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Development of Metal Foam Characteristics Based on Simulation Method

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Abstract

Gas-filled fluid-filled pores make up metal foam. Open-cell and closed-cell metal foam exist. Porosity is the ratio of metal foam pores to volume. Metal foam's thermal, sound, impact energy, acoustic, and weight characteristics depend on its flow rate and porosity. Thus, metal foam arrangement and substance must be studied. ANSYS Fluent simulation is used to study how foam layout and material affect flow rate and heat transfer. Project development includes modeling, meshing, solution, and analysis. Three arrangements which are uniform, closely pack and mixing are used in analysis the flowrate of the metal foam. Three materials for metal foam which are Alumina, Zirconia and Steel are matching with the arrangement to perform rate of heat transfer analysis. The velocity of the inlet is set as 0.001 m/s while the temperature for the case and fluid are set as 50°C and 30°C, respectively. Based on the result and analysis, that the design of closely pack arrangement have the highest viscosity which is 3.9897227×10^{-4} kg/s, then followed by uniform arrangement and the last is mixing arrangement. While for the rate of heat transfer, the highest value is closely pack alumina which is -6.9879 J/s and the lowest is uniform zirconia which is -2.1718 J/s. As the conclusion, the closely pack alumina is the most desire selection which have the highest viscosity and rate of heat transfer which can apply in decrease its flowrate and fasten the heat dissipation.

1. Introduction

Gas-filled fluid-filled pores make up metal foam. Open-cell and closed-cell metal foam exist. Porosity is the ratio of metal foam pores to volume. Porosity makes metal foam light and dense. Although alumina is the most frequent, zinc, copper, steel, and nickel can be foamed. Metal foam may be created in several ways. This includes powder, melt, sputtering, and deposition foams [1]. The flow rate and heat transmission of metal foam affect its heat, sound, impact energy, acoustic, and weight performance. The simulation methodology may be utilized to study metal foam's flow rate and porosity as most heat transfer and flow rate research was done using experimental and mathematical methods [2]. Metal foam is a well-known substance that finds widespread application across a variety of industries, including commercial, construction, and industrial. Metal foam has several applications, including absorbing impact energy, providing thermal insulation, serving an acoustic purpose, and being lightweight. The global sales of metal foam were around 82 million USD in 2016, and the demand is expected to continue expanding due to the widespread acceptance of the product in a variety of industries [3].

Sound is best absorbed by metal foam, which is the best material overall. It sees regular application in the building, car, and aerospace industries, among others. As a passive noise control package, metallic foam, which comprises of a metal frame with a linked pore network, is utilized to lessen the effect of vibration and sound. The sound wave will reflect and absorb as it travels through the metal foam until it reaches its destination [4]. Due to the metal foam's higher strength, it is more suited for use as a crash absorber for automobiles than plastic foam. Aluminium is by far the most common and widely used material among the several types of metal that are appropriate for use as a crash absorber. This is since aluminium is a lightweight material that also offers some residual slope in the stress strain curve. Therefore, the metal foam will have a greater capacity for energy absorption [5]. In the orthopaedic application that makes use of metal foam, porous coating and metal provide the initial degree of rigidity for the bone. For the implant, a press-fitting approach is being taken as the method of choice due to resistance to corrosion and their degree of strength are quite high in these materials [6].

Steel is made by mixing iron with carbon and, in certain instances, just trace amounts of other components. It is a material that has the potential to be utilized in the manufacturing of metal foam. Some types of steel, such as stainless steel, can withstand corrosion better than others. Steel is a material that has a low influence on the ecosystem that it is in due to the ease with which it can be recycled. Steel may have its mechanical properties improved with the application of heat treatment [7]. Al_2O_3 is the scientific notation for alumina, and the word aluminium oxide is the chemical name for this compound. Crystals of aluminium oxide almost always take on a hexagonal form and are extremely minute in size. The grain sizes of the alumina that may be found in abrasives typically range anywhere from 100 to 600 mesh, however this does not always hold true. Large grains of silicon carbide normally consist of a single crystal, but grains of larger sizes comprise multiple crystals of a smaller size [8]. Zirconia has a monoclinic crystal structure and looks colourless when it is at a temperature where it is normal. Zirconia is distinguishable from other materials by possessing exceptionally high tensile strength, in addition to high degrees of hardness and resistance to corrosion. Complete sintering will result in higher total manufacturing costs due to its lengthier production time compared to partial sintering [9].

