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The Effect Of Container Shape And Porous Media On Heat Transfer

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ABSTRACT: The Porous media play a major role in improving heat transfer and saving system from three decades for energy production and storage system. In this research, the porous media was investigated in a container with 20 cm width, 20 cm high and 2.7 cm depth. The two side of the container was left isolated; the base of the container was set to heat flux of 500 W/m^2, whereas the top of the container was set to heat convection with 10 W/m^2 ^oC, heat transfer coefficient. Three materials was used as medium (Aluminum, Al_2O_3, Glass, and Silica -sand). The results shows that the Glass and water porous media give the maximum velocity and pressure, Aluminum and water porous media give the minimum velocity, temperature and pressure

KEYWORDS: Porous media, Container shape, Alumina, Aluminum, Glass, Silica-sand, Heat flux, Ansys CFX, Numerical simulations.

INTRODUCTION

The porous media transfer phenomenon have investigated initially by the examine activity in chemical engineering and geophysical systems industry. Nevertheless, a new free fluid flow research area was established due to the porous media engineering rank. Therefore, the subject of the transfer phenomena through fluid-saturated porous materials represents a serious area of rapid development in the contemporary heat transfer research [1]. Several researchers investigated the porous media both experimentally and numerically. Kumar et al. 2010 [2] numerically analyzed a porous enclosure that involve a vertical wavy surface, finite element method was used to investigate the steady heat flux and the free convection resulted. It was found that the high frequency and the vertical wall deviation enhance the free convection. Bhuvaneswari et al. 2011 [3] numerically investigation the aspect ratio effect and the active zones of partially thermally on heat transfer and convective flow in a rectangular porous enclosure. The sidewalls bottom and top of the enclosure are adiabatic while along the vertical walls there is five different zone of cooling and heating. The location of zones has a significant effect on the flow pattern and the heat transfer in the enclosure. The heat transfer rate is fall with raised the aspect ratio. Abood 2011 [4] numerically presented the heat transfer by free convection in two enclosures have different shape. The first enclosure was a right-angle trapezoidal, while the second enclosure was square. A saturated porous media filled the enclosures. The upper wall was cooled, heated the lower wall and the other walls were adiabatic. The results appear that the coefficient of heat transfer increases with increasing of aspect ratio and Ra. Saleh et al. 2011 [5] Numerical study of the transit heat transfer natural convection in enclosure the shape of it inclined cylindrical consist of fluid-saturated porous media .The (3-D) Darcy-Boussinesq equations were used solving by finite difference method. Results show that maximum velocity and temperature occur at angle α=45 and there is a strong buoyancy force influenced on convective flow from calculated average and local Nu. The heat transfer proportional directly with time, angle of inclination, Rayleigh number, period and amplitude. Ismael 2011 [6] studies numerically the heat transfer by natural convection and fluid flow inside a fluid-saturated porous media wavy enclosure heated by an internal circular cylinder. The effect of inner cylinder position, Darcy modified Rayleigh number, and waviness of wavy walls was studied. It was found that for any values of inner cylinder position and wall waviness, the heat transfer are an increasing function of Darcy modified Ram. Higher heat transfer is obtained when the inner cylinder is positioned below the mid enclosure height. Kalaoka and Supot 2014 [7] numerically investigated a square enclosure that was occupied with porous media. One wall was partially cooled while the other was heated. The results showed that altered heat fields and temperature flow was established from varied Rayleigh and Darcy numbers. These conclusions are suitable to be used in electronic devices cooling systems and buildings thermal insulation. Srinivasacharya et al. 2015 [8] numerically studied the influence of thermal conductivity and variable viscosity for a Darcy porous media in vertical wavy surface. It was found that variable viscosity rising lead to improve the Sherwood number but at the same time reduce the Nusselt number, concentration, temperature and velocity of the flow. Meanwhile the thermal conductivity increasing lead to improve the Sherwood number and the temperature but at the same time reduce the Nusselt number, concentration, and velocity. Kumar 2015 [9] numerically studied a two dimensional, steady state porous media heat transfer in a rectangular enclosure. The data resulted showed the influence of solid-gas combinations, void fraction and pressure on the effective thermal conductivity. Jeremy Vu 2017 [10] the enhancement of the precision of porous continuum models studying numerically. The geometric model is spherical-void-phase porous media was used to create many domains over a scope of porosity and pore diameter ideal of graphitic foams. Subsequent simulations were performed to show that the tortuosity was purely a geometric function-depending only on the solid phase structure. Ali (2010) [11] two-dimensional numerical study showing the effect of thermal conductivity barriers on natural convection was carried out in a saturated porous medium within a space the upper and lower surface are isolated and the two columns are flat and have different fixed temperatures .Finite difference method used to solve the governing equations. Also the results show that Ra is a function to the Nu for two cases. But in the two cases the increasing in the barriers length results a decreases in Nu. Karamallah et al. 2013 [12] studied experimentally the convection heat transfer of porous media saturated cavity. One of the cavity sides was heated and the opposite one left in a cold temperature. It was found that as the angle of inclination rises to 45 degree, the temperature as well as the heat transfer and Nusselt number of the porous media rises too but with further rising in the angle there values were reduced. Mohammed et al. 2015 [13] experimentally studied the heat transfer in a porous media packed. A saturated spherical stainless steel particle was used as porous media. They concluded that the Nusselt number as well as the heat transfer coefficient rises by raising the Reynolds number. Alwan et al. 2017 [14] experimental study of the unsteady heat transfer natural convective through porous materials sample were investigated. Plastic balls and Glass spheres saturated by water was used as the porous media; heat flux is subjected at the lower surface as a boundary condition. The (h , Nu_e , Nu_f and Ra_m) parameters were calculated from the temporal and spatial distribution of temperature profile at different locations of sample. These parameters found from results are dependent upon, the dimensions of solid and the heating time and fluid layers of sample. It was found that the values of air velocity are less than 0.08 m/s. The Re was experimentally less than 10.

