

Numerical investigation of natural convection heat transfer in a cavity utilizing Al_2O_3 -water nanofluid: Effect of baffle height



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The objective of this work is to investigate numerically the single phase natural convective heat transfer in a cavity with baffle utilizing Al_2O_3 -water nano fluid. The study is carried out numerically for a range of baffle heights, $h=0.2, 0.5$ and 0.8 . Results are presented in the form of streamline and isotherm plots. The results show that heat transfer decreases considerably with increasing partition height. For the two-baffle cavity, as the height of baffle increases, separation in the vortices is seen and there is only conduction heat transfer between two baffles. Compared to the top-attached cavity, for the top-attached cavity, streamlines and isotherms are symmetric to the central line. For the two-baffle cavity, all the plots are symmetric to the central line.

Keywords: Nanofluid; Natural convection; Cavity.

1. INTRODUCTION

Natural convection in cavities is an example of the confined fluid in many technical applications such as electronic industry, cooling systems for nuclear reactors, heat exchangers, solar energy collectors, transportation, drying technologies, chemical processing equipment and etc. A numerous number of experimental and theoretical studies have been done to investigate the flow in cavities. The term of nanofluid which is introduced by Choi [1], refers to a mixture of solid–liquid that solid nanoparticles are dispersed in a fluid. Although a lot of studies have been carried out to investigate the natural convection in cavities [2-5], most of them have considered cavity without partitions. Anilkumar and Jilani [6] studied heat transfer

enhancement of nano fluid in a finned cavity investigated for various pertinent parameters like volume fraction, fin height, Rayleigh numbers and aspect ratio of the cavity. The results showed that the presence of nano particles in the fluid alters the structure of the fluid flow. Moreover, as Rayleigh number increases, natural convection overcomes and the temperature variation is restricted over a gradually diminishing region around the fin. It is also noticed that the heat affected zone becomes larger with the increasing fin height. Habibzadeh et al. [7] investigated the natural convection heat transfer of a partitioned square cavity filled with Al₂O₃-water nanofluid. According to the results, the partition height and Rayleigh number increasing leads to the decrease of the heat transfer rate and increase of the average Nusselt number, respectively. Also, it is proved that the average Nusselt number is maximum when the partition is placed at the center. Sayehvand et al. [8] studied the natural convection heat transfer in a partitioned square cavity using computational fluid dynamics. They showed that Rayleigh number and height of the partition are important factors that extremely affect the streamlines and isotherms and for a fixed amount of the partition height, Nusselt number increases as the Rayleigh number goes up. The aim of this study is to study a cavity containing baffle in 3 conditions: baffle attached to the bottom wall, baffle attached to the top wall, 2 baffles attached to the top and bottom walls.

2. PHYSICAL MODEL AND GOVERNING EQUATION

Fig. 1 displays the schematic diagram considered in this study which is a two-dimensional cavity containing insulated baffles. The horizontal walls of the cavity are assumed to be insulated while the left and right vertical walls are maintained at a uniform temperature (T_h) and (T_c), respectively as the heated and cooled walls.

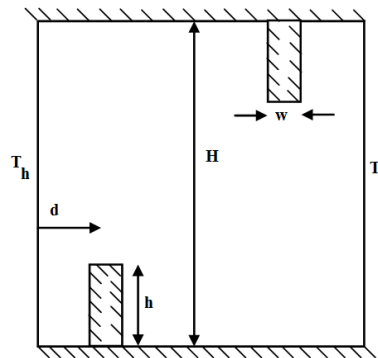


Figure1. Schematic diagram of the cavity

The cavity is filled with nanofluid which is composed of Aluminum oxide nano particles in water. The nanofluid is Newtonian, incompressible, and laminar and is assumed to have uniform shape and size. Also, it is assumed that the base fluid and the nanoparticles are in thermal equilibrium and no slip occurs between them. Constant thermophysical properties are considered for the nanofluid, except for the density variation, which is determined based on the Boussinesq approximation.

Table 1 Thermophysical properties of base fluid and nanoparticles.