The study of systems involving fluid flow and heat transfer using computer-based simulation is known as computational fluid dynamics (CFD). The method is extremely effective and has both industrial and non-industrial applications. CFD is now frequently used by automakers to forecast drag forces, under-bonnet airflows, and the interior climate. CFD is increasingly playing a key role in the design of industrial processes and products. The amount of data points and tested configurations directly relates to the variable cost of an experiment in terms of facility hire and/or manpower expenses. Contrarily, CFD programmed may provide extraordinarily high quantities of results for practically no additional cost, and parametric studies can be easily performed at a very low cost, for example to optimize equipment performance [10].

Mass flow rate (m) is the amount of mass that moves across a cross section per unit of time. A symbol's dot indicates changing rate. Fluids enter or leave control volumes using pipes or ducts. The fluid density, V_n, and differential mass flow rate of fluid traveling through the element of small area dA_c in the cross-section of a pipe are proportionate.

$$\delta\dot{m} = \rho v_n dA_c \tag{1}$$

Both and signify differential quantities but are used for route functions with inexact differentials like heat, work and mass transfer, while d is used for point functions with exact differentials like characteristics [11].

Control volumes like water heaters and car radiators entail mass flow into and out of systems. Most control volume evaluations occur in steady operating situations. Stable means no change over time. Unsteady means transient. Uniform also indicates a surface or region has no position variation over time. Definitions match ordinary use. Control volumes have constant energy during steady-flow operation. Thus, the control volume's energy remains constant during the operation. A steady-flow system with one inlet and exit must match mass flow into and out of the control volume. In other words, $m_{in}=m_{out}=\dot{m}$. The energy balance for such a steady-flow system reduces to: where the variations in kinetic and potential energies are small, which is typically the case, and there is no work interaction [12].

$$\dot{Q} = \dot{m}\Delta h = \dot{m} c_p \Delta T \tag{2}$$

In this study, the different types of foam arrangements are explored in terms of heat transfer and flow rate. The characterization of different types of foam material in terms of flow rate and rate of heat transfer. Foam arrangement limited to three types of arrangement that are uniform arrangement, closely packed arrangement, and mixing arrangement. Besides, material foam consists of Steel foam, Alumina foam, and Zirconia foam. The simulation is done through ANSYS software. This study demonstrates how the simulation approach can analyses metal foam flow and heat transfer. This research helps determine how to utilize simulation to replace traditional approaches which are more cost effective and time efficient.

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2. Materials and Method

In this study, the drawing and dimension for the sample are using Ansys Workbench. The boundary condition and meshing are model based on the foam arrangement. In solution, the parameter is inserted for different conditions and then the calculation and simulation process began. In the simulation, the k-omega and k-epsilon model are used in simulation of flowrate and rate of heat transfer respectively.

2.1 Configuration and Dimension of the Metal foam

The foam arrangement is designed with the ducting case. Three types of metal foam arrangement are designed which the uniform arrangement, the hollow sphere with radius of 5mm and inner radius of 4.8 mm are tightly packed and packing in regular pattern. For the densely packed arrangement of metal foam, the spheres need to be arranged as closely together as is humanly feasible. It is composed of two different diameters of a hollow sphere and is used for the mixing arrangement of metal foam. Fig. 1 represent three designs of metal foam arrangement and the Table 1 shows the dimension of the hollow sphere and the case.

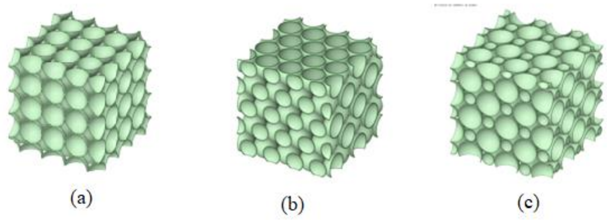


Fig. 1 *The metal foam arrangement of (a)Uniform (b) Closely packed (c) Mixing*

Table 1 *Dimension of the hollow sphere and the case*

No.	Characteristic	Size
1.	The radius of the bigger hollow sphere	5 mm
2.	The radius of the smaller hollow sphere	2.5 mm
3.	The thickness of the bigger hollow sphere	0.2 mm
4.	The thickness of the smaller hollow sphere	0.1mm
5.	The length, width and height of the case	60mm×20mm×20mm
6.	The thickness of the case	2mm

2.2 Meshing

Mesh is an important element for calculation. To ensure the quality is good for simulation, the mesh quality is added and the skewness is set to 0.90. The fluid region is extracted for further analysis. The inlet is set as the velocity inlet and the outlet is set as the pressure outlet. The detail setting is shown in Table 2.