NUMERICAL METHOD

To solve a mathematical system theoretically a (ANSYS 19.0) under CFX-solver manager is used to analyze flow field and temperature distribution. The geometry model in the present work is a three dimensional closed cavity filled with a porous media. The cavity is taken in three forms as shown in figure (1).Various types of porous media were taken as solid phase and saturated by water such as silica-sand, aluminum, glass and alumina (Al_2O_3), table (1) shows the material properties. For a three-dimensional mesh tetrahedral type of mesh is used, figure (2) shows the mesh of the container used in the simulations. The upper surface is exposed to room temperature with 10 W/m^2K heat transfer coefficient and 300 K ambient temperature. The lower surface is under the influence of constant heat flux of 500 W/m^2, and the side walls are completely insulated. Steady state laminar flow was simulated.

Figure 1. The two shapes of the container studied

Table 1. material properties

Material name	ρ (kg/m^3)	K (W/m.k)	C_P (J/kg.k)
Aluminum	2719	202.4	871
Al_2O_3	1090	40	1419.633
Glass	2500	1.4	750
Silica -sand	2300	0.1976	1170

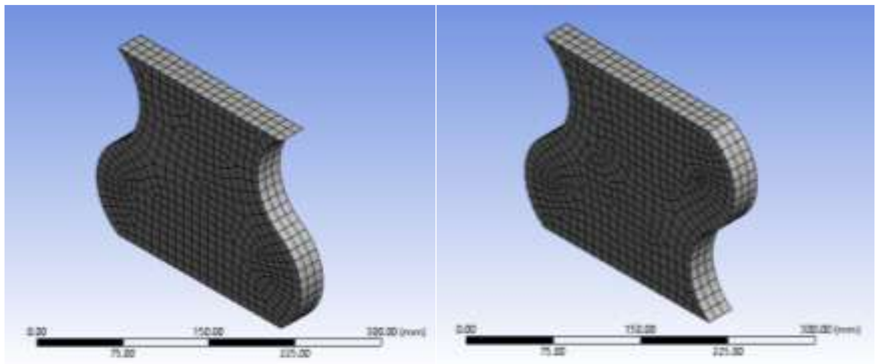


Figure 2. mesh of the model

The governing equations

The mass, momentum, and energy equations, which govern the convection phenomena inside the porous media, are produced as follows [16]:

