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FLOW VISUALIZATION AND PRESSURE DROP STUDY OF OPEN CELL METAL FOAM USING UNIT CELL MODELING

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ABSTRACT

Open cell metal foams are the revolutionary materials that exhibit different attractive characteristics when compared to their solid material counterparts. Currently these foams are used in the heat transfer and cooling application in various engineering field. Main disadvantage of the flow through the metal foam is huge pressure drop. Highly complicated structure of this metal foam limits the modeling and flow visualization of the entire flow domain through the foam. Various researches have clearly shown that no correlation can be used for predicting the flow through the open cell metal foam satisfactorily. Heat transfer through the metal foam will not be satisfactory with the actual experimental test results due to the complicated heat transfer area. Here the flow of water through the open cell aluminum foam is visualized and the pressure drop is calculated with the help of sphere-centered tetra kaidecahedron geometry.

KEYWORDS: Open cell metal foam, Flow visualization, CFD analysis of open cell metal foam, Pressure drop in open cell metal foam.

1. INTRODUCTION

Open cell metal foam is widely used in the heat transfer application in the expense pressure, this study is mainly focus on the flow patterns in the metal foam and pressure drop in the flow. Pressure drop limits the application of open cell metal foam in the flow passages through the cooling channel and heat exchangers. Various studies has be carried out in this field experimentally and numerically. Koh and Colony [1] in the year 1974 investigated the enhancement of heat transfer for forced-convection in a channel filled with a high thermal conductivity porous medium. In their theoretical study, Koh and Colony found that for a fixed wall temperature case, the heat transfer rate increased by a factor of three. For a constant heat flux case, the wall temperature and the temperature difference between the wall and the coolant can be drastically reduced. Koh and Stevens [2] experimentally validated the results analytically obtained by koh and Colony [1]. Chung et al. [6] studied about heat transfer augmentation using metal foam by keeping pressure drop as constant. CFD analysis was done using air as fluid and SST K-was viscous model. Results using CFD under predicts experimental results mainly because of the rough edges in metal foam that are not included in CFD model, and some pores are totally sealed in actual foam which contributes to higher pressure drop. Krishnan et al. [5] found the effective thermal conductivity, Nusselt number and friction factor with very small Reynolds number using direct simulation of open cell foam. Bai and Chung [9] Studied analytically the heat transfer enhancement in a diamond shaped unit cell with vertical and horizontal interconnecting micro-cylinders to form the network for a channel filled with metal foam. CFD model of metal foam with tetrakaidecahedron shape is also modeled. Unit cell is used to study the pressure drop in a foam sample. Results showed that tetrakidecahedron structure is capable of capturing pressure. Abhay et al. [10] studied the effect of increasing the number of cell in CFD model, as single model cannot predict the heat transfer and pressure drop properly. A numerical model with 6 cells was modeled in ANSYS and realizable k-e model was used for turbulence model. Hafeez and Chandra [12] studied the effect of different bonding materials, for bonding metal foam on structure, on the heat transfer. Nickel foam of 10 and 40 PPI were used. Plasma spraying, simple brazing and bonding adhesives were studied, out of which plasma spraying gave better results. It was also found that EDM cutting gave better surface which decreased the thermal

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contact resistance. Yuan et al. [4] made use of an experimental system to investigate the heat transfer enhancement and pressure drop in an annular channel filled with foams. Heat transfer enhancement was found of the order of twenty times over the open channel for the same Darcy velocity. The pressure drop per unit channel length of the foam-filled channelis at least two orders of magnitude larger than the open channel case. Dukhan and Patel [8] in their paper studied the effect of length (or thickness) of the porous medium in the flow direction. The paper establishes a minimum length necessary for the foam to have length-independent (or bulk) permeability and form drag coefficient. Boomsma et al. [3] made use of an experimental system to investigate the effect of compression on foam coefficient and permeability. The study found that the post compression porosity governs the permeability and the resulting pressure drop.

In this study the flow is visualized through the model of unit cells in the case of 10 PPI aluminum metal foam inserted in the channel of water flow.

