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Study of Heat Transfer in a Baffled Cavity Using Nanofluid

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Abstract

In this paper, studying the heat transfer in a baffled square cavity using Al2O3 nanofluid has been carried out. The left and right walls are assigned as hot and cold walls and baffles are assumed to be adiabatic. The effect of different factors such as Rayleigh number, distance from hot wall and height of the baffle have been studied. The results are provided as streamlines, isotherms and average Nusselt number. According to the results, the position and height of the baffle are important factors that influence streamlines, isotherms and in particular increases Rayleigh number.The average Nusselt number increase is dependent on the distance of baffle from the hot wall. Moreover, increase in Rayleigh number will cause to the increase of the average Nusselt number.

Key words: nanofluids, heat transfer, baffle, square cavity

Nomenclature

C: specific heat at constant pressure (J/kg K)
d: distance of partition from hot wall (m)
H: cavity hight (m)
h: partition height (m)
k: thermal conductivity (W/m K)
p: pressure (N/m^2)
Pr: Prandtl number

Ra: Rayleigh number
Nu: Nusselt number
T: temperature (K)
u,v: x and y components of velocity (m/s)
w: partition width (m)
x,y: Cartesian coordinates (m)

Greek symbols

β: thermal expansion coefficient (K^{-1})
φ: nanoparticle volume fraction
ρ: density (kg/m^3)
μ: dynamic viscosity (m^2/s)
θ: temperature (K)

Subscripts (Non-dimensional form)

c: cold
f: fluid
h: hot
nf: nanofluid
p: particle

INTRODUCTION

Study of heat transfer in a baffled cavity with adiabatic horizontal walls and isolated vertical walls has attracted the attention of many researchers. This is the subject of many engineering applications, including electronics cooling, transmission, energy storage systems and power plants. On the other hand, heat transfer in the field of nanotechnology is the point of contact between nanoscience and the heat engineering. Nanofluid is defined as the fluid in which nanosized solid particles are suspended. Metallic and nonmetallic nanoparticles provide better thermal properties for fluids such as water, ethylene glycol and engine oil.

Khanafer et al. [1] studied the heat transfer increase in a two-dimensional enclosure using nanofluids. They found that the suspended nanoparticles caused a significant increase in heat transfer rates in different Grasshof numbers. Abunada and Chamkha [2] investigated the natural heat transfer in a chamber filled with CuO-EG nanofluid. According to the results, the studied viscosity models have a greater impact on the behavior of the average Nusselt than the thermal conductivity models. Eastman et al. [3] found it experimentally that Al2O3 and CuO nanofluids with the volume fraction of 5% increase the thermal conductivity values 29% and 60%, respectively. Moreover, other researchers proved that the type of the nanoparticle is a crucial factor in convective heat transfer applications.

Most of the previous studies have investigated the role of nanofluids in no baffled enclosures. Therefore, it seems necessary to study the performance of the nanofluids in baffled cavities. The aim of this study is to evaluate the baffled square cavity using Al2O3 Nanofluid. The effects of different positions of baffle along with the height of the baffle in different Rayleigh numbers and volume fraction of nanoparticles have been studied. Furthermore, the effect of different parameters on the local Nusselt number is studied.

MATERIALS AND METHODS

Schematic diagram of the two-dimensional cavity is shown in Figure 1.

The vertical walls are assumed adiabatic, and Al2O3 nanoparticles in water are used as the working fluid. Nanofluid is assumed as Newtonian, incompressible and the flow is considered to be laminar. The base fluid and nanoparticles are in thermal equilibrium. Properties of the base fluid and the nanoparticles are presented in Table1.