1. Continuity equation: The general continuity equation is:

$$\frac{\partial}{\partial t}(\gamma\alpha_q\rho_q) + \nabla\cdot\left(\gamma\alpha_q\rho_q\vec{v}_q\right) = \gamma\sum_{p=1}^{n}\left(\dot{m}_{pq} - \dot{m}_{qp}\right) + \gamma S_q \tag{1}$$

2. Momentum equation:

$$\begin{aligned}\frac{\partial}{\partial t}(\gamma\alpha_q\rho_q\vec{v}_q) + \nabla\cdot(\gamma\alpha_q\rho_q\vec{v}_q\vec{v}_q) = \quad & -\gamma\alpha_q\nabla p + \nabla\cdot(\gamma\bar{\tau}_q) + \gamma\alpha_q\rho_q\vec{g} \\ & +\gamma\sum_{p=1}^{n}(\vec{R}_{pq} + \dot{m}_{pq}\vec{v}_{pq} - \dot{m}_{qp}\vec{v}_{qp}) \\ & +\gamma(\vec{F}_q + \vec{F}_{lift,q} + \vec{F}_{vm,q}) \\ & -\alpha_q\left(\frac{\gamma^2\mu}{K_q}\vec{v}_q + \frac{\gamma^3 C_{2q}}{2}\rho_q|\vec{v}_q|\vec{v}_q\right)\end{aligned} \tag{2}$$

Energy equation:

$$\begin{aligned}\frac{\partial}{\partial t}(\gamma\alpha_q\rho_q h_q) + \nabla\cdot(\gamma\alpha_q\rho_q\vec{v}_q h_q) = \quad & -\gamma\alpha_q\frac{\partial p_q}{\partial t} + \gamma\bar{\tau}_q:\nabla\vec{v}_q - \nabla\cdot(\gamma\vec{q}_q) + \gamma S_q \\ & +\gamma\sum_{p=1}^{n}(Q_{pq} + \dot{m}_{pq}h_{pq} - \dot{m}_{qp}h_{qp}) + Q_{sp}\end{aligned} \tag{3}$$

VALIDATION OF THE NUMERICAL MODEL

The numerical result was validated with the results from Al-Meiyahi 2017 [15], a numerical investigation set for a porous media. The model that was used was a two dimensional model, the porous media that was used is a silica sand particles with water filling the voids. The boundary conditions for the walls set as constant heat flux through the base of the cavity while the top of the cavity exposed to convection with the ambient atmosphere, the other walls set as adiabatic. Figure (3) shows the velocity from the above reference in compared with the numerical result that was performed in this investigation. The results showed that the velocity maximum value happened within significant area, these areas are as follows.

1. The sides of the convex where the flow become turbulent.

2. The lower and upper surfaces since the direction of the flow get inversed.

3. The cavity middle reign where the velocity increases by the flow gathering at that point.

While figure (4) shows the total temperature from the reference [15] in compared with the numerical result that was performed in this investigation. It was found that the even by increasing the waves number, the distribution of isothermal lines was symmetrically and uniformly around the cavity center line.

