STUDY ON THE CHARACTERISTICS OF OFFSET STRIP FIN IN A HEAT EXCHANGER

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Abstract: Heat pump system as a cooling and heating unit becomes increasingly popular and important. Especially, its efficiency and availability for green products attracted public attentions. For the higher efficiency, the heat exchanger has a great role in the heat pump system. In this paper, the performance of heat exchanger fin such as offset strip fin is studied and analyzed. Offset strip fin is designed to enhance the heat transfer by eliminating flow stream conduction effect. Several parameters such as fin pitch, height are examined. Experiments are performed for the comparison. In addition, for predicting the performance, a correlation is introduced and simulation is conducted. Pressure drop and heat transfer characteristics are identified. When compared with louver fin, the performance is found to be more effective under the low velocity region.

Key Words: heat pump, heat exchanger, offset strip fin, pressure drop, heat transfer

1 INTRODUCTION

Compact heat exchangers are used in a wide variety of applications. Typical among these are automobile radiators, air-conditioning evaporators and condensers, electronic cooling devices, recuperators and regenerators, and cryogenic exchangers (Manglik and Bergles 1995). These heat exchangers are generally characterized by extended surfaces with large surface area/volume ratios that are often configured in either plate-fin or tube-fin arrangements (Shah and Webb 1983). There are several types of a plate-fin exchanger such as plain fins, wavy fins, offset strip fins, perforated fins, pin fins, and louvered fins (Shah and Webb 1983). Among these fins, offset strip fins are very generally used because they have a high degree of surface compactness, and substantial heat transfer enhancement is obtained. Heat transfer and pressure drop correlations for rectangular offset strip fin are widely surveyed and analyzed (Manglik and Bergles 1995, 1990). Some of studies are focused on the effect of Prandtl number. Tinaut et al. (1992) developed a model and analyzed heat exchanger performance for different Prandtl numbers. Hu and Herold (1995) conducted experimental and numerical investigations of the effect of the Prandtl number on the f and j factors for air, water, and polyalphaolefin(PAO), observing little effect on the f factor and a significant effect on the j factor. Bhowmik and Lee (2009) used a steady-state three-dimensional numerical model to study the heat transfer and pressure drop characteristics of an offset strip fin heat exchanger.

In this study, the characteristics of offset strip fin for evaporative cooling with heat pump are examined and analyzed. Experimental approaches are conducted and a prediction for the performance is simulated by using correlation. Through this study, design specification for the offset strip fin under the constraint of system is offered.

2 EXPERIMENTAL SETUP

A small duct type calorimeter is made to evaluate a fin performance of heat exchanger as shown in Fig. 1. This apparatus includes an air blower to supply the air, cooling coil & heater for controlling the supply air temperature, a humidifier for humidity control, an air sampler for measuring dry & wet bulb temperature, an air mixer for mixing the air and etc. A nozzle is installed in order to measure the air flow rate. The pressure drop and dry & wet bulb temperature can be measured in the front and rear of the test material through differential pressure gauge and RTD sensor. The apparatus is closed type and the supply air temperature is controlled by PID control. The signals in measuring instruments are transferred into personal computer and the data can be processed and stored by a special program. The test materials are sealed for the air not to leak through cover and insulation material such as Styrofoam is used to minimize heat loss. The specifications of the test materials are as follows in table 1 and the photos are shown in Fig. 2.