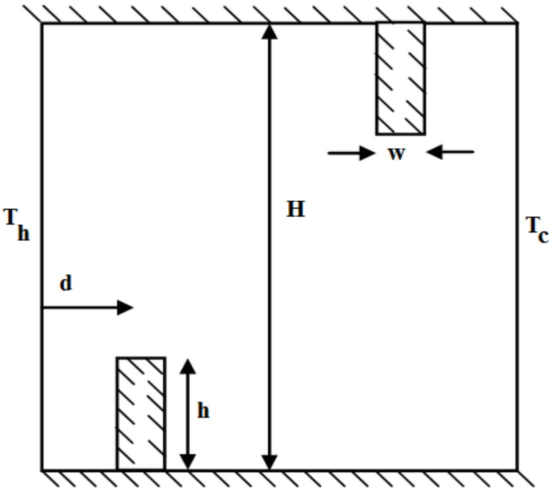


Fig.1 Schematic diagram of baffled cavity

Table 1. Thermo-physical properties of fluid and nanofluid

Properties	water	AL2O3
ρ (kg/m3)	997.1	3970
Cp (J/kg K)	4179	765
β (K-1)	2.1×10^4	0.85×10^5
k (Wm/K)	0.613	25

Equations used to solve the problem are:

$$\frac{\partial u^*}{\partial x^*}+\frac{\partial v^*}{\partial y^*}=0 \tag{1}$$

$$u^*\frac{\partial u^*}{\partial x^*}+v^*\frac{\partial u^*}{\partial y^*}=-\frac{\partial p^*}{\partial x^*}+\Pr\left(\frac{\partial^2 u^*}{\partial x^{*2}}+\frac{\partial^2 u^*}{\partial y^{*2}}\right) \tag{2}$$

$$u^*\frac{\partial \theta}{\partial x^*}+v^*\frac{\partial \theta}{\partial y^*}=\frac{\partial^2 \theta}{\partial x^{*2}}+\frac{\partial^2 \theta}{\partial y^{*2}} \tag{3}$$

$$\rho_{nf}=\phi\rho_p+(1-\phi)\rho_f \tag{4}$$

$$(\rho c)_{nf}=\phi(\rho c)_p+(1-\phi)(\rho c)_f \tag{5}$$

$$k_{nf}=\frac{k_p+2k_f+2(k_p-k_f)\phi}{k_p+2k_f-(k_p-k_f)\phi}k_f \tag{6}$$

$$\mu_{nf}=\frac{1}{(1-\phi)^{2.5}}\mu_f \tag{7}$$

$$(\rho\beta)_{nf}=(1-\phi)(\rho\beta)_f+\phi(\rho\beta)_p \tag{8}$$

$$Nu_{avg}=\int_0^1 Nu(y)\mathrm{d}y \tag{9}$$

In order to validate, numerical results for the average Nusselt in a square cavity with no baffle were compared with results obtained by other researchers which are shown in Table 2.

Table 2. Comparison between this work and other researchers

Error %	10^6	Error %	10^5	Error %	10^4	Ra
-	8.919	-	4.526	-	2.241	This work
1.334	8.8	0.154	4.519	-0.089	2.243	De Vahl Davis [4]
1.042	8.826	0.088	4.522	-0.178	2.245	Khanafer et al.

RESULTS AND DISCUSSION

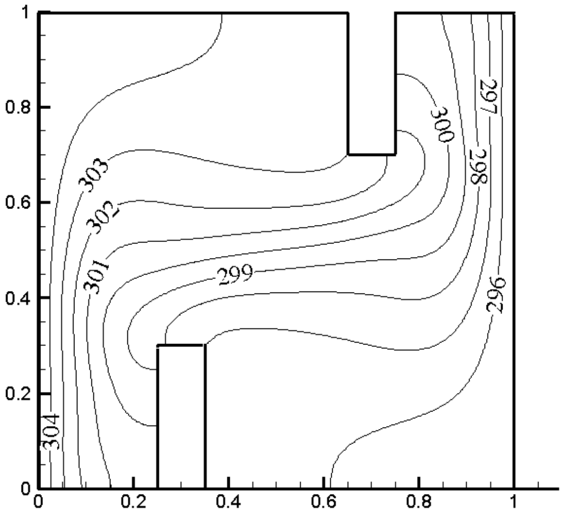
Figure 2 shows the case when the two baffles with the thickness of w=0.1 and height of h=0.3 have been located with equal distances from hot and cold walls at Ra=105. For d=0.3, as there is a distance between the baffle and the walls, the stream can flow in the distance. When the baffles move to the center, the figure shows that the streamlines are pressed between the two baffles. To satisfy the continuity law, there are equal amounts of flow in the hot and cold sides and the streams tend to separate. It can be found from isotherms that the lines between the baffles are horizontal and the lines next to the walls are vertical. Generally it should be noted that wherever there are horizontal lines conduction heat transfer excels convection and the curves indicate that convection heat transfer surpasses conduction.