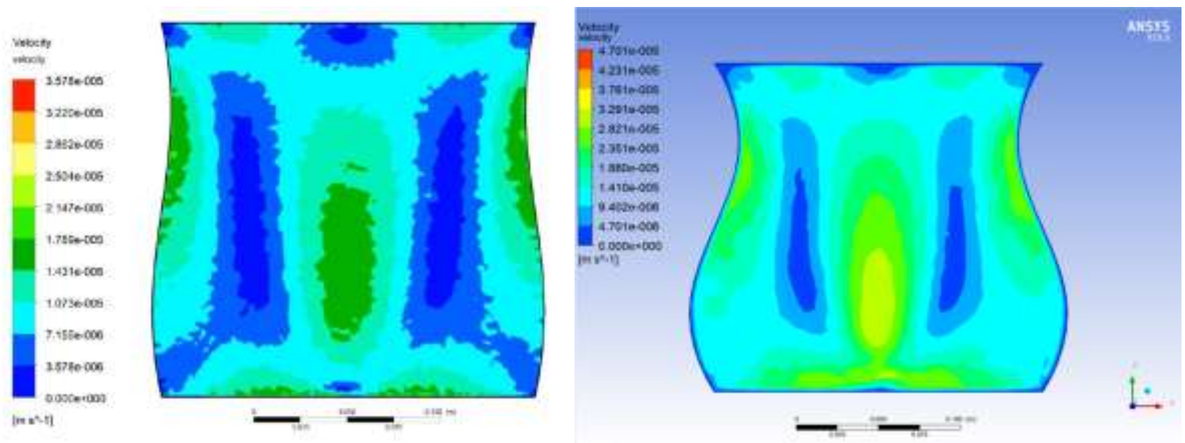


Figure 3. Velocity contour comparison

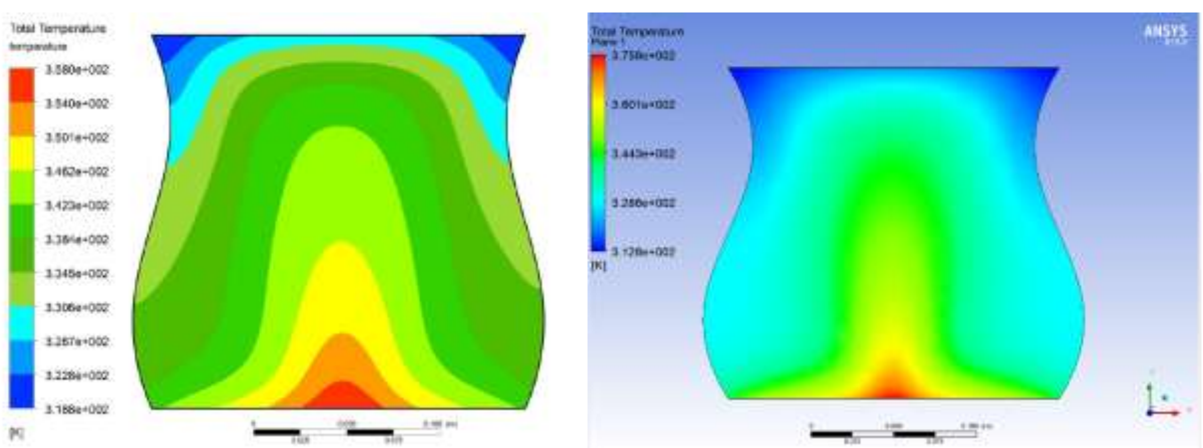


Figure 4. Total temperature contour comparison

RESULTS AND DISCUSSION

The behavior of the flow inside the container is presented by the velocity distribution, temperature distribution, and pressure distribution.

