

A Study on the Heat Transfer Characteristic of FeCrAl Metallic Foam

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ABSTRACT: To enhancement heat transfer performance, the metallic foam as heat exchanger was studied rapidly. This was attributed to its high surface area to volume ratio as well as intensive flow mixing by tortuous flow passages. So the experimental study about the heat transfer characteristic of 10 ppi metallic foam is presented in this paper. Additionally, pressure drop inside the metallic foam was measured and also it was compared with the simulation results. The material in this experiment was used as FeCrAl which has density of 10 ppi and the results show the heat transfer is rise with permeability Reynolds number increase. The results show that the pressure drop metallic foam of 10 ppi was increased with the air velocity increase.

Keywords: Metallic Foam, Porous Medium, Heat Transfer, Pressure Drop, Nusselt Number

NOMENCLATURE

ε porosity [%]
 μ coefficient of viscosity [N•s/m²]
 ρ density [kg/m³]
 ΔP Pressure drop [Pa]
 L Length of foam sample in flow direction [m]
 K Permeability [m²]
 U Velocity of air [m/s]
 Re_K Pore Reynolds number
 d_p pore diameter
 θ Nondimensional temperature

X, Y Nondimensional length of x or y Direction

H Height of foam sample [m]
 T_∞ Ambient temperature [°C]
 T_w Wall temperature [°C]
 T_f Fluid temperature [°C]
 q Heat flux [W/m²]
 $k_{s,eff}$ Effective thermal conductivity of the metallic foam
 $k_{f,eff}$ Effective thermal conductivity of the air
 h_w Coefficient of heat transfer
 Nu Nuselt number

1. INTRODUCTION

As a new material, metal foams are attracting increasing attention for a variety of applications. The advantages of porous medium lie on their low density, large surface area in a limited volume and high strength structure. Due to high manufacturing costs porous medium have until recently, mainly been used in the aerospace, ship building and defence industries. Heat transfer of a porous medium subject to oscillating flow has been investigated widely for a channel filled with spherical particles, granular beds or wire-screens[1]. Some research efforts have been made to obtain fundamental understanding of oscillating flow characteristics in a channel filled with particles or wire-screens[2] studied the oscillating flow characteristics of a Stirling engine regenerator made of wire-screens or sponge metals. They found that the prediction of pressure drop loss was possible by use of the hydraulic diameter as the representative length defined by the friction factor and Reynolds number[3] experimentally investigated oscillatory pressure drop characteristics in a packed column composed of three different sizes of woven screen and subjected to a periodically reversing flow of air. They showed that the oscillatory pressure drop factor increases with the kinetic Reynolds number and the fluid displacement and a correlation equation for the friction factor was obtained[4] studied the oscillating pressure drops and phase shift characteristics for regenerators filled with wire-screens under high frequency oscillation. They obtained values for the cycle-averaged pressure drop in the oscillating flow across the regenerator which are two to three times higher than that of a steady flow at the same Reynolds numbers based on the cross-sectional mean velocity.[5] Fourie et al(2002) studied pressure drop modelling in cellular metallic foams and they defined the model clearly the metallic foams for numerical analysis.

And also they found that the experimental results for flow through isotropic, highly porous, cellular metallic foam clearly show that the morphological model and the representative hydraulic diameter concept introduced to complement the representative unit cell concept are capable of accurately predicting the pressure gradients in both Darcy and Forchheimer flows.[6] Boomsma et al[7] presented a new approach for modelling the flow through an intricately structured porous medium.

This study was carried out experimental analysis about the temperature profile of metallic foam as heat exchanger and also numerical analysis about the pressure drop was carried out using FLUENT which commercial software. Finally, the results were compared with experiment results.

2. EXPERIMENT

2.1 Experiment device

Fig. 1 shows schematic diagram of the experiment device. Experiments were performed using metallic foam of 10 PPI. The fan was used to variable the velocity using controller. So the velocity can be control 0.4 m/s to 2.4 m/s. Pressure drop between inlet and outlet of foam was measured using micro manometer.

Heating plate was installed at the bottom of the metallic foam and it was connected to slidac which can variable voltage to keep the constant heat flux. Consequently the heat flux was calculated by dividing the power by the surface area of the heater. The heat flux was 761 W/m^2 for each experiment.