Open cell metal foam

Open-cell metal foam is considered to be a promising alternative for compact heat exchanger applications, owing to its high heat transfer surface area density, superior thermo hydraulic characteristics, and other favorable mechanical properties [7]. SEM photograph of the nickel foam is shown in fig 1, from that picture it clear that the flow is highly obstructed by the ligaments of the metal foam. Some pores are shown in the magnified view of the metal foam in this picture. These foams are specified in the terms of PPI (pores per inch), it is the number of pores in the linear dimensions. Porosity is another factor which depends the flow properties while the flow is taken place through the metal foam.

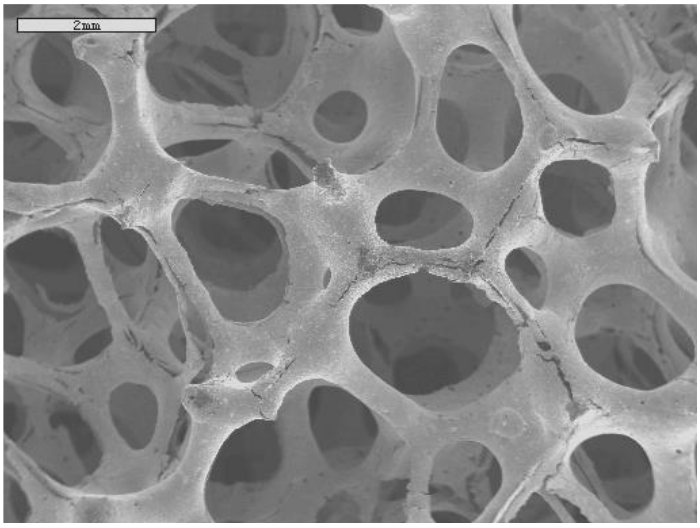

Fig 1. A SEM photograph of the nickel foam [4]

Porosity is the ratio of material volume of the foam to the volume of the solid material. Generally aluminum, copper, nickel etc. are material used for making the open cell metal foam for the use of heat transfer applications.

These type of structures are manufactured by evolving the gas through the molten metal.

2. CFD SIMULATION OF FLOW THROUGH THE FOAM FILLED CHANNEL

CFD simulation of flow through the metal foam filled channel cannot be simulated completely for the entire fluid domain because the elements required to simulate the model will be very huge and it is impossible to compute that much of elements by using currently available machines. So the geometry is generated for the part of the foam using sphere-centered tetrakaidecahedron geometry and flow patterns and stream lines are analyzed to understand the flow behavior of the fluid within the open cell foam structure. Entire simulation is carried out in the Ansys Fluent 19.2.

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Geometric modelling

Unit cell approach is used in this study to visualize the flow through the metal foam, the geometry chosen should be space filling and should have minimum surface energy. This is required because of the nature of the foaming process. The body-centered-cubic BCC structure (similar to Kelvin's tetrakaidecahedron unit cell) has been shown to have minimum surface-area to volume ratio compared to all other space filling structures [5]. Nihad Dukhan et al introduced a geometry of tetrakaidecahedron with the correlation for the diameter of cell [8]. By using that correlation geometry of the single cell is generated and made a bundle of 36 cell to get the actual structure in the channel of fluid flow. Generation of unit cell is shown in fig 2.

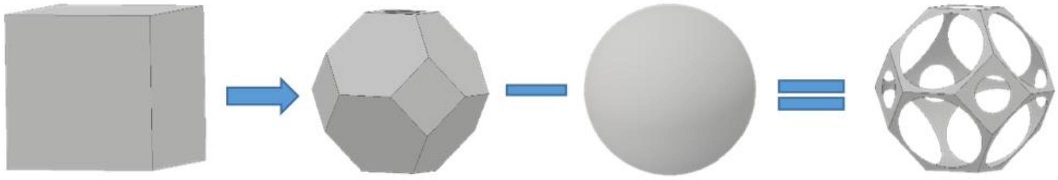

Fig 2. Generation of tetrakidecahedron model for unit cell of metal foam

This unit cells used to represent the foam in a channel to a length of 3 cells. Because the more cells makes the so many elements in the meshing and cause very slow computing process during the simulation and required very higher specification for the computing machine. Fig 3 shows the finally made geometry of foam as a results of the combination of unit cells.