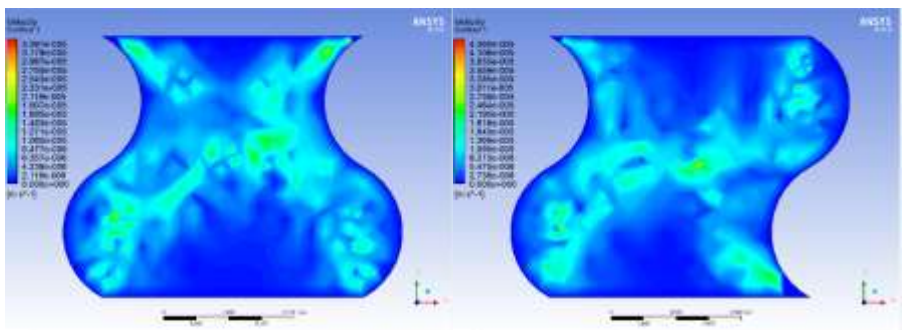
Velocity distribution

The velocity distributions are shown in figure (5) for two shapes of the container. It was observed that there are two areas in the cavity where zero velocity occurs, the areas are;

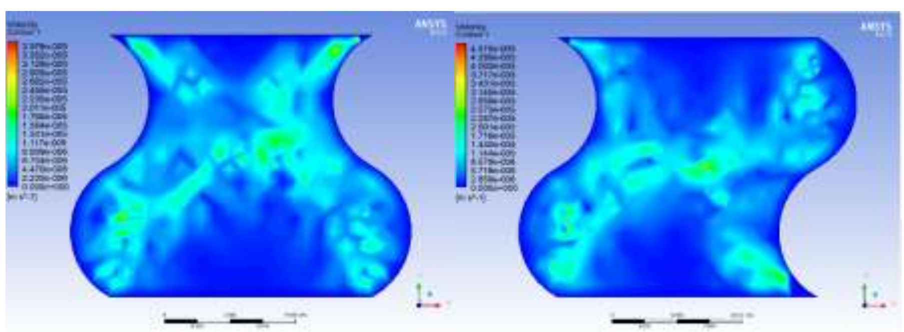
1. At the top and base of the container which represent the center of the cellular where the fluid flows around.

2. At the edge around the container which represent as a die flow areas of the container.

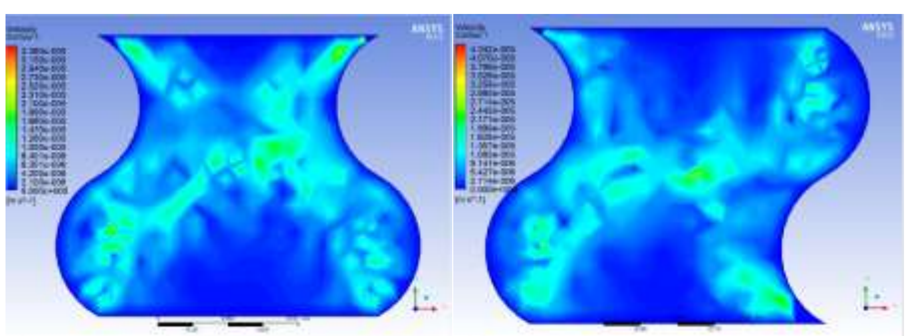
A turbulent distribution of the flow shown in the middle of the container, Figure (5), small eddies where formed around the diagonal of the container to be mixed in the middle and form a large big vortex. The distribution for the velocity did not change much as the shapes of the container change and as well as when the medium of porosity changed, however, the values of the velocity changed significantly. As the container shape changed from the first shape to the second as shown in figure (5) the velocity increased for all the porous media that were tested. Using different types of porous media changed the velocity values as well, using aluminum and water as porous media gave minimum velocity compared to the other porous media that were tested, figure (5d). Glass and water being used as porous media gave the maximum velocity value, figure (5b).



