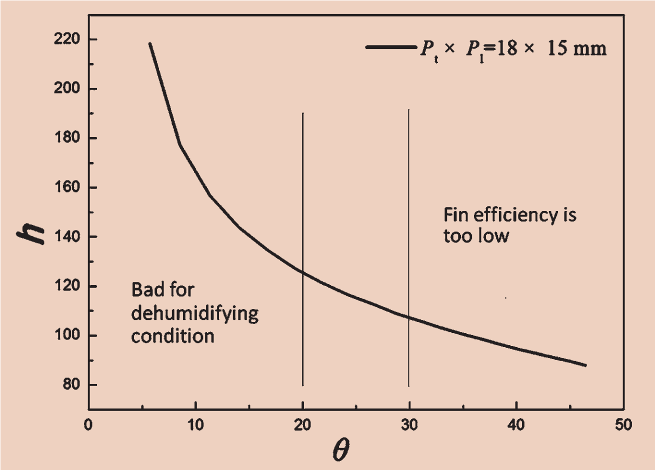


Figure 5: Variation of heat transfer efficiency with louver angle (ϑ)

1) As *Figure 5* shows, heat transfer efficiency of louver fin decreases and louver angle (ϑ) increases under certain pressure drop. Louver angle (ϑ) should be smaller than 30° to guarantee high heat transfer coefficient (h>110).
2) If the louver angle (ϑ) is too small, condensate water of heat exchanger cannot flow through louvers easily, which can cause the blocking of condensate water and worsen the heat transfer performance. The louver angle (ϑ) should be higher than 20° to guarantee that the condensate water can flow througn louvers according to the relevant literature.
3) Generally the exsiting louver angle (ϑ) is 25°. The optimal fin configuration can be ditermined by CFD calculation.

Optimization of Number of Louvers

The width of the optimized unit fin differs from that of current unit fin, so the number of louvers should be changed. We shall determine the optimal number of louvers and fin configuration with the optimal size of $P_t \times P_l$=18×15 mm by analyzing heat transfer performance and pressure drop of fins with different number of louvers by CFD.

Meanwhile, this article will also calculate fins of different configurations with the same $P_t \times P_l$ (such as the fin with the size $P_t \times P_l$=17×14.2 mm) by CFD to analyze the heat transfer performance of fins with optimal size and the optimization effect.

CFD Geometric Model

The fin with the size $P_t \times P_l$=18×15 mm has 3 louvers in unit fin, and the fin with the size $P_t \times P_l$=17×14.2 mm has 4 louvers in unit fin. Take the unit fin as infinitesimal and mesh as *Figure 6* shows.

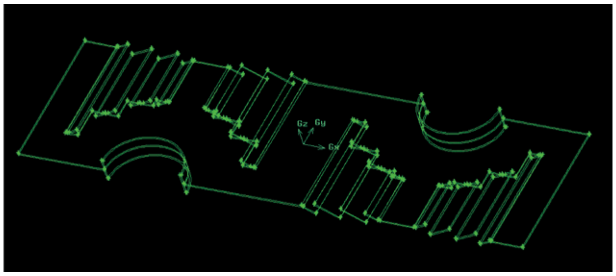
Note: The infinitesimal is a computation cell. In the CFD calculation, a grid in a mesh is a computation cell. The CFD software will automatically calculate the energy equation, momentum equation and continuity equation of each computation cell.

CFD Mathematical Model

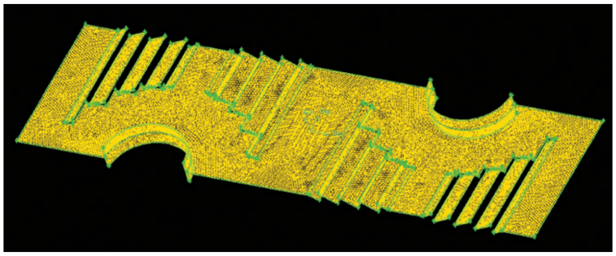
Simple method and laminar model are adopted in the calculation. *Table 3* shows the constant in the model.