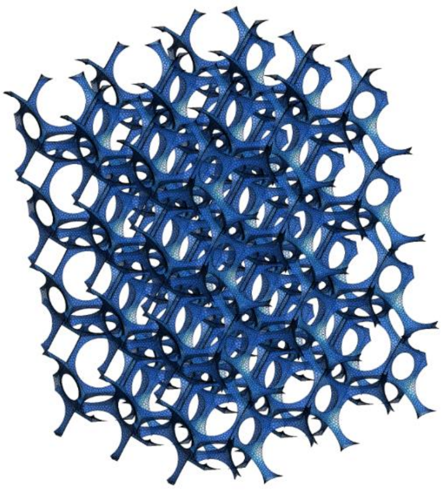

Fig 3. 3Dview of foam geometry (meshed)

Meshing and boundary conditions

Number of elements and meshing plays a major role in the CFD analysis. In this case very fine mesh is required to capture all the minute curvature of the wired structure of the metal foam. Due to the large number of the elements the computation time increases and required a higher specification for the computing machine. Here the number of nodes are 6340650 and the number of elements are 1178046.

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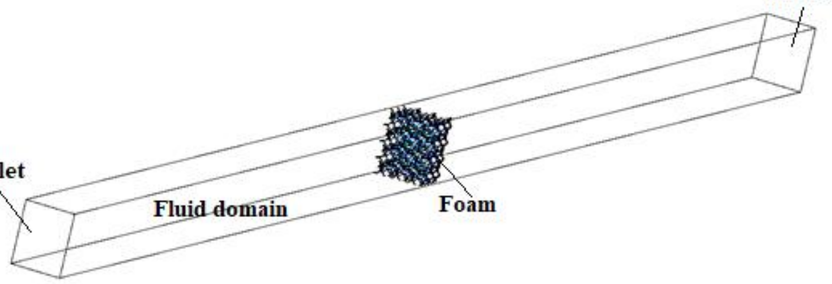

Fig 3. Fluid domain for the CFD analysis of metal foam

Foam body is subtracted to generate the fluid domain for the CFD analysis through the foam. Here inlet is given as velocity inlet, outlet is given as pressure outlet, and all other walls are given as adiabatic walls. Velocity at the inlet is given in the rage for different cases its magnitude is varying corresponding to the change of Reynolds number form the 3000 to 12000. In the pressure outlet ambient pressure assigned. Flowing fluid through the metal foam, thus the fluid domain is specified as the water.

3. RESULTS AND DISCUSSION

Mainly this study is aimed to compute the pressure drop through the metal foam and to visualize the flow of the fluid through the metal foam. In the case of the porous media approach for the metal foam simulation only the bulk flow parameters are visualized but in the case of the unit cell approach even flow through the ligaments gaps can be visualized. Table1 shows the pressure drop of the water when it flowing through the metal foam is tabulated.

Table1. Pressure drop of water flowing through metal foam

Re	DP (mbar) With foam	DP (mbar) Without foam
3000	2.54	0.07666
6000	8.5253	0.2378
12000	25.42	0.7802

Porosity of the geometry is observed to be 98.20 % by calculating the volume of the foam geometry. Pressure drop occurred in the foam is increasing exponentially as the Reynolds number increasing. Pressure drop observed is to be around 3 times when the Reynolds number is doubled.

Contours and flow visualization of flow through the foam

Flow through the foam can be visualized by stream line and vector through the cells of the foam, it gives an ideas that how this flow is varying with in the foam location.