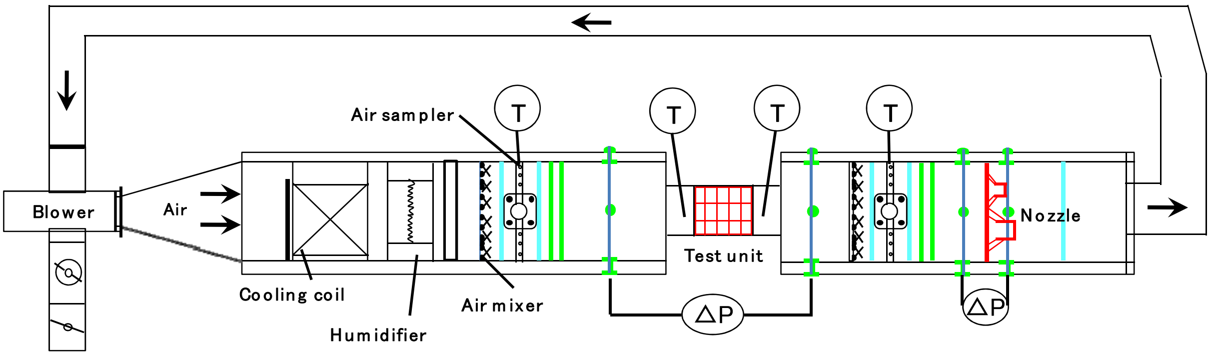
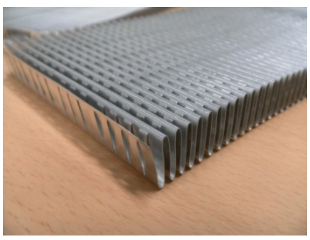


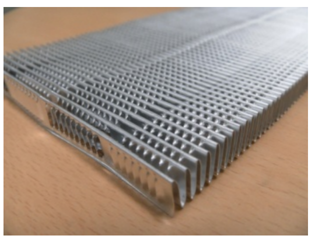
Figure 1: Schematic Diagram of Experimental Setup

Table 1: Test fins for Heat Exchanger

No.	1	2	3	4
Fin type	Offset strip fin	Offset strip fin	Offset strip fin	Louver fin
Fin height	15	15	12	15
Fin pitch	3	4	4.5	4



(a) offset strip fin



(b) louver fin

Figure 2: Photo of Offset Fin & Louver Fin

The four different types of fins are tested and a louver fin is also tested for comparison. The offset strip fins have two parameters, that is, fin height and fin pitch. Fin No. 3 is different

from No. 1, 2 in contact shape between fins and base wall. The contact type in fin No. 3 is face contact whereas the others are line contact.
For the test of the heat transfer performance, the test materials are made as shown in Fig. 3. A plate heater is inserted between two fin channels and it supplies heat into both channels through the fin base wall and finally to heating the air.

Figure 3: Configuration of fin channels with heating plate

Test conditions in this study are as follows.
Air side:

Inlet air dry bulb temperature: 20 ℃

Inlet air wet bulb temperature: 15 ℃

Inlet air velocity: 1.5 m/s

Heating side:

Heat supply: 90~100 W

The pressure drop of the fin channel is measured by differential pressure gauge which is installed between inlet and outlet of the fin channel. The temperature measuring points are (1) the inlet & outlet of the fin channel, (2) base wall of the heating side. The air temperature inside the channel is assumed to be mean temperature between the air inlet and outlet.

$$T_{a,m} = \frac{T_{a,in}+T_{a,out}}{2} \tag{1}$$

where $T_{a,in}$ and $T_{a,out}$ are air inlet and outlet temperature, and $T_{a,m}$ is mean temperature.
In this study, UA is considered as the heat transfer performance and calculated as follows.

$$UA = q/dT \tag{2}$$

$$dT = T_{h,s} - T_{a,m} \tag{3}$$

where q is the heat which is transferred from base wall to the air, and $T_{h,s}$ is the base wall temperature of the heating side. The heat transfer path inside the channel is displayed in Fig. 4.