Internal temperature measurements were performed inside the sample using T-type thermocouples. A total of thirty thermocouples were used at different points inside the sample as shown Fig. 1. And the thermocouples were attached to the channels of an automatic data acquisition system, which was connected to a computer, where the temperature readings were recorded every 2 second.

The outside of the chamber on the test section was keep adiabatic condition using insulating material.

The characteristics of the material which was used in this experiment are as follow table 1.

Table 1 Metallic foam properties and experimental parameters

Material	ppi	ε	ρ (g/cm ³)	$k_{s,eff}$ (W/mK)
FeCrAl	10	0.88	7.1	2.54

In the table 1, the ε mean porosity which can be calculates as follow:

$$\varepsilon = \frac{\text{weight of the metallic foam}}{\text{weight of pure material}} \quad (1)$$

2.2 Pressure drop numerical approaches

A wide variety of analytical and numerical models for porous media analysis have appeared in the literature. The first of such models is the Darcy law, which was

the first mathematical model of the pressure drop of a porous medium of a length (L) and a permeability (K) to the flow velocity (U) in a porous medium based on experimental observations.[7]

$$\frac{\Delta P}{L} = \frac{\mu}{K} U \quad (2)$$

Dupuit's law(1863) includes a quadratic term, which important in the higher flow velocity range

$$\frac{\Delta P}{L} = \frac{\mu}{K} U + \frac{\rho c_F}{\sqrt{K}} U^2 \quad (3)$$

These two models is dependent on the Reynolds number of the flow as shown by Kaviany[8], Boomsma and Poulikakos[9-10]. In porous media, two methods of calculating the Re of a flow was defined by Boomsma and Poulikakos as shown below:

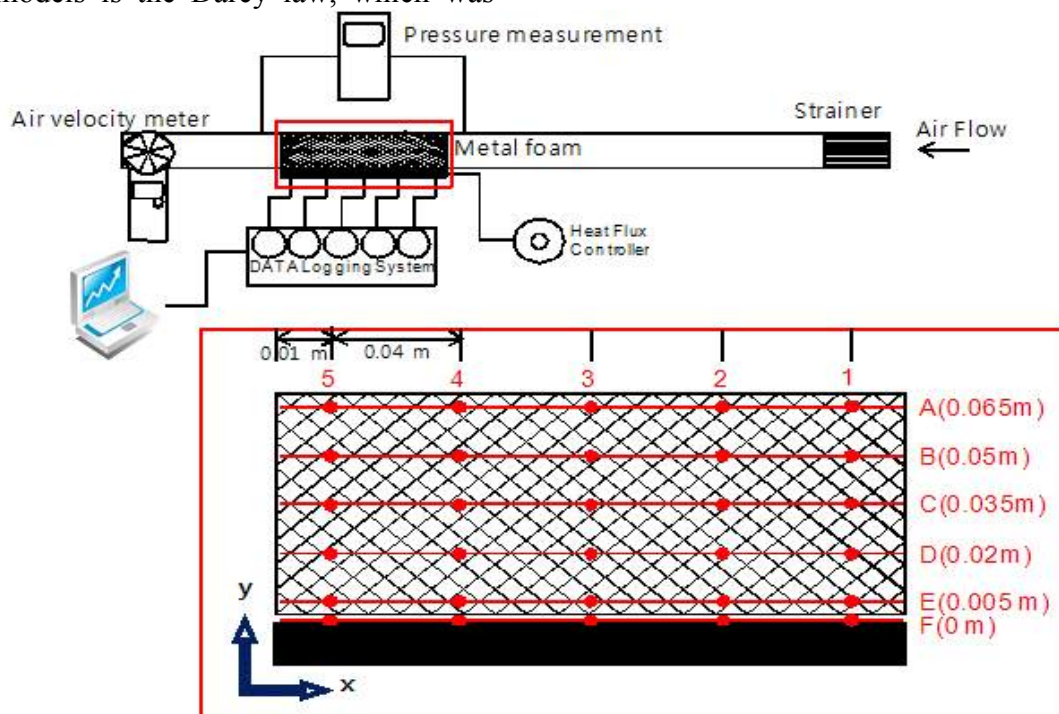


Fig. 1 Schematic diagram of experiment device

$$Re_K = \frac{\rho U K^{1/2}}{\mu} \quad (4)$$

$$Re_K = \frac{\rho U d_p}{\mu} \quad (5)$$

In equation (5), the square root of the permeability was replaced by pore diameter.