Property	Water	Al2O3
ρ (kg/m ³)	997.1	3970
Cp (J/kgK)	4179	765
k (W/mK)	0.613	40
$\alpha \times 10^7$ (m ² /s)	1.47	131.7
$\beta_T \times 10^6$ (1/K)	210	24

Under the above assumptions, the steady-state two-dimensional dimensionless government equations are:

$$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0$$

$$U \frac{\partial U}{\partial X} + V \frac{\partial U}{\partial Y} = -\frac{\rho_f}{\rho_{nf}} \frac{\partial P}{\partial X} + \frac{1}{\nu_f \text{Re}} \frac{\mu_{nf}}{\rho_{nf}} \left(\frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 U}{\partial Y^2} \right)$$

$$U \frac{\partial V}{\partial X} + V \frac{\partial V}{\partial Y} = -\frac{\rho_f}{\rho_{nf}} \frac{\partial P}{\partial Y} + \frac{1}{\nu_f \text{Re}} \frac{\mu_{nf}}{\rho_{nf}} \left(\frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 V}{\partial Y^2} \right) + \frac{(\rho\beta)_{nf}}{\beta_f \rho_{nf}} Ri\theta$$

$$U \frac{\partial \theta}{\partial X} + V \frac{\partial \theta}{\partial Y} = -\frac{\alpha_{nf}}{\alpha_f} \frac{1}{\text{PrRe}} \left(\frac{\partial^2 \theta}{\partial X^2} + \frac{\partial^2 \theta}{\partial Y^2} \right)$$

where α is the thermal diffusivity of the nanofluid that is expressed by :

$$\alpha_{nf} = \frac{k_{eff}}{(\rho c_p)_{nf}}$$

The effective dynamic viscosity of the nanofluid is given by Brinkmann's model:

$$\mu_{nf} = \frac{\mu_f}{(1-\phi)^{2.5}}$$

The effective density of a fluid containing suspended particles is given by:

$$\rho_{nf} = (1 - \varphi)\rho_f + \varphi\rho_s$$

The thermal expansion coefficient of the nanofluid can be determined by:

$$(\rho\beta)_{nf} = (1 - \varphi)(\rho\beta)_f + \varphi(\rho\beta)_s$$

The specific heat capacity of nanofluid is:

$$(\rho c_p)_{nf} = (1 - \varphi)(\rho c_p)_f + \varphi(\rho c_p)_s$$

The effective thermal conductivity of a fluid for the two-component spherical particle suspension can be determined by Maxwell-Garnett's approximation model:

$$\frac{k_{nf}}{k_f} = \frac{(k_s + 2k_f) - 2\varphi(k_f - k_s)}{(k_s + 2k_f) + \varphi(k_f - k_s)}$$

For validation, the results of the numerical results for average Nusselt number in a square cavity are compared with the results of other researches. The comparison is shown in Table 2 which shows a very good agreement.

Table 2 Comparison between present work and other published data.

	10⁴	10⁵	10⁶
Present work	2.241	4.526	8.919
de Vahl Davis [9]	2.243	4.519	8.8
House et al [10]	2.254	4.561	8.923
Merrickh and Lage [11]	2.244	4.536	8.86

3. RESULTS AND DISCUSSION

1- The cavity with an attached baffle to the bottom wall

Figure 2 shows the isotherms and streamlines of the cavity with a baffle attached to its bottom wall. The baffle is located at d=0.3 and height of the baffle is considered to be 0.2, 0.5 and 0.8 and Rayleigh number is Ra=10⁵.

