Experimental study on heat transfer performance of aluminium foam parallel-flow condenser in air conditioner

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Abstract: Open cell aluminium foam was used in parallel-flow condenser in air conditioner, and two condensers with different pore density were fabricated. The experimental study was conducted on the heat transfer performance and temperature distribution. The experimental results show that both of the heat transfer load and air pressure drop increase with the increase of pore density, air velocity is 2.5m/s, the heat transfer capacities of the condenser with 10PPI and 8PPI are 4.786kw and 3.344kw respectively. Along the flow direction of refrigerant, the outlet temperatures of refrigerant drop with the rise of air velocity when the inlet temperature is constant. The outlet temperature of the refrigerant decreases with the increase of pore density.

1. Introduction

It is well known that Open-cell foam aluminum have many interesting physical properties, such as low weight high specific surface area combined with relatively high thermal conductivity. Consequently, they have become a focus in industrial applications\cite{1}. With the development of compact heat exchanger, the air flow in the metal foams could form turbulence, thus it could enhance the heat transfer performance and be used in heat exchanger more and more.

Tadrist L et.al\cite{2} investigated the flow and heat exchange characteristics in aluminum foam, the best structural parameter of aluminum foam was investigated based on the heat exchanger performance and pressure drop. NohJ S et.al\cite{3} investigated the aluminum foam heat exchanger. It was found that the aluminum foam could enhance the performance significantly. T’JoenC et.al\cite{4} investigated the heat exchanger design with metal foams through wind tunnel testing experimentally. The results indicated that a good metallic bonding between the foam and the tubes can be achieved. Comparing with helically finned tubes, metal foam covered tubes with small tube spacing, small foam heights and high specific surface area potentially offer more benefits at higher air velocities (>4 m/s) Han X et.al\cite{5} et.al used aluminum foam for the dehumidifying heat exchangers, both of the dry condition and wet condition were experimental investigated. The results showed that the drainage from metal foam is as good as or better than drainage from the louver-fin exchangers, (the heat transfer efficiency enhanced with the PPI). RibeiroG B et.al\cite{6} experimentally investigated three different copper metal foam structures with distinct pore densities (10 and 20 PPI) and porosities (0.893 and 0.947). The results showed air-side pressure drop increases with the increase/decrease of pore density and decreases with porosity, and the air-side thermal conductance increases with pore density and decreases with porosity. Ranut P et.al\cite{7} adopt high resolution μ-CT-based CFD
simulation, performed on three different open-cell aluminum foams samples. The results demonstrate demonstrated that open-cell aluminum foams are effective means for enhancing heat transfer. Moreover, the procedure proved that μ-CT is a valid tool for capturing the peculiar details of the foam structure, thus to overcome the limits associated to the use of economical, but simplified, geometric models. Hua H et.al [8] analyzed the effect of tube diameter on pressure drop characteristics of refrigerant–oil mixture flow boiling in metal-foam filled tubes. Experiments on metal-foam filled tubes with an inner diameter of 7.9 mm were performed. The research results show showed that, the pressure drop increases with increasing PPI, and the impact of PPI becomes more insignificant as the tube diameter decreases. A new pressure drop correlation was developed, and it agrees well with the experimental data for different diameter tubes.

The aluminum foam is used for fin in air conditioner parallel-flow heat transfer. Two condensers with different porosity were fabricated. The heat transfer performance was investigated in different air velocity and refrigerant flow.

2. Test Sample

The model of parallel-flow condenser is shown in Figure 1, it consists of header, louver fin and multi-channel flat tubes. The refrigerant flows from header to the flat tubes while the air flow is passing the louver fin. The refrigerant flow direction is perpendicular to the direction of air flow. The overall size of the condensers is 608mm*390mm*16mm. The specific parameters are as shown in Table 1.

![Figure 1. Structure of the aluminium foam parallel-flow condenser](image)

| Parameter                      | Value | Parameter                  | Value |
|-------------------------------|-------|----------------------------|-------|
| Micro-channel width CHw (mm) | 0.94  | Flat tube height Th (mm)   | 2.0   |
| Micro-channel height CHh (mm) | 0.6   | Flat tube Width Tw (mm)    | 16    |
| Micro-channel number          | 10    |                            |       |
The tube number from first pass to forth pass is $t_{14}$, $t_{12}$, 8 and 6. The specific parameters are shown in Table 2.