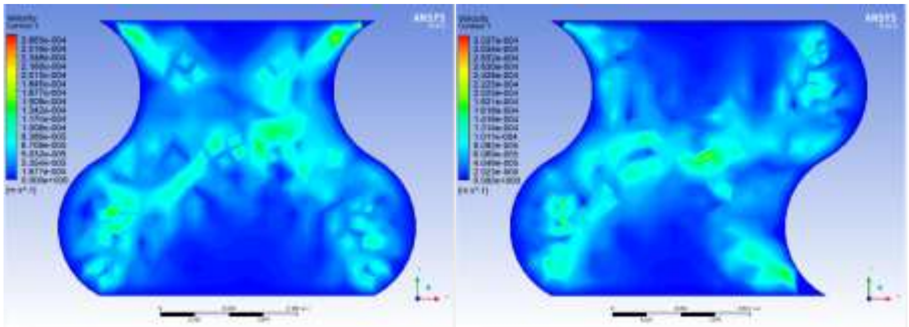
(a) Sand



(b) Glass



(c) Alumina



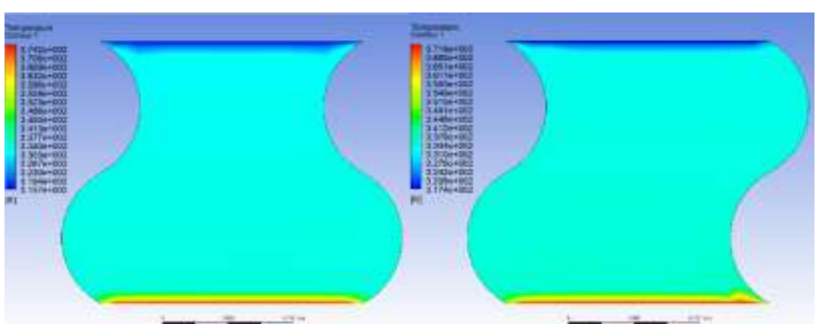
(d) Aluminum

Figure 5. Velocity distribution shape comparison using different porosity medium (a) Sand (b) Glass (c) Alumina (d) Aluminum

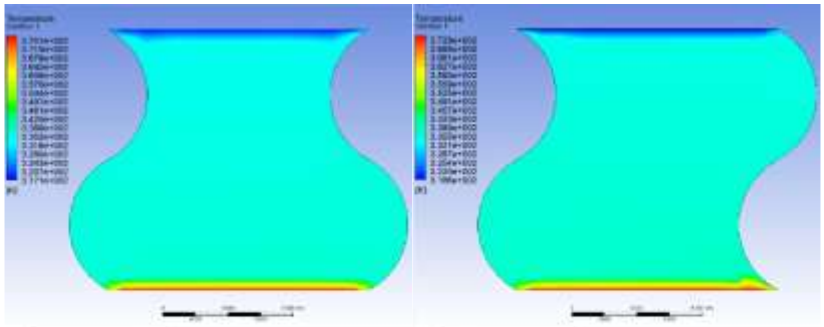
Temperature distribution

It is observed that even by increasing the waves number, the distribution of temperature was symmetrically and uniformly around the cavity center line as displayed in figure (6). High temperature distribution was illustrated at the base of the container while low temperature distribution was illustrated at the top of the container.

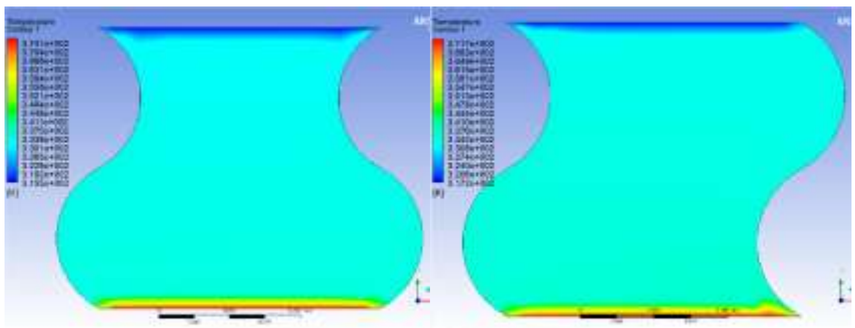
The distribution for the temperature did not change much as the shapes of the container change and as well as when the medium of porosity changed, however, the values of the temperature changed significantly. As the container shape changed from the first shape to the third as shown in figure (6) the temperature decreased for all the porous media that were tested. Using different types of porous media changed the temperature values as well, using aluminum and water as porous media gave minimum total temperature compared to the other porous media that were tested, figure (6d), and this is due to the velocity values that was discussed earlier. As the velocity was in its lowest value when using aluminum and water as porous media, figure (5d) lead to the temperature being in its lowest value in the same conditions and circumstances. The other tested porous media gave the same average total temperature depending on the shape of the container.