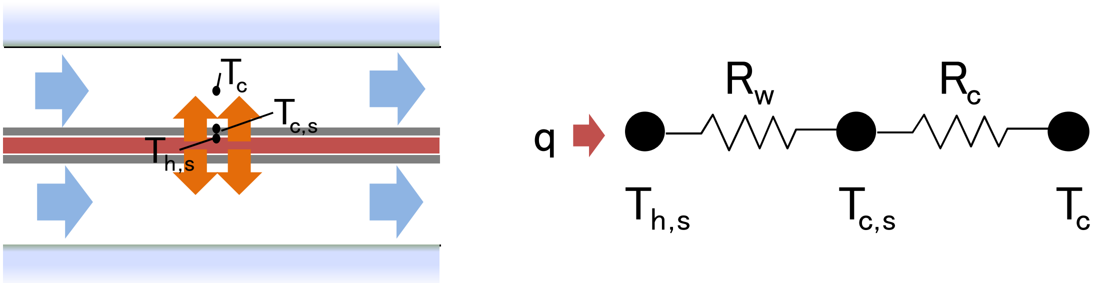


Figure 4: Configuration of fin channels with heating plate

where, $T_{c,s}$ is the base wall temperature of the cooling side and T_c the air temperature. R_w is the thermal resistance by conduction heat transfer through aluminum plate with thickness of 0.15 mm, which is very small compared with the thermal resistance of the air, R_c. In this reason, the base wall temperature of the air side, $T_{c,s}$ is assumed to be same as the base wall temperature of the heating side, $T_{h,s}$ and data are handled under this assumption.

3 RESULTS AND SIMULATION

Fig. 5 shows the comparison of the pressure drop in different fin type. The air velocity changes from about 1.3 m/s to 2.3 m/s. Offset strip fin shows low pressure drop when compared with louver fin because of low air flow resistance. At the air velocity, 1.5 m/s, the pressure drop of offset strip fin is about 55 % compared with louver fin with same fin height and pitch. The pressure drop of offset strip fin inclines slowly when compared with louver fin as the air velocity increases. When the fin pitch changes 4 mm to 3 mm under the same fin height in offset strip fin, the pressure drop increases by about 60 %. As the heat transfer area increases by about 33 %, the skin friction increases, and consequently the pressure drop is found to be increased. The results in offset strip fins with 15/4(fin height 15 mm, pitch 4 mm) and 12/4.5 show that the pressure drop slightly increases as fin pitch increases.

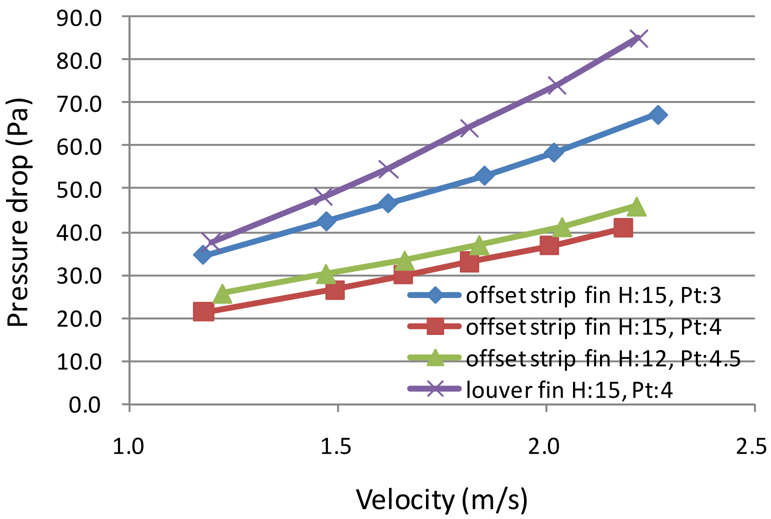


Figure 5: Pressure drop in various fin type

Fig. 6 shows the results of the heat transfer performance. X-axis is air velocity and y-axis is UA, which means heat transfer performance. The reason that UA is compared as heat transfer performance is to design a heat exchanger considering both heat transfer area and heat transfer coefficient. It is shown that offset strip fin with height 15 mm, pitch 3mm has the biggest UA value. It is due to small fin pitch. Low fin pitch means large heat transfer area and it increases heat transfer performance. When offset strip fin 15/3(fin height 15 mm, pitch 3 mm) and 15/4(fin height 15 mm, pitch 4 mm) are compared, the heat transfer area of offset strip fin 15/3 increases by about over 30 %. This means UA increases by over 30 %. The heat transfer performance of louver and offset strip fin with same fin height and pitch is almost same. Consider pressure drop, it is found that offset strip fin is very favorable at same air velocity. On the other hand, UA of offset strip fin 12/4.5 is bigger than that of offset strip fin 15/4, which results from contact shape between fin and fin base wall. Offset strip fin 15/4 is line contact whereas offset strip fin 12/4.5 is face contact between fin and fin base wall. Since the heat transfer passage from fin base wall to fin is relatively favorable in offset strip fin 12/4.5, the performance is higher than that of offset strip fin 15/4.