Figure 3 shows the effect of Rayleigh number on the cavity. Streamlines, display forming a central oval shape vortex. With increasing Rayleigh number, the central vortex is divided into two vortices of the same strength which are located above and below the center of the cavity due to the baffles. With further increase in Rayleigh number, the vortices move toward the hot and cold walls.

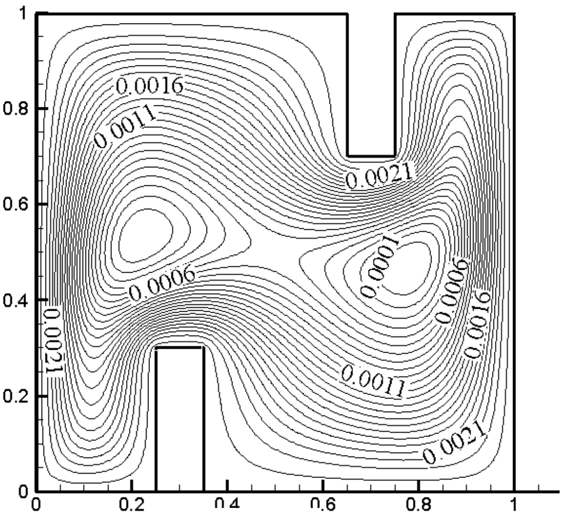
The effects of baffle height and Rayleigh number on the average Nusselt are shown in Figure 4. Generally, the average Nusselt number increases with increasing Rayleigh number. Nusselt number determines the amount of heat transfer from the activated walls. This amount decreases with the increasing baffle height. Baffle height causes a steady decline in the Nusselt number, with a greater effect at higher Rayleigh.

CONCLUSION

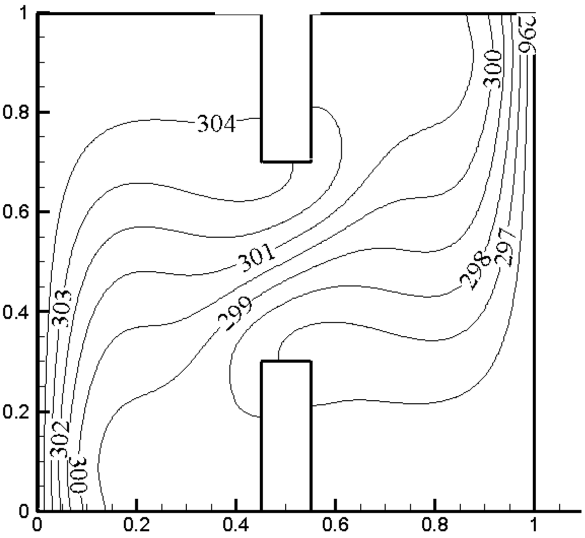
For a definite baffle height, the baffle which is attached to the center of the side, have the greatest effect on the flow. With increasing Rayleigh number, convective heat transfer enhances and flow isotherms become similar to the streamlines. Moreover, when the Rayleigh number increases, the velocity rises and the heat transfer near the active walls increases. With increasing Rayleigh number, the flow rate at the center increases sharply and the temperature decreases gradually from top to bottom. The Nusselt number decreases with increasing baffle height which is remarkable at high Rayleigh numbers.