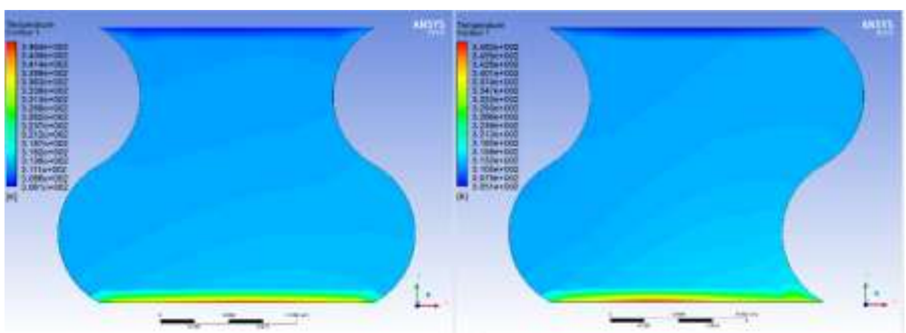
(a) Sand



(b) Glass



(c) Alumina

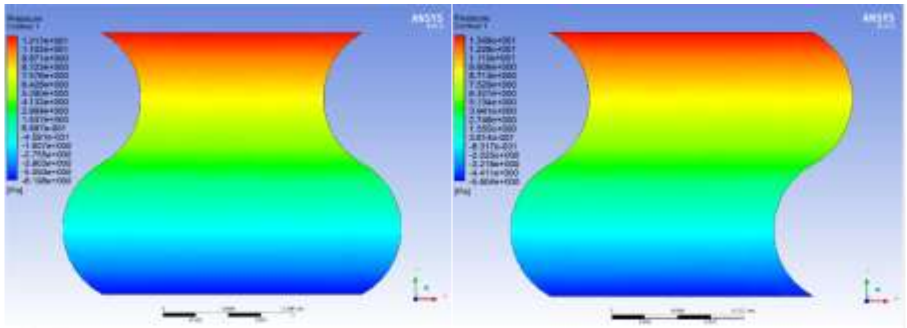


(d) Aluminum

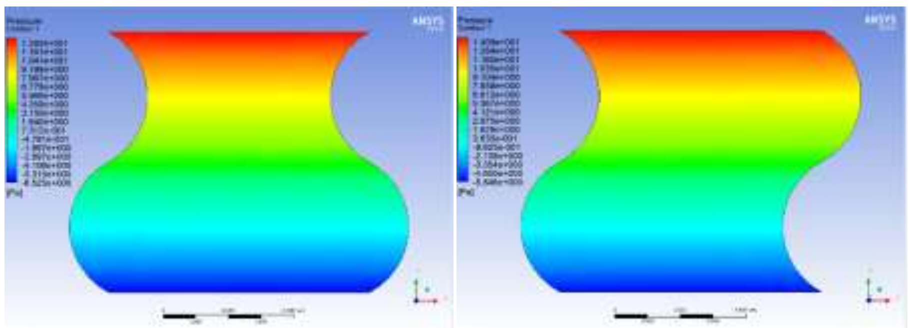
Figure 6. Velocity distribution shape comparison using different porosity medium (a) Sand (b) Glass (c) Alumina (d) Aluminum