The comparisons of the heat transfer performance, UA are shown in Fig. 7 when the frontal area is assumed to be same. In this case, offset strip fin 12/4.5 has the best heat transfer performance. It is better than that of offset strip fin 15/3. The fin with smaller pitch under the same contact shape between fin and fin base wall is expected to increase the heat transfer performance. Since fins with small pitch, 3 mm can be manufactured, the simulation for predicting the thermal performance is conducted. The following correlation is used for the offset strip fin in rectangular contact shape (Manglik and Bergles, 1995).

$$j = 0.6522\,Re^{-0.5403}\left(\frac{s}{h'}\right)^{-0.1541}\left(\frac{\delta}{l_s}\right)^{0.1499}\left(\frac{\delta}{s}\right)^{-0.0678} \times\left[1 + 5.269\times10^{-5}Re^{1.340}\left(\frac{s}{h'}\right)^{0.504}\left(\frac{\delta}{l_s}\right)^{0.456}\left(\frac{\delta}{s}\right)^{-1.066}\right]^{0.1} \qquad (4)$$

where the symbols are explained in figure 8 and hydraulic diameter is as following equation.

$$D_h = \frac{4A_{o,cell}}{A_{cell}/l_s} = \frac{4sh'l_s}{2(sl_s+h'l_s+h'\delta)+s\delta} \qquad (5)$$

where $A_{o,cell}$ and A_{cell} means flow area and surface area in the unit cell.

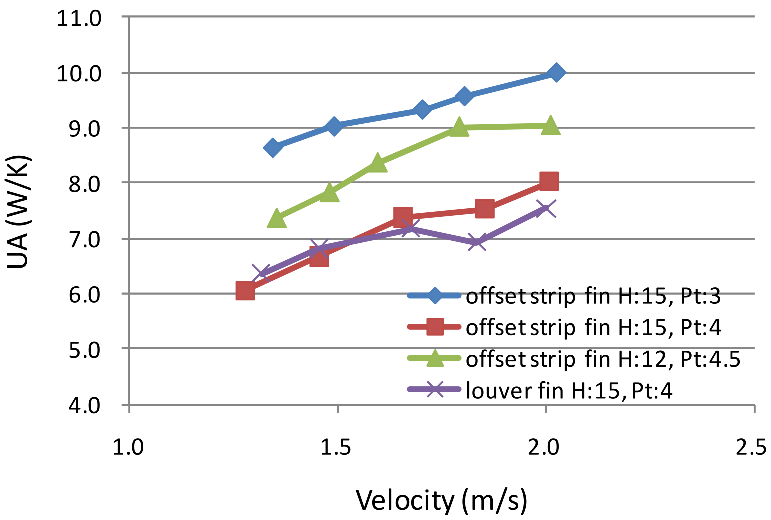


Figure 6: Heat transfer performance in various fin type

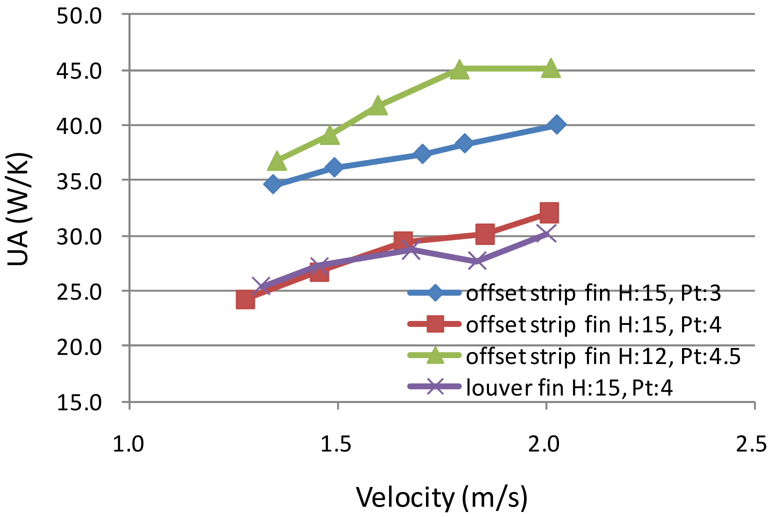


Figure 7: Comparison of heat transfer performance in same frontal area (height 60 mm)

The symbols of the above equation are shown in Fig. 8 in which $s = p_f - \delta, h' = b - \delta, b = b_1$.