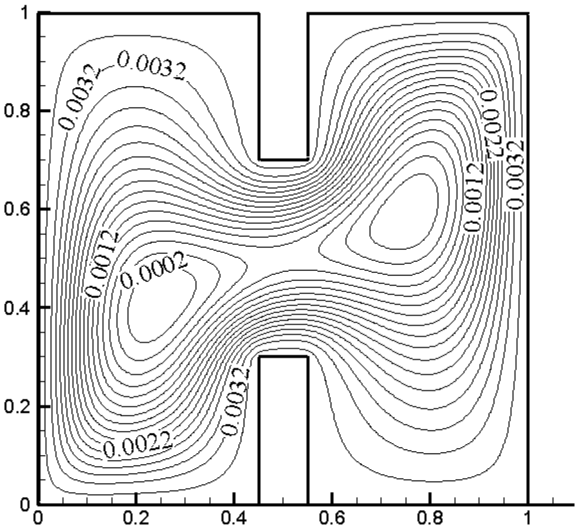
(a)



(b)
d=0.3

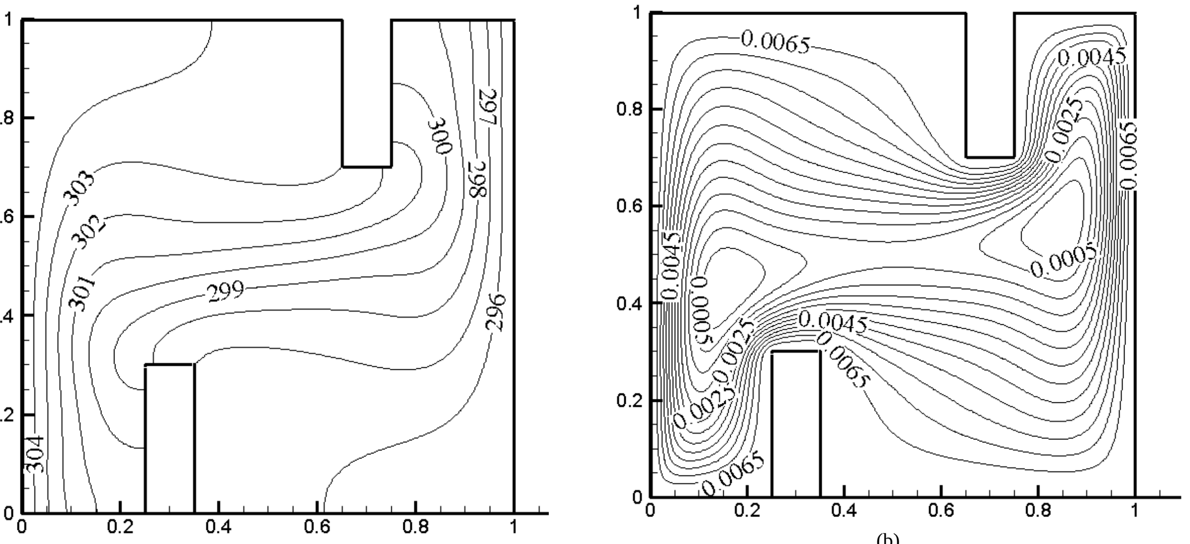


(a)



(b)
d=0.5

Fig.2. the effect of the positions of two baffles attached to top and bottom walls in different locations for h=0.3, Ra=10^5 and $\phi = 10\%$ (a. Isotherms b. Streamlines)

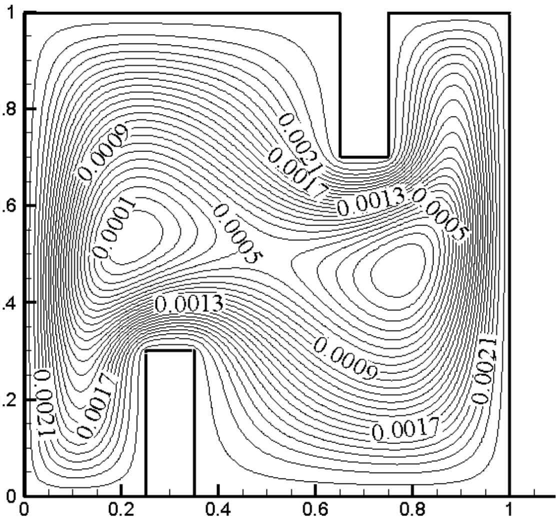


(a)