Table 2 *Parameter in meshing setting*

Parameter			
Add local sizing	No	Will you cap opening and extract fluid region?	Yes
Use Custom Size Field Control?	No	Do you need to share Topology	No
Minimum Size (m)	5.8594e-5	Estimated number of fluid region	1
Maximum Size (m)	0.0015	Add boundary layer	No
Growth Rate	1.2	Generate volume mesh	
Size Function	Curvature	Fill with	Polyhedra
Curvature Normal Angle (deg)	18	Growth rate	1.2
Improve meshing quality	0.9	Max cell length	0.00194803
Geometry type	only solid region	Change all fluid-fluid boundary types from wall to internal?	Yes

2.3 Solution

In solution, the parameter setting for the model is done by assigning the velocity inlet to let the water flow from the inlet and exit at outlet boundary. For the rate of heat transfer, alumina, zirconia and steel for different foam arrangement is assigned respectively and the thermal for wall and fluid region is set by following the parameter. The iteration is also done in setting to ensure the simulation can be converged. All the related data are shown in Table 3.

Table 3 *Parameter of Solution*

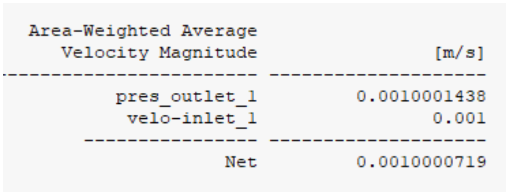
Parameter name	Parameter
Velocity inlet	0.001m/s
Thermal of wall	303K
Thermal of fluid	323K
Number of iterations	100

3. Results and Discussion

The result of the simulation was divided into two parts. The first part is about the flow rate and second part is about the heat transfer rate.

3.1 Simulation Result of Three Different Arrangement Model in Velocity

At a speed of 0.001 meters per second, the watery liquid moves through the pipe that contains the metal foam. The model was defined using the SST k- ω =double equation model in order to produce the desired results of calculating the water velocity and pressure. When using the surface integral, the pressure of the water liquid can determine that was exactly 0.344 Pa. The surface integral method, in conjunction with the area weighted average of the report type, may be used to calculate the ultimate velocity of the model as it exits the outlet. Fig. 2 and Fig. 3 show the example final velocity and velocity contour of the mixing foam arrangement.



Area-Weighted Average Velocity Magnitude	[m/s]
pres_outlet_1	0.0010001438
velo-inlet_1	0.001
Net	0.0010000719

Fig. 2 *Final velocity of mixing foam arrangement*

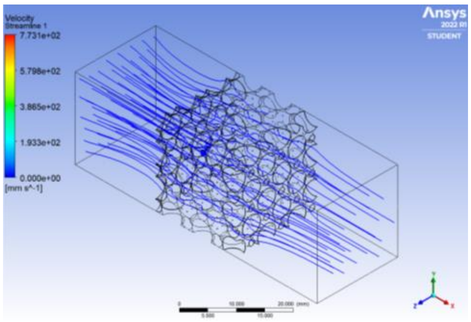


Fig. 3 *Velocity contour of mixing foam arrangement*

3.2 Flowrate for Different Arrangement

Before adding the validation data, it is necessary to accomplish the streamline inside the pipe and ensure that it does not pass through the model. This is done to ensure that an accurate simulation of the flow of water is created. Fig. 4 presents the streamline representation of the uniform foam arrangement. The air flowed to the inner surface of the hollow sphere that faced outside, where it was then reflected back and allowed to flow into the structure's empty area. It is possible to conclude from this that the model was successfully created and is meshing.