continued on page 44

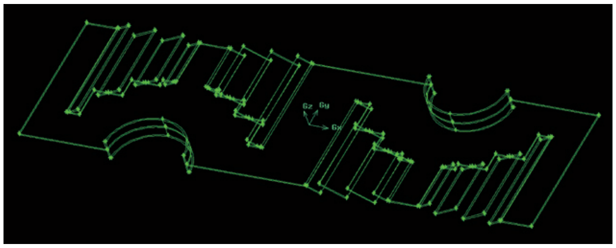
continued from page 42



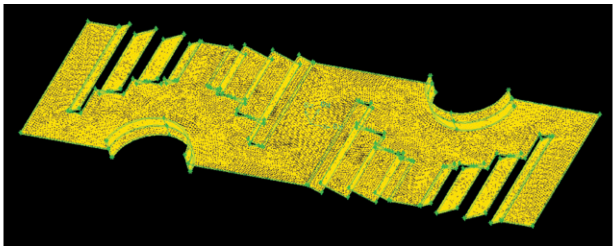
(a) P_t=18, P_l=15, 3 louvers model



(b) P_t=18, P_l=15, 3 louvers model with mesh



(c) P_t=18, P_l=16.4, 4 louvers model



(d) P_t=19, P_l=15, 4 louvers model with mesh

Figure 6: Mesh to the CFD calculation infinitesimal

Table 3: The constant in the k-ε mode

Cu	C1ε	C2ε	TKE Pr	TDR Pr
0.09	1.44	1.92	1	1.3

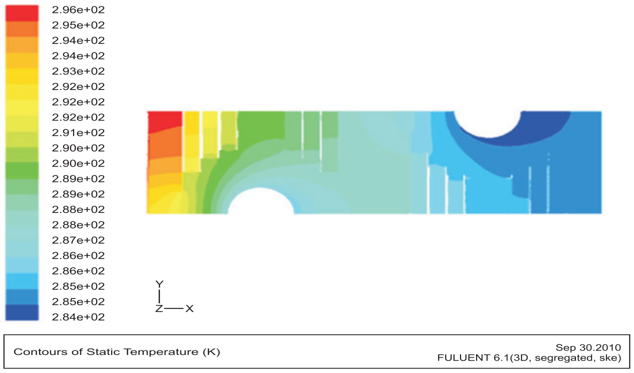
Table 4 shows the boundary conditions of the fin model.

Table 4: Boundary condition settings of CFD model

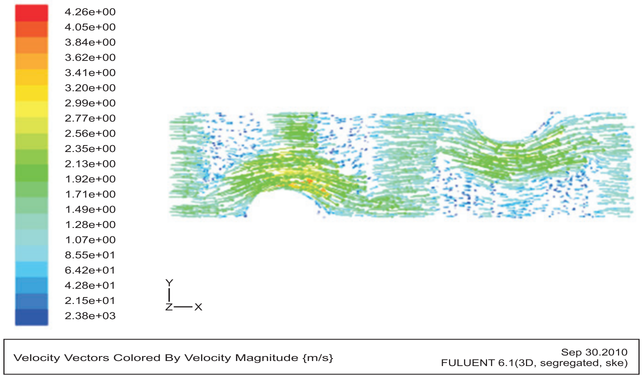
Boundary	Settings	Material
Air inlet	Inlet velocity: 1.5 m/s, inlet temperature: 300 K, flow pattern: laminar	---
Infinitesimal air of upper and lower surface	Periodic boundary conditions without pressure drop	---
Tube wall	Constant wall temperature, 280 K	Copper tube
Fin wall	Coupling calculation of fin heat conduction and heat convection between fins and air	Aluminum fin

Optimal Conclusion

Calculate the fins by CFD with the size $P_t \times P_l$=17×14.2 mm and $P_t \times P_l$=18×15 mm, with different numbers of louver. *Figure 7* shows the fin temperature pattern and the air velocity pattern simulated by CFD.



(g) P_t=18, P_l=15, 4 louvers, temperature pattern



(h) P_t=18, P_l=15, 4 louvers, air velocity pattern

Figure 7: CFD results of temperature pattern and air velocity pattern

Figure 7 shows that the temperature pattern of the fin with the size $P_t \times P_l$=18×15 mm is more uniform than that of the fin with the size $P_t \times P_l$=17×14.2 mm; air velocity pattern of fins with 4 louvers is more uniform than that of fins with 3 louvers.

The heat transfer performance and the pressure drop is shown in *Table 5*.

Table 5: CFD calculation results

Fin Number	Fin size	Louver height (mm)	Number of louvers	Heat transfer rate per height of 1-row fin (W)	Pressure drop (Pa)
1	P_t=17, P_l=14.2	0.35	3	14.30	38.14
2		0.3	4	14.50	29.24
3	P_t=18, P_l=15	0.35	3	16.35	43.43
4		0.3	4	16.53	34.97

Table 5 shows:

Comparison between fins with different number of louvers

Heat transfer rate per height of 4 louvers with 2 fin sizes is respectively 1.4% and 1.1% higher than for height of 3 louvers. The main reason is that increase in the number of louvers can improve the heat transfer between fins and air. Thus, it enhances fin heat transfer rate.

continued on page 46

continued from page 44

Pressure drop with 4 louvers with 2 fin sizes is respectively 23% and 19% lower than with 3 louvers. It is because fin height decreases as the number of louvers increases under certain fin size. It decreases the air flow resistance. As a result, pressure drop decreases.

Therefore, number of louvers should be 4 to guarantee high heat transfer rate per height of 1-row fin and low air pressure drop.

Comparison between fins with different sizes

Heat transfer rate of fins with size $P_t \times P_l = 17 \times 14.2$ mm per height is 14% lower than fins with size $P_t \times P_l = 18 \times 15$ mm. Pressure drop of fins with size $P_t \times P_l = 17 \times 14.2$ mm per height is 20% less than that fins with size $P_t \times P_l = 18 \times 15$ mm, which means the decrease is 5.73 Pa.