(b)
Ra=10^6

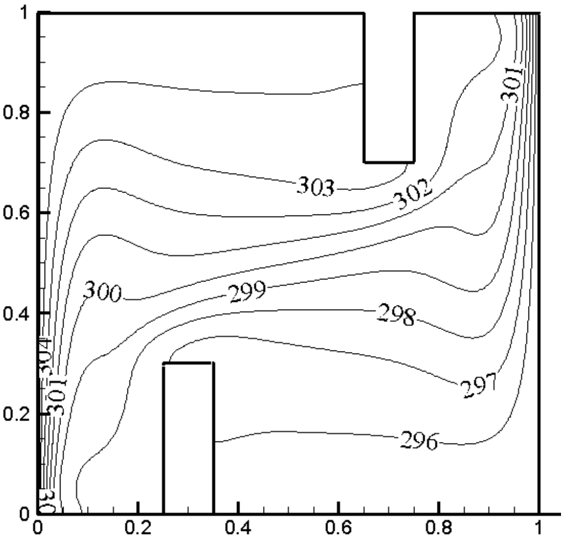
1

Fig.3. The effect of Rayleigh number for h=0.3, d=0.3 and ϕ =10% (a. Isotherms b. Streamlines)

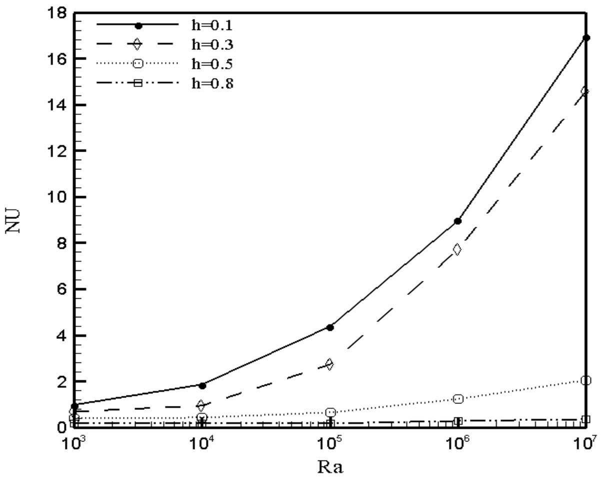


(b)
Ra=10^5

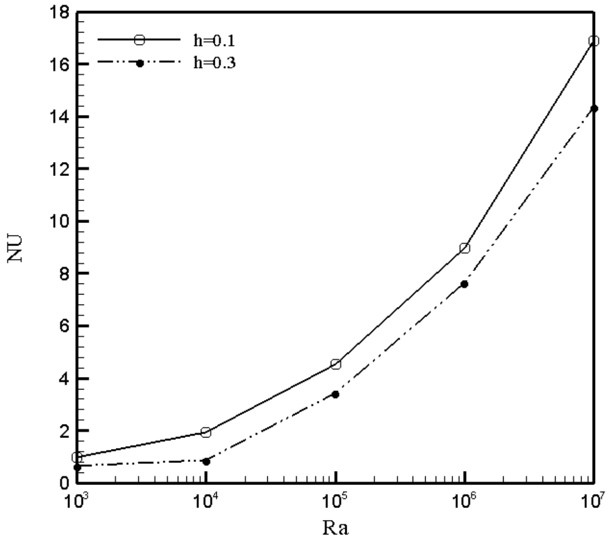
5



(a)



d = 0.3



d = 0.5

Fig.4. the effect of Rayleigh number on Nusselt number for different baffle height

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