Pressure distribution

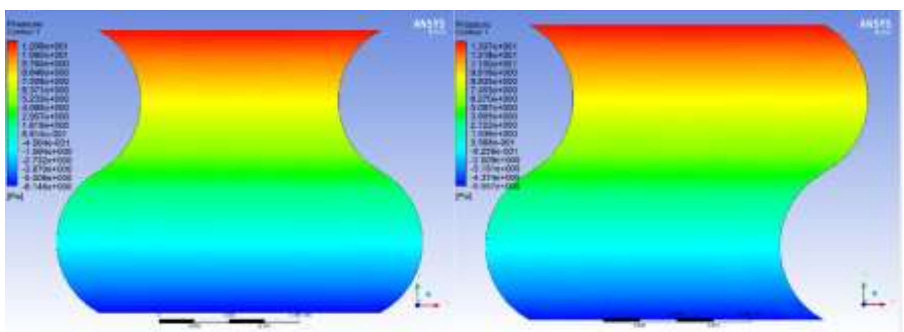
The pressure distributions are shown in figure (7) for two shapes of the container. The pressure magnitude of the flow distributed at four main regions. The distribution for the pressure did not change much as the shapes of the container change and as well as when the medium of porosity changed, however, the values of the pressure changed significantly. As the container shape changed from the first shape to the second as shown in figure (7) the pressure increased for all the porous media that were tested. Using different types of porous media changed the pressure values as well, using aluminum and water as porous media gave minimum pressure compared to the other porous media that were tested, figure (7d). Glass and water being used as porous media gave the maximum pressure value, figure (7b).



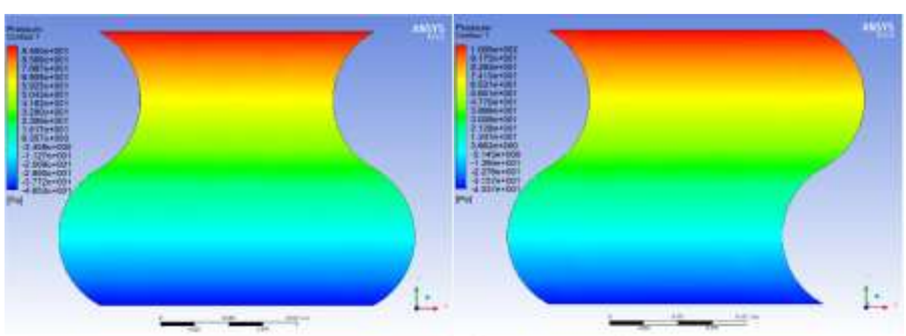
(a) Sand



(b) Glass



(c) Alumina



(d) Aluminum

Figure 7. Velocity distribution shape comparison using different porosity medium (a) Sand (b) Glass (c) Alumina (d) Aluminum

CONCLUSION

In this research, the porous media was investigated in a three shapes container with four materials being used as porous media along with water. Aluminum, Al_2O_3, Glass, and Silica -sand was used as porous media materials. The two side of the container was left isolated; the base of the container was set to heat flux of 500 W, whereas the top of the container was set to heat convection with 10 W/m^2 ^oC, heat transfer coefficient. The remarks that was concluded involve

1. The velocity in the first second shape container was higher than the second third shape

2. The temperature in the first shape container was higher than the other

3. The pressure in the first second shape container was higher than the second third shape

4. Aluminum and water porous media give the minimum velocity, temperature and pressure

5. The Glass and water porous media give the maximum velocity and pressure

Samples

μ	Dynamic viscosity	kg/m.s
Cp	Specific heat capacity	J/kg.K
ε	Porosity	
g	Gravitational acceleration	m/s^2
k	Thermal conductivity coefficient.	W/m.K
P	Pressure	Pa
t	time	s
T	temperature	K
u	Velocity component at x-axis	m/s
v	Velocity component at y-axis	m/s
α	Thermal diffusivity coefficient	m^2/s
β	Thermal expansion coefficient	1/K
ρ	Density	kg/m^3

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