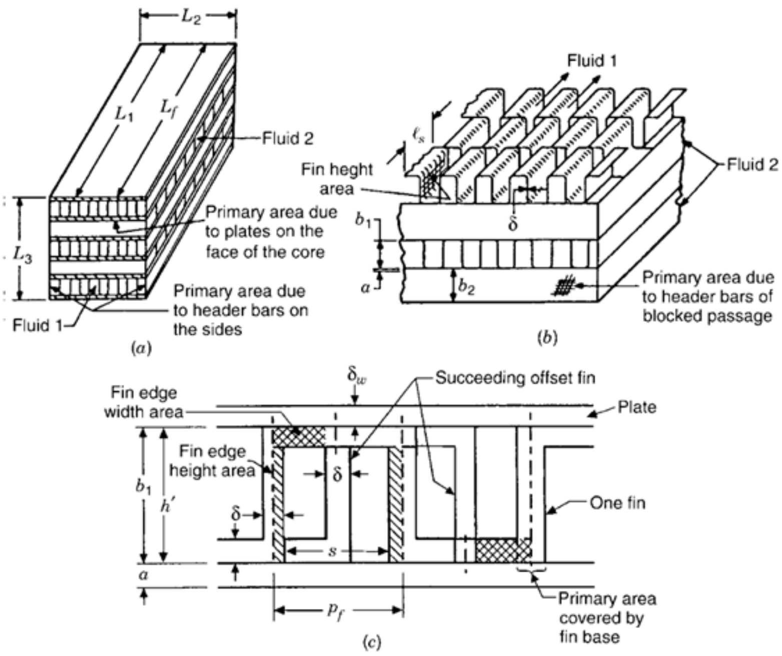


Figure 8: Offset strip fin geometry (Shah and Sekulic 2003)

Input values for simulation are shown in Table 2.

Table 2: Geometric data of offset strip fin

symbol	Input data(mm)
s	2.1
h'	12
δ	0.15
l_s	4.5

where the symbols, s, h', δ and l_s are flow width, flow height, fin thickness and offset length respectively.
From input values, D_h is calculated as 3.5 mm, Re number 327. When pitch changes 4.5 mm to 3 mm, the ratio of j factor can be obtained as follows.

$$\frac{j_3}{j_{4.5}} = \frac{0.0345}{0.0272} = 1.27 \tag{6}$$

where j_3 and $j_{4.5}$ are j factors based on pitch 3 and 4.5 mm, respectively.
It is found that the heat transfer performance can increase by 27 %. Considering f factor, the pressure drop increases by about 90 %. With these results, when offset strip fin in rectangular contact shape is manufactured to be fin pitch 3 mm with height 12 mm, it is thought that the heat transfer is 1.8 times better than that of louver fin 15/4 and the pressure drop is below 60 Pa.

4 CONCLUSION

In this study, the characteristics of offset strip fin were experimentally analyzed. To examine the pressure drop and heat transfer performance, experimental apparatus was setup and different types of offset and louver fins for comparison were adopted as test materials. Simulation by existing correlation was also conducted for predicting performance. The following conclusions were obtained.

1) Under the same fin height and pitch, the pressure drop of offset strip fin decreased by about 50 % when compared with that of louver fin. Changing fin pitch from 4 mm to 3 mm induced the pressure drop by 60 %.
2) Under the same fin height and pitch, the heat transfer performance, UA, of offset strip fin was similar to that of louver fin and it increased by about 30 % when it changed fin pitch from 4 mm to 3 mm.
3) By applying rectangular type of offset strip fin shape, the heat transfer performance increased. When it changed pitch to be 3 mm, it was simulated that the heat transfer performance increased by 80 % with 60 Pa of pressure drop compared with louver fin 15/4.

With these results, it is thought that the fin design can be optimized for the purpose of achieving the desired performance

5 Acknowledgement

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