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Review on Metal Foam as Supreme Material for Air Cooling Heat Exchangers

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Abstract: Metal foam heat exchangers are a type of compact heat exchanger having large surface-area-to- volume ratio, tortuous flow path, and relatively high thermal conductivity. They are being considered for a wide range of heat transfer applications. Metal foam is a cellular structure consisting of a solid metal with gas-filled pores comprising a large portion of the volume. The pores can be sealed (closed-cell foam) or interconnected (open-cell foam). High porosity metal foams have interesting properties, such as thermal, mechanical, electrical. Such properties make them attractive for various engineering applications. Metals foams with closed pores are already introduced as rigid and strong lightweight materials. The open cell metal foam is suitable for thermal engineering application. The current study reveals various recent advancements in the metal foam in order to enhance heat transfer capacity of heat transfer devices in air conditioning such as condenser. Conventional Heat Exchanger with open-cell foam aluminum has many interesting physical properties, such as low weight high specific surface area combined with relatively high thermal conductivity. The air flow in the metal foams increase turbulence, it enhanced the heat transfer performance of heat exchanger. Different modules of metal foam are designed based on numbers of pores per inch and the effect of the number of pores is analyzed. Also the effect of pore density on heat transfer load and air pressure drop is reviewed. The heat transfer load and air pressure drop increase with the increase of pore density. Higher number of pores and the lower porosity presents the highest friction factor.

Keywords —Air Cooling, Air Conditioning, Heat Exchanger, Heat Transfer enhancement, Metal Foam

I. INTRODUCTION

Metal foams are made up different materials such as aluminum, copper, nickel, or metal alloys. Metal foams have application in different areas like Thermal, Cryogenics, Orthopedics, Automotive, Energy absorption, heat exchangers etc.

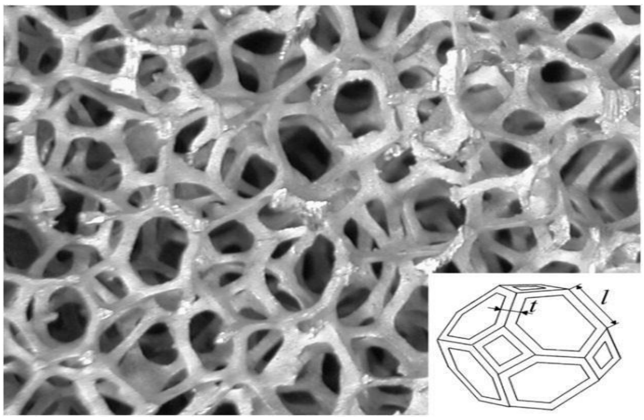

Figure1. Metal Foam

A. *TYPES OF METAL FOAMS:*

1. Open Cell Foam:

Open celled metal foam is also called as metal sponge. It is manufactured by power metallurgy process. Open cell metal foams are use in heat exchanger to increase heat transfer rate. Also they can be used in applications like energy absorption, flow diffusion and lightweight optics.

2. Closed cell Foam:

Closed cell Foam is commonly manufactured by injecting a gas into a molten metal. It is used as impact absorbing material.

B. *CONDENSERS:*

Each type of condenser has its own unique application. Some determining factors include the size and weight of unit, weather conditions, location, availability of electricity and water.

Selection of condenser type depends on following criteria:

- Condenser heat capacity
- Condensing temperature and pressure
- Flow rate of refrigerant and coolant
- Climatic condition
- Operation period

1) Types of condensers:

- **Water-Cooled Condenser:**

Water cooled condenser generally of shell and tube type heat exchanger with refrigerant flow through the shell and water flow through tubes. These condensers are widely used in large heat capacity refrigerating and chilling application.

- **Air-cooled condenser:**

Air cooled condensers find applications in domestic, commercial and industrial refrigeration, air conditioning system with common capacity of 20-120tons. The centrifugal fan air –cooled condenser are used for heat recovery and auxiliary ventilation application. Fan draw air past the refrigerant coil and latent heat of refrigerant is removed as sensible heat by the air stream.

Air-cooling heat exchangers widely use to dehumidify the conditioned air for this it operates below dew point temperature of air. Condensate collects on the surface and is holding on surface by surface tension property. One have to removed it by gravitational or air-flow forces. Overall performance of the air-conditioning system is depends on it. Presence Condensate affects the heat transfer and pressure drop performance of system. Condensate removal is very difficult in metal foam. Heat exchangers having a complex geometry have huge concern of condensate removal.