Therefore, fin with size $P_t \times P_l = 18 \times 15$ mm has better heat transfer performance, and the increase in pressure drop is only 5.73 Pa.

Therefore, optimal louver configuration is: $P_t \times P_l = 18 \times 15$ mm, number of louvers=4.

Heat Exchanger Circuit Design Optimization

Because the diameter of copper tube is reduced and the pressure drop is increased, we need to redesign the heat exchanger circuit when we use small diameter copper tube heat exchanger to replace a larger one, to obtain the same performance. We can use International Copper Association's Simulation Software to optimize and design the heat exchanger and the system. We shall introduce the design method based on a real life case study.

Introduction to Air Conditioner Design Parameters

Constant Parameters

The design parameters of indoor unit and outdoor unit are shown in *Table 6* and *7*. The tube and fin in each unit are the same, and their parameters are shown in *Table 8*.

Table 6: Parameters of the indoor unit

Parameter	Value	Parameter	Value
Length (mm)	558	Row space (mm)	13.37
Height (mm)	273	Column space (mm)	21
Depth (mm)	27.34	Front boundary space (mm)	6.68
Number of rows	2	Bottom boundary space (mm)	5.25
Number of column return bends	13		15.75

Table 7: Parameters of the outdoor unit

Parameter	Value	Parameter	Value
Length (mm)	750	Row space (mm)	13.37
Height (mm)	504	Column space (mm)	21
Depth (mm)	27.34	Front boundary space (mm)	6.68
Number of rows	2	Bottom boundary space (mm)	5.25
Number of column return bends	24		15.75

Table 8: Parameters of fins and tubes

Louver fin		7 mm enhanced tube	
Fin thickness (mm)	0.105	Outside diameter (mm)	7.00
Height (mm)	0.7	Tube thickness (mm)	0.24
Breadth (mm)	1.4	Fin height (mm)	0.18
Louver angle (°)	30	Fin space (mm)	0.43
Outside diameter of tube (mm)	7.21	Helix angle (°)	18
Transverse pitch (mm)	21.0	Apex angle (°)	35
Longitudinal pitch (mm)	13.37	Fin (numbers)	50

Air Flow Distribution of Prototype Outdoor Unit

The vertical view of the prototype outdoor unit is shown in *Figure 8*. The air flow distribution of the prototype outdoor unit is obtained from experimental measurement as shown in *Table 9*.

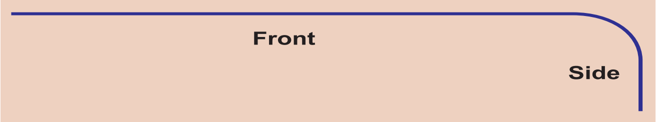


Figure 8: Vertical view of the prototype outdoor unit

Table 9: Air flow distribution of prototype outdoor unit

Front top (left to right)					Side top
2.4	2.8	3.1	2.7	2.9	3.1
2.5	2.9	3.3	3.2	3	3.2
2.4	2.8	3.4	3.6	3	3
2.6	3.2	3.4	3.3	3	3
Front bottom (left to right)					Side bottom

The inlet enthalpy of the prototype outdoor unit is the value that can be calculated by the inlet pressure and inlet temperature of the prototype outdoor unit. The mass flow rate of the prototype is equal to that of the prototype indoor unit.

Variable Parameters

The parameters of 5 mm tube are shown in *Table 10.*

Table 10: Parameters of 5 mm tube

Parameter	Value
Outside diameter (mm)	5.05
Tube thickness (mm)	0.20
Fin height (mm)	0.14
Fin space (mm)	0.343
Helix angle (°)	18°
Apex angle (°)	40°
Fin (numbers)	40

Optimized Fin

Fin Structure

The fin parameters are shown in *Table 11*.

Table 10: Parameters of 5 mm tube

Parameter	Value
Outside diameter (mm)	5.05
Tube thickness (mm)	0.20
Fin height (mm)	0.14
Fin space (mm)	0.343
Helix angle (°)	18°
Apex angle (°)	40°
Fin (numbers)	40

continued on page 48

continued from page 46

Table 11: Fin parameters

Parameter	Fin
Thickness (mm)	0.105
Height (mm)	0.7
Breadth (mm)	1.4
Louver angle (°)	32
Outside diameter of tube (mm)	5.2
Transverse tube pitch (mm)	19
Longitudinal tube pitch (mm)	11

In the case study, 19×11mm fin is used.

Fin Pitch

It is found from the survey that the fin pitch in the designed air conditioner with 5 mm tube is among 1.2 mm, 1.3 mm, 1.4 mm and 1.5 mm.

Throttling Device

In the system simulation, the capillary tube length and the refrigerant charge are adjusted until the superheat temperature and the subcooling are 5°C and 7°C to get the best performance of the air conditioner.

In Part 2 of this article, to be published in the July-August issue of the Journal, we shall discuss condenser design optimization with microgroove copper tubes.