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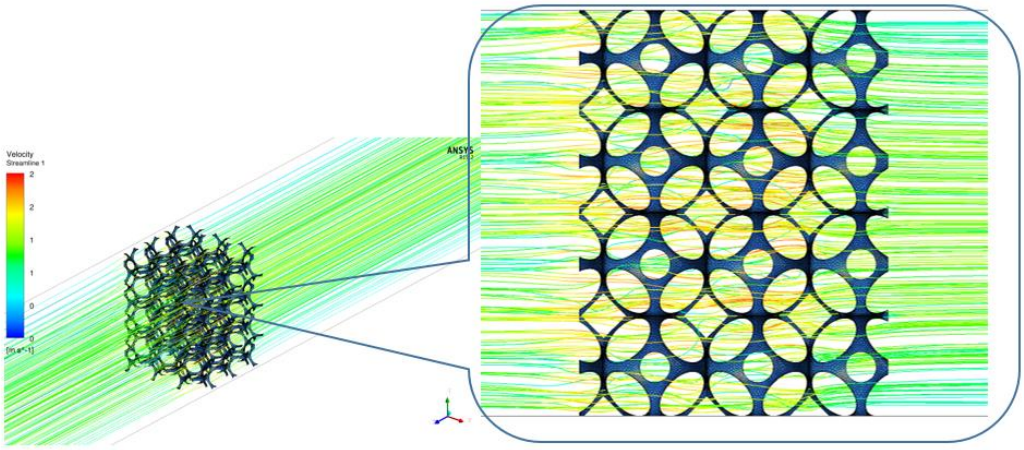

Fig 4. Stream line through the metal foam

Stream line through the metal foam is shown in the fig 4 .it shows the turbulence created among the ligaments of foam cell structure. This turbulence makes the convective heat transfer in improvements while using the metal foam in the heat transfer or cooling application.

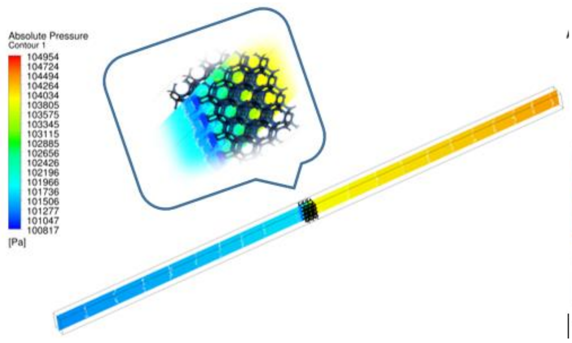

Fig 5. Contour of pressure of flow through foam

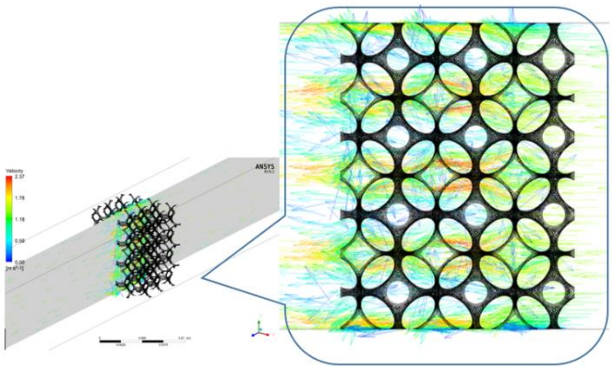

Fig6. Velocity vector of flow through the foam

Contour of velocity vector also shows the turbulence created in the cells of the foam structure which aids the proper mixing of fluid at different temperature and enhance the heat transfer capability of the metal foam. Due to the huge obstruction offered by the number of ligaments in the flow path make the larger pressure drop, as the Reynolds number increasing the pressure drop also increasing.

4. CONCLUSION

CFD analysis of the water flow through the open cell metal foam is conducted. It is observed that the pressure drop has an exponential variation as the Reynolds number of the flow through the foam changes. This variation of pressure drop follows similar trend with the experimental results in literatures [4].Higher heat transfer and pressure drop is generated in the flow through the open cell metal foam is due to the enormous mixing of the fluid within the wired structure of foam. From this it can be infer that porosity and number of pores per inch plays a major role in the heat transfer and fluid flow characteristic in the application of open cell metal foam. Due to the sliced geometry used in this study, it could generate more similar effect to the cut section of actual metal foam.

5. ACKNOWLEDGEMENTS

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