Henk Huisseune, Sven De Schampheleire, conduct the research on comparison of Metal foam heat exchanger and conventional finned-tubes air-cooled condensers. The result reveals that metal foam condensers with a higher number of pores and a lower porosity presented higher heat transfer coefficients..

Osada *et al.* conducted research on corrugated multi louvered fins (shutter with horizontal slats) under dehumidification. This experiment concluded that fin geometry, wettability, and the characteristics of the airflow, especially at the exit face of the heat exchanger were important factors in condensate drainage. Thermal performance of an evaporator gets influenced by coil inclination.

Elsherbini and Jacobi developed a model for predicting the amount of condensate retained as drops on the air-side of heat exchangers operating under dehumidifying conditions.

Air-side condensate retention has an important effect on the thermal-hydraulic performance of compact heat exchangers.

Hsieh *et al.*carried out an experimental study to characterize the heat transfer behavior of several heat sinks made of aluminum metal foams (height 60 mm) with different porosity (0.87– 0.96) and PPI (10–40). This experiment showed that the heat transfer load and air pressure drop increase with the increase of pore density.

G. B. Ribeiro, J. R. Barbosa Jr.*, A. T. Prata This study consists of an experimental analysis of the thermal-hydraulic performance of micro channel condensers with open-cell metal foams to enhance the air side heat transfer Three different metal foam samples were tested with distinct numbers of pores per inch The heat transfer and the air side pressure drop were observed to increase with the number of PPI and decrease with increasing porosity.

Bhattacharya et al. provided analytical and experimental results for the permeability and the friction coefficient for aluminum foam. They represented the foam by a two-dimensional array of hexagonal cells and proposed models for the inertia coefficient and the friction factor. Experiments covered porosities from 90 to 98% and pore densities of 5, 10, 20, and 40 PPI. K increased with the pore diameter and porosity, while the friction factor depended only on the porosity. They used the Forchheimer equation to describe the pressure drop in the foam, which was fully saturated with air or water.

Boomsma et al. modeled the flow in aluminum foam using a periodic unit of eight cells. The pressure drop predicted by the model was 25% lower than values obtained by experiment. This difference was reduced to 12% after the wall effects were included in the simulation. The wall effects were probably important due to the small size of the foam sample (12 mm by 38 mm by 80 mm long). They found the Reynolds number based on the pore diameter more applicable than the permeability-based Reynolds number for metal foams. The surface area controlled the viscous drag, which was the dominant factor for the pressure drop in the foam.

Kim et al. measured the heat transfer coefficient with air flowing in three aluminum foams with 10, 20, 40 PPI and The height of the specimen was 9.0 mm. The heat transfer coefficient increased with air Reynolds number raised to the power 0.426 and with the PPI.

Viskanta presented an experimental investigation to characterize the volumetric heat transfer coefficient between a heated air stream and ceramic foams (alumina and cordierite), Younis and using a transient single-blow technique. The heat transfer coefficient increased with air velocity.

This paper covers various recent advancements and effects of various parameters such as porosity pressure drop etc. in the metal foam in order to enhance heat transfer capacity of heat transfer devices in refrigeration and air conditioning. The air flow in the metal foams increase turbulence, it enhanced the heat transfer performance of heat exchanger**.** Different modules of metal foam are designed based on numbers of pores per inch and the effect of the number of pores is analyzed. Also the effect of pore density on heat transfer load and air pressure drop is reviewed.

II. PROPRTIES

A. Effect of Pressure drop:

One of the major criteria while designing a heat exchanger is Pressure drop. Power required is directly proportional to pressure drop at any volumetric flow rate. This power requirement should be minimized. To achieve this objective, the heat exchanger design depends majorly on pressure drop criteria. Metal foam heat exchangers have relatively high pressure drop per unit length because of very high surface-area-to-volume ratio.

The pressure drop phenomenon can be explained with the help of different conditions as given below:

The open cell metal foam condensers were designed as part of small-scale refrigeration system. Three different samples of metal foam were tested with distinct numbers of pores per inch (10 and 20) and porosity (89.30 and 94.70%).