It was specified that this method is better than first one to know the characterizing the flow in the metallic foam by Boomsma and Poulikakos[9-10].

The simulation about the pressure drop was performed using commercial software FLUENT.

3. RESULTS AND DISCUSSION

3.1 Pressure drop

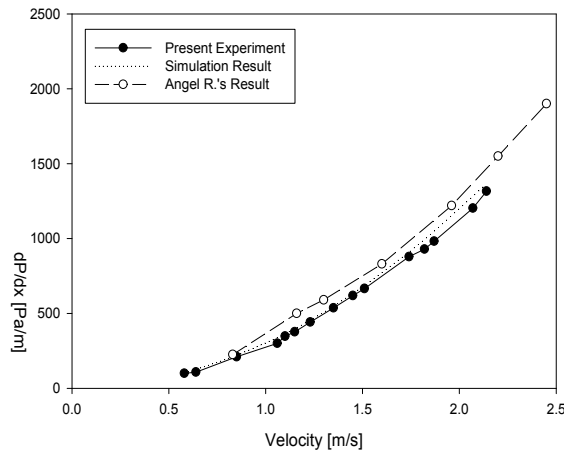


Fig. 2 Comparison between numerical analysis and experiment about pressure drop with velocity

The experiment about pressure drop was performed within the range of velocity 0.6 to 2.2 m/s and the pressure drop was measured between inlet of material and outlet.

Fig. 2 shows the results of comparison between simulation result and experiment about pressure drop and Angel R.'s experimental result. The results show that the pressure drop is increase with velocity as

polymer. The average error range between experiment result and numerical analysis indicated within 5.5 %. Approximately, pressure drop distribution show the simulation result is higher than experimental result.

3.2 Temperature profile

The temperature measured in this experiment can be assumed that air temperature flow inside the metallic foam.

To calibrate the error that occurring experiment process along outside condition change, non-dimensional temperature distribution was calculated as below:

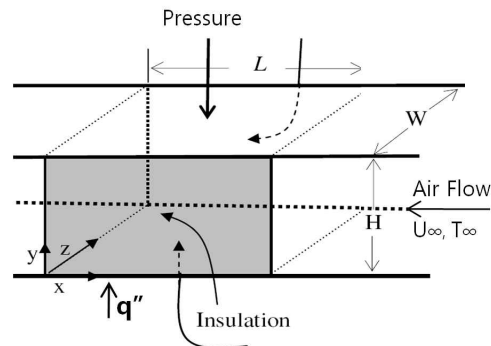


Fig. 3 Schematic of metallic foam in the test section

$$\Theta(X, Y) = \frac{T - T_{\infty}}{q'' H / k_{s,eff}} \quad (6)$$

$$X = x/L, Y = y/H \quad (7)$$

Fig. 4-6 show the experimental temperature profile in direction of the flow with Reynolds number of 76.7, 188.0 and 249.5 respectively. The experimental data is given for the none-dimensional axial distances 0.05, 0.26, 0.47, 0.68 and 0.89 which correspond to the physical distances 1, 5, 9, 13 and 17 cm from the inlet of the each foam sample. From these figures, temperature distributions decrease with y length increase. The temperature of all the Y position in material drops down to the

ambient temperature at an axial distance of about 0.85.

And also the temperature difference between air inlet and outlet is decrease with Reynolds number as shown Fig. 7