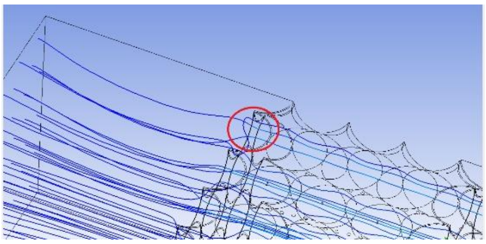


Fig. 4 *Streamline in the uniform foam arrangement*

Table 4 shows the average outflow velocity of various foam arrangements. The flowrate for any foam configuration can be determined by having knowledge of the water liquid density, as well as the cross-sectional area of the inlet and outflow boundaries of the model.

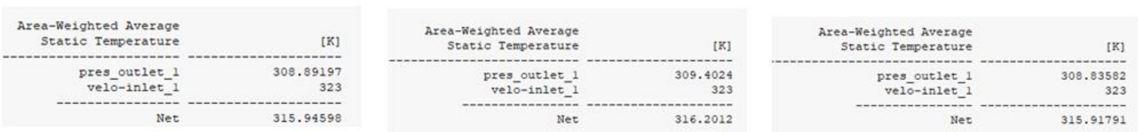
Table 4 *Calculation for all foam arrangement*

Foam Arrangement	Uniform Arrangement	Closely pack Arrangement	Mixing Arrangement
Fluid density		$998.2\ kg/m^3$	
Inlet velocity		0.001m/s	
Cross sectional area of inlet	$4\times10^{-4}m^2$	$4\times10^{-4}m^2$	$4\times10^{-4}m^2$
Flow rate in inlet	$3.99280\times10^{-4}\ kg/s$	$3.99280\times10^{-4}\ kg/s$	$3.99280\times10^{-4}\ kg/s$
Outlet velocity	0.00010002377 m/s	0.000099922918 m/s	0.00010001438 m/s
Cross sectional area of inlet	$4\times10^{-4}m^2$	$4\times10^{-4}m^2$	$4\times10^{-4}m^2$
Flowrate in outlet	$3.9897227\times10^{-4}\ kg/s$	$3.99289490\times10^{-4}\ kg/s$	$3.993374165\times10^{-4}\ kg/s$

Based on Table 4, the closely pack arrangement has the highest flowrate drop, from $3.99280\times10^{-4}\ kg/s$ to $3.99289490\times10^{-4}\ kg/s$ compare to other arrangement. The mixing arrangement has the lowest flowrate change that is from $3.99280\times10^{-4}\ kg/s$ increase to $3.993374165\times10^{-4}\ kg/s$. The uniform pack arrangement flowrate drop is between mixing arrangement and closely pack arrangement that is from $3.99280\times10^{-4}\ kg/s$ to $3.9897227\times10^{-4}\ kg/s$. Thus, as the conclusion the design of closely pack arrangement have the highest viscosity, then is uniform arrangement and last is mixing arrangement.

3.3 Simulation Result of Three Different Arrangement and Three Different Material Model in Temperature Change

The liquid water moves through the pipe made of metal foam at a speed of 0.001 meters per second at a temperature of 50 °Celsius, which is equivalent to 323 °Kelvin. In order to carry out the temperature result, the model was defined using a realizable k-epsilon, double equation. Fig. 5 shows the example result obtained in steel, zirconia and alumina in uniform foam arrangement.



(a) (b) (c)

Fig. 5 *Result obtained of uniform foam arrangement for (a) Steel (b) Zirconia (c) Alumina*

3.4 Temperature Change for Simulation

All the rates of heat transmission have been calculated and the data presented in Table 5. For uniform foam arrangement the rate of heat transfer of steel is -2.8306 J/s, -2.1718 J/s for zirconia and -4.9769 J/s for alumina. Next, for closely pack foam arrangement the rate of heat transfer of steel is -3.9859 J/s, for zirconia is -3.1034 J/s and alumina is -6.9879 J/s. For mixing foam arrangement, the rate of heat transfer of steel is -3.3958 J/s, -2.6026 J/s for zirconia and the alumina is -5.9375 J/s. Because the water-liquid in the pipe is experiencing the energy loss that exchanges with the heat of the casing, all the values for the rate of heat transfer are in the negative range. This is because the water-liquid in the pipe is experiencing the energy loss that exchanges with the heat of the pipe.