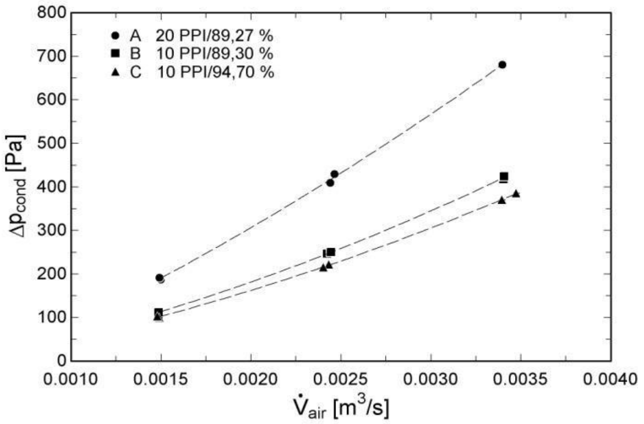

Figure 2. Pressure drop versus air flow rate

From above graph we could say that, the pressure drop increases with the increasing air flow rate. By comparing condenser A and B, it can be seen that increasing the number of pores increases the pressure drop. Decreasing the porosity increases the pressure drop.

B. *Effect of porosity:*

The number of pores is defined as the quantity of pores experience in an inch of structure, whereas the porosity can be defined as the volume fraction occupied by the fluid.

Porosity is most important characteristic of metal foams.

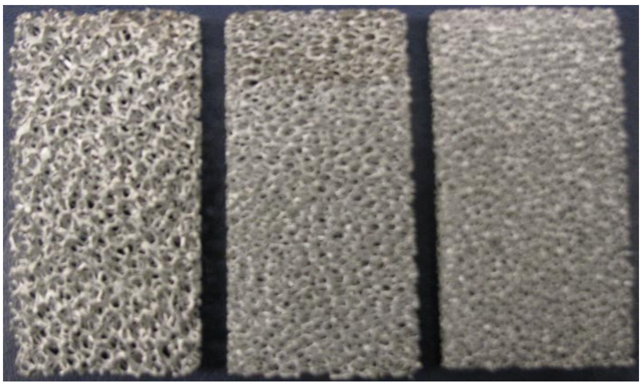

Figure.3 Metal foam samples with different porosities (10, 20 and 40PPI)

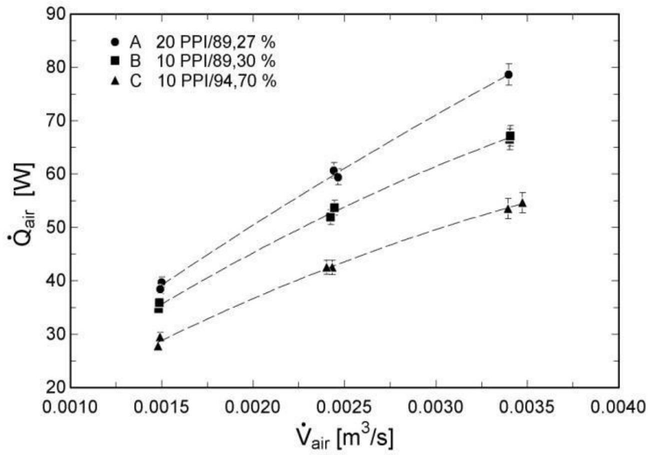

Figure.4 Heat transfer versus air flow rate

From the above graph we could say that, condenser 'A' gives higher heat transfer rates than condenser B. Therefore we can conclude that, higher number of pores resulted in higher heat transfer rates. Higher heat transfer rates achieve by lower porosity.

C. *Effect of Base metal:*

Copper have larger thermal conductivity than aluminum. If the base metal used to manufacture metal foam has larger thermal conductivity, then resulting heat transfer rate will be larger.

D. *Effect of geometry:*

Thermal performance of heat exchanger is greatly affected by geometry. Frontal area, flow depth, and fin arrangement are important parameters of geometry.

Pressure drop of system can be considerably reduced by proper design.

III. CONCLUSION

- Higher number of pores and the lower porosity presents the highest friction factor
- Pressure drop increases with the increasing air flow rate.
- The heat transfer load and air pressure drop increase with the increase of pore density
- Higher number of pores resulted in higher heat transfer rates
- Increasing the number of PPI and decreasing the porosity resulted in a higher air-side pressure drop and in a higher overall thermal conductance
- The foamed heat exchanger's show up to 6 times higher heat transfer rate than the bare tube bundle at the same fan power.

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