h=0.2

h=0.5

h=0.8

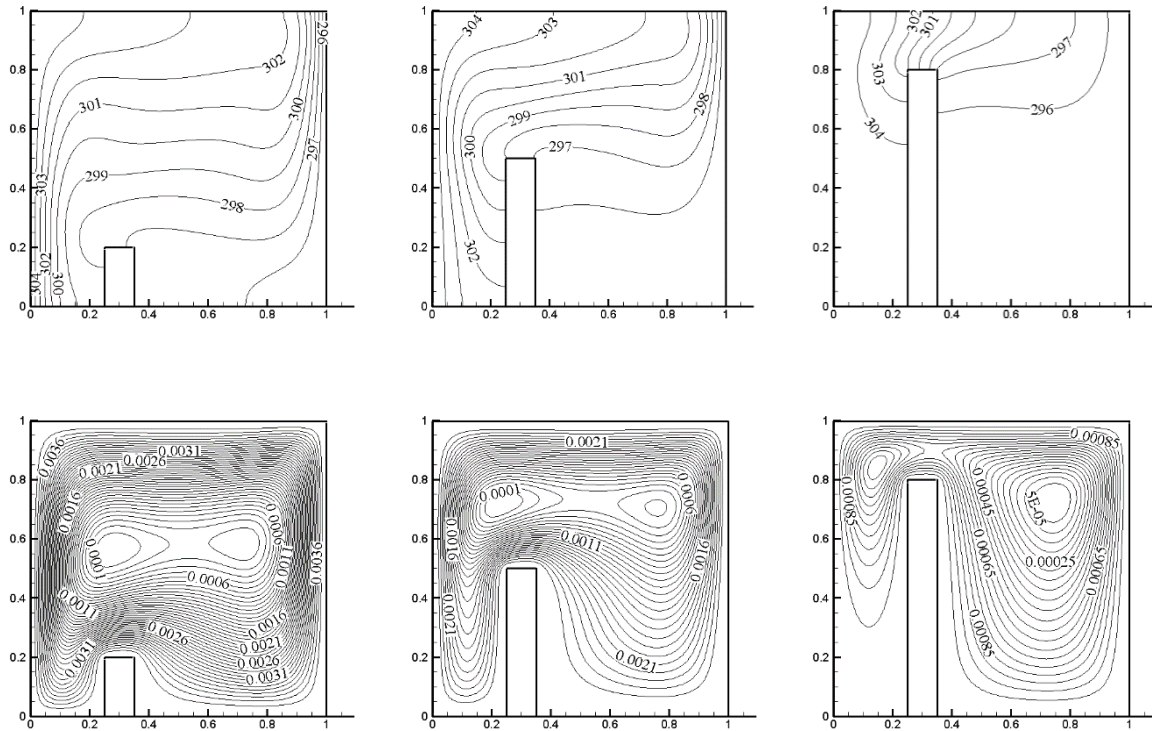


Figure2. The effect of the variation of baffle height attached to the bottom wall. Isotherms and streamlines for $d=0.3$, $Ra=10^5$, $\phi = 10\%$

According to the figures, it is found that the effect of the baffle with $h=0.2$ is mostly changing the local temperature distribution and the other parts of the cavity have got no effects. This phenomenon can be explained in this way that the initial vortex has not changed considerably with the presence of the baffle with $h=0.2$ and baffle has just affected the local velocity. In the middle parts of the cavity, as the conduction heat transfer is predominant the lines are horizontal but, in the areas, next to hot and cold areas, the lines are vertical which shows the predominance of the convective heat transfer. When the distance between the top and bottom decreases with the increase of the baffle height, the congestion of the isothermal lines is observed in this distance. The congestion of the isotherms is a sign of better heat transfer in this area. With the baffle height increasing, the low temperature area next to the cold wall and the high temperature area next to hot wall increase because the natural direction of the flow will be confined for the presence of the baffle. In the lower heights, because of the higher convective heat transfer flow, better distribution of isothermal lines is observed. The graphs make it clear that by reaching $h=0.8$, the separation of the hot area and cold area is appeared.

The streamline show that lower height of the baffle has not caused great effect on the fluid flow. The two holes-which are the center of the flow circulation- display this fact that some of the fluid particles could not remove heat from hot wall and transfer it to the cold wall. As the height of the baffle goes up, these small holes become more. The presence of the baffle is a barrier in front of the heat and flow transfer. Therefore, according to graphs, it is noticed that with the rising of baffle height, streamlines in the hot side move to upper part of the cavity because the high baffle does not allow the heat to be transferred in the lower parts of the hot

wall which leads to the separation of the flow to hot and cold areas. The graphs apparently show that in $h=0.2$ and 0.5 , big vortices are formed which cover hot and cold areas but in $h=0.8$, as there is not enough space for heat transfer, except some, most of the vortices are formed in hot or cold areas. Moreover, increase in the baffle height causes the reduction of the streamline strength.

2- Cavity with an attached baffle to top side

Figure 3 depicts the cavity in which an insulated baffle is attached to its top wall. Because of the symmetry characteristic, the results are similar to the cavity with an attached baffle to the bottom side.