Table 5 *Calculation of the rate of heat transfer*

Arrangement	Material	T_1(°C)	T_2(°C)	Rate of heat transfer, ϕ (J/s)
Uniform	Steel	50.000	35.892	-2.8306
	Zirconia		36.402	-2.1718
	Alumina		35.836	-4.9769
Closely pack	Steel	50.000	30.118	-3.9859
	Zirconia		30.554	-3.1034
	Alumina		30.097	-6.9879
Mixing	Steel	50.000	33.137	-3.3958
	Zirconia		33.707	-2.6026
	Alumina		33.104	-5.9375

Fig. 6 shows the rate of heat transmission with their arrangement. The rates of heat transfer for different foam arrangement and material were used to generate the graph and were arranged in increasing order from lowest to highest. Closely pack Alumina has been found to have the highest of heat transfer rate, which is 6.9879 J/s, as demonstrated in the graph. The data arrangement that is uniform and made from zirconia has the lowest rate, which comes in at 2.1718 J/s. This is because zirconia has a lower thermal conductivity than other materials. The material with the highest specific heat capacity is alumina, followed by steel, while zirconia is the material with the lowest value. When it comes to flowrate, materials that are tightly packed experience the least amount of change, followed by materials that are mixed, and finally materials that are evenly placed experience the maximum flowrate. However, if one looks at the graph, that the rate of heat transfer that occurs via the configuration of uniform steel foam is far lower than that which occurs via the zirconia that is packed firmly. This indicates that even if the foam arrangement is not competitive with other arrangements, changing its substance can also have the potential of having a larger rate of heat transfer, and vice versa. Even though the foam arrangement is not competitive with other arrangements.

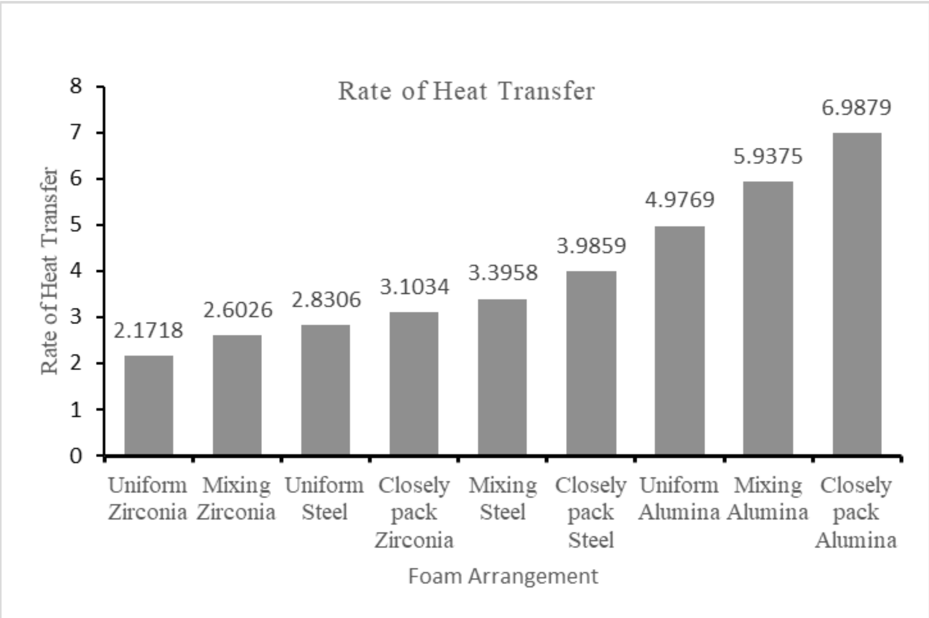


Fig. 6 *Rate of heat transfer*

4. Conclusion

The characteristic of the behavior of the water flow for the different foam arrangement and material in the duct were computationally studied and analyses. The different types of foam arrangement which are uniform, closely pack and mixing arrangement are modelling and meshing successfully in Ansys Workbench. All the data was obtained by the ANSYS Fluent simulation. By using different arrangements, the flowrate at the output has the different value. As a result, the design of closely pack arrangement have the highest viscosity, then the uniform arrangement and last is mixing arrangement. The objective of investigation the characterization of different type of foam material term of flow rate is achieved.

Next, the influence of the foam arrangement and material in terms of rate of heat transfer also investigate and simulated successfully. The rate of the heat transfer rate arrangement in ascending order, which is start with uniform zirconia, mixing zirconia, uniform steel, closely pack zirconia, mixing steel, closely pack steel, uniform alumina, mixing alumina and the highest is closely pack alumina.

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