### Table 2 Structure parameter of the aluminium foam parallel-flow condenser

| Parameter     | Value | Parameter     | Value |
|---------------|-------|---------------|-------|
| Pores Per Inch | 10PPI | Pores Per Inch | 8PPI  |
| Proximity     | 0.92  | Proximity     | 0.935 |
| Foam height   | 8     | Foam height   | 8     |
| Foam width    | 16    | Foam width    | 16    |

3. **Experiment apparatus**

The experiment is conducted in the high accurate laboratory, and the schematic is shown in Figure 2. The fan and compressor are controlled by PLC, data collector is DA100 produced by Heng He corporation, the test error of temperature sensor is less than $\pm 0.1^\circ C$. The temperature sensors are set in the inlet and outlet of the condenser, the enthalpy difference is obtained, the heat transfer is calculated.

![Figure 2. Schematic view of the experimental system](image)

1-compressor, 2-oil separator, 3-precooler, 4-subcooler, 5-sight mirror, 6-flow meter, 7-solenoid valve, 8-heater, 9-Electronic expansion valve, 10-auxillary evaporator, 11-gas separator, 12-temperature controller

4. **Experiment result discussions**

4.1. Effect of face air velocity on heat transfer performance

Two condensers with different porosity are used to conduct experiment. Experimental condition: the temperature of refrigerant at condenser inlet is $65^\circ C$, the condensate temperature is $50^\circ C$, the air dry and wet temperature at inlet is $35^\circ C$, $24^\circ C$ respectively. The air velocity is 1.0m/s, 1.5m/s, 2.0m/s, 2.5m/s respectively.
The experimental results at different air velocity are shown in Figure 3 and Figure 4. The heat transfer capacity increases with the increase of air velocity. When air velocity is 2.5 m/s, the heat transfer quality of 10PPI is 4.786 kW while the 8PPI is 3.344 kW, the difference is 43.1%. Because of the pore diameter is small, air in the aluminum foam with 10PPI could form turbulent three dimension flow, thus the heat transfer capacity increases rapidly with increase of the air velocity. When the pore diameter is bigger, the capacity of heat transmission is not enough. Thus the heat transfer capacity increases. As is shown in Figure 4, the pressure drop increases rapidly. Thus the air velocity should not be too high to avoid the increase of the energy consumption.

4.2. Effect of flow rate of refrigerant on heat transfer performance
Two condensers with different porosity are used to conduct experiment. Experiment condition: the temperature of refrigerant at condenser inlet is 65°C, the condensing temperature is 50°C, the inlet air dry and wet temperature is 35°C, 24°C respectively. The flow rates of refrigerant are 70 Kg/h, 80 Kg/h, 90 Kg/h, and 100 Kg/h, 110 Kg/h, 120 Kg/h, respectively.

The experimental results of six kinds of flow rate of refrigerant are shown in Figure 5. The heat transfer capacity increases with the raise of refrigerant flow rate. The increasing trend is almost the same, when flow rate of refrigerant is 120 Kg/h, the heat transfer capacity of 10PPI is 5.714 kW while the 8PPI is 5.203 kW, and the former is 9.8% higher than the latter.
4.3. Temperature distribution in different face air velocity

The heat exchanger has 4 pass, the thermocouples are set at condenser inlet, first pass inlet, second pass inlet, third pass inlet, forth pass inlet and the condenser outlet, as is shown in Figure 1, the condenser temperature distributions at different air velocity are experimental investigated.

![Figure 6. Temperature distribution of the aluminium foam parallel-flow condenser](image)

The experimental results of temperature distribution are shown in Figure 6. The temperature decreases with the increase of air velocity in refrigerant flow direction. The temperature between the first pass inlet and the second pass inlet decreases the fastest. It is found the capacity of heat transmission in the first pass is larger than other three pass. The outlet temperature of 10PPI condenser is lower than that of 8PPI, that is to say heat transfer of 10PPI condenser is better than that of 8PPI.

The temperature reaches 50 °C in the third pass, it shows the refrigerant begin to subcooling in the third pass. When the air velocity is 2.5m/s, the dropping speed of temperature in 10PPI condenser toward condensing temperature is the fastest while the 8PPI one is the slowest.

5. Conclusions

Open cell aluminum foam is used in parallel-flow condenser in air conditioner, two condensers with different pore density are fabricated, and the experimental study is conducted on the heat transfer performance and temperature distribution. The experimental results show that both of the heat transfer capacity and air pressure drop increase with the increase of pore density. At the air velocity is 2.5m/s, the heat transfer capacities of the condenser with 10PPI and 8PPI are 4.786kw and 3.344kw respectively. The heat transfer capacity increases with the raise of refrigerant flow rate. When flow rate of refrigerant is 120Kg/h, the heat transfer quality of 10PPI is 5.714kW while the 8PPI is 5.203kW, and the former is 9.8% higher than the latter. In the flow direction of the refrigerant, the outlet temperature of refrigerant decreases with the raise of air velocity when the inlet temperature is constant. The outlet temperature of the refrigerant decreases with the increase of pore density.

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