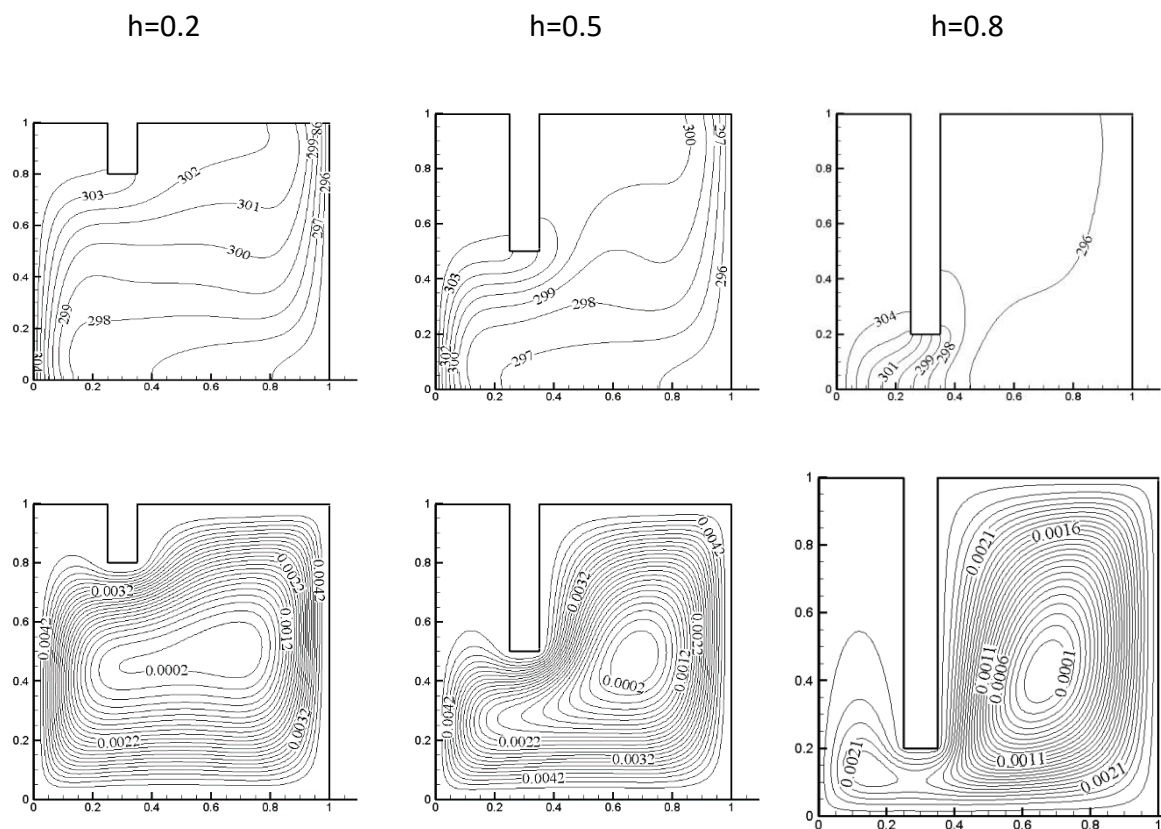


Figure3. The effect of the variation of baffle height attached to the top wall. Isotherms and streamlines for $d=0.3$, $Ra=10^5$, $\phi = 10\%$

3- Cavity with two baffles attached to top and bottom sides

Figure 4 shows the isothermal and streamlines for the cavity with two baffles which have been placed with the same distance $d=0.3$ from the hot and cold walls. Like other studied cavities, baffles with $h=0.2$ have not influenced the cavity flow a lot. For $h=0.5$, isotherms have curves in the top left and bottom right parts but they are horizontal between the two baffles. It is happened as convection heat transfer is higher in top left and bottom right part of square but between the two baffles because of the separation, heat transfer is weak. According to the

streamlines, it is clear that great amount of the flow is in the space between the baffles and insulated walls. The initial big vortices that have been formed for lower baffle heights, tend to separate in the center of the cavity and compared with the previous studied case, the power of the stream is decreased as the height of baffle increases. For the maximum studied height, in the vortical areas, the isothermal lines are disappeared but for the confined fluid between the two baffles, these lines are seen as bulk. This fact happens because the circulation of the fluid in the vortical areas makes the temperature difference lower whereas is higher for the confined fluid. It is also seen that in the distance between baffles and the top and bottom walls, the lines are compressed and vertical but are horizontal between the two baffles. These patterns show this fact that the confined fluid prevents the heat transfer from the hot wall to the cold wall and conductive heat transfer is just considered in the central part of the cavity. For this height, the streamlines show complete separation of the flow and the compression of the streamlines is the sign of the predominance of conductive heat transfer.