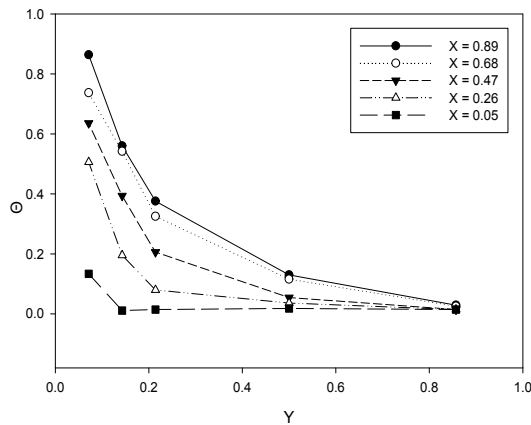


Fig. 4 Temperature distributions in the direction of the flow at Re = 76.7

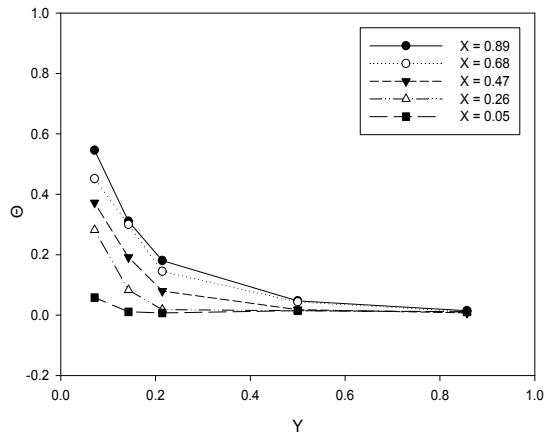


Fig. 5 Temperature distributions in the direction of the flow at Re = 188.0

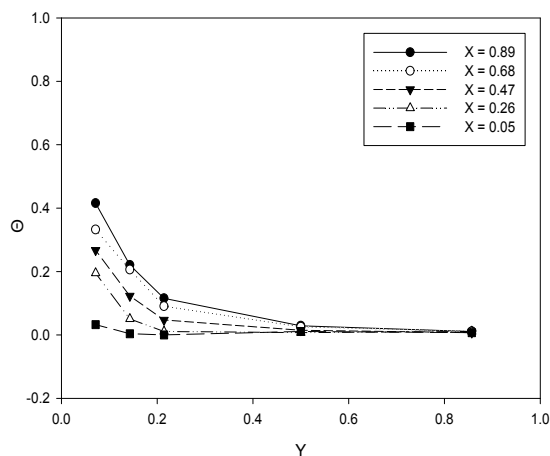


Fig. 6 Temperature distributions in the direction of the flow at Re = 249.5

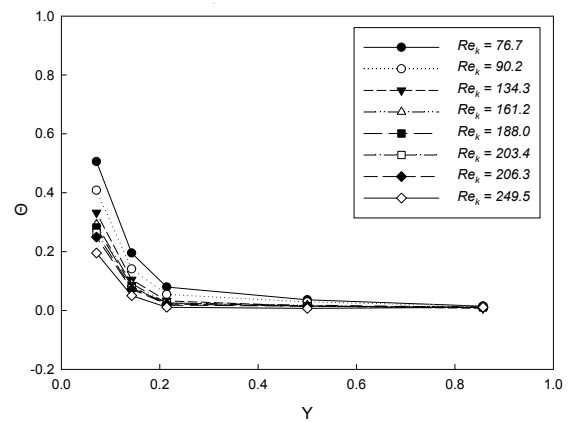


Fig. 7 Experimental temperature profiles at x=0.05 m for different Reynolds numbers

Nuselt number which define heat transfer characteristic defined as below:

$$Nu = \frac{h_w H}{k_{f,eff}} \quad (8)$$

$$h_w = \frac{q_w}{T_w - < T_f >} \quad (9)$$

Fig. 8 shows the Nuselt number with different pore Reynolds numbers. The results show overall heat transfer increase with Reynolds number increases. Because high Reynolds number leads to a higher local heat transfer coefficient, and in turn this enhances the heat transfer between the solid and fluid.

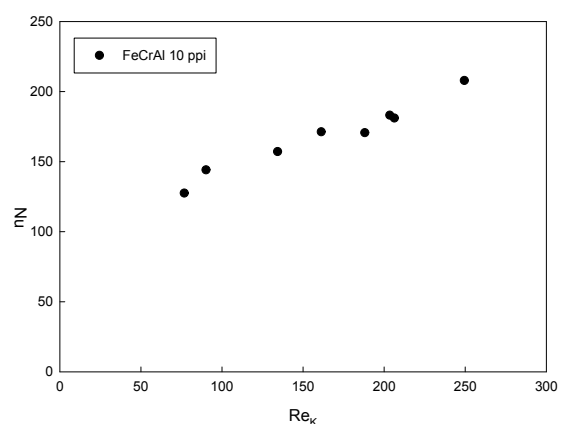


Fig. 8 Variation of Nusselt number with Reynolds

4. CONCLUSION

The pressure drop and heat transfer characteristic of FeCrAl metallic foam of 10 ppi was performed experimental study. The results show that pressure drop is increase with velocity and from comparison with the simulation results, average error range indicated within 5.5 %. From this results, it could confirm that the pressure drop depend on the permeability. The heat transfer characteristics show that Nuselt number is increase along pore Reynolds number increasing.

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