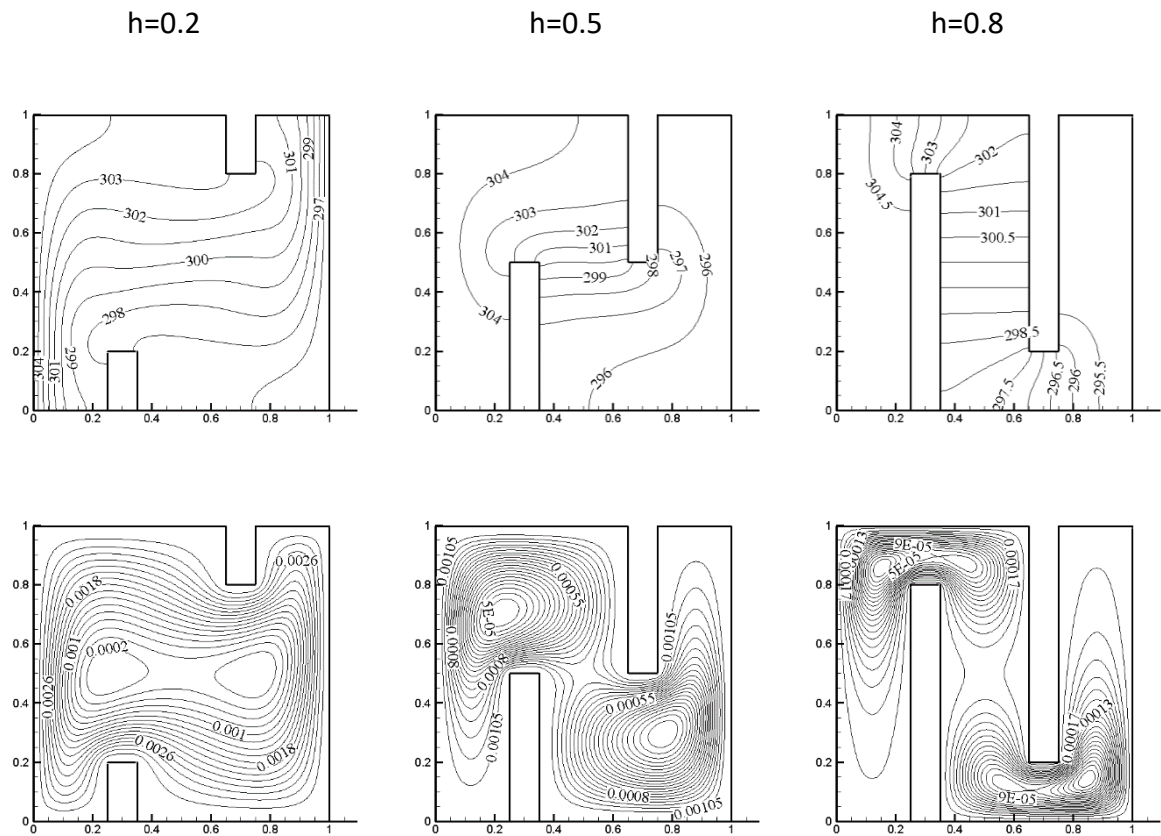


Figure4. The effect of the variation of baffle height attached to the top and bottom wall. Isotherms and streamlines for $d=0.3$, $Ra=10^5$, $\phi = 10\%$

4. CONCLUSIONS

A numerical study has been performed to investigate the effect of baffle height on the natural convection in a cavity having isothermal vertical walls and adiabatic horizontal walls filled with Al₂O₃-water based nanofluid. The main conclusions of the present analysis are as follows. The results show that heat transfer decreases considerably with increasing partition height. In the lower heights, the baffle is mostly changing the local temperature distribution and fluid flow and the other parts of the cavity have got no effects. Moreover, because of the higher convective heat transfer flow, better distribution of the isothermal lines is observed. Furthermore, increase in the baffle height causes the reduction of the streamline strength.

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