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ORIGINAL RESEARCH PAPER

Effect of nanoparticle shape on natural convection heat transfer in a square cavity with partitions using water-SiO_2 nanofluid

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ABSTRACT: In this paperA numerical investigation is performed to study the effects of different nanofluids on convective heat transfer enhancement in a partitioned square cavity subject to different shapes of nanoparticle using water-SiO_2 nanofluid. This study has been carried out to analyze the effects of SiO_2 nanoparticle, its volumetric fraction between 2 and 4%, and nanoparticle shape (i.e. blades, platelets, cylindrical, bricks, and spherical), on the fluid flow and heat transfer characteristics. The overall continuity, momentum, and energy equations are solved by using the finite-volume method and the SIMPLE algorithm. The influence of related parameters such as Rayleigh number ($Ra=10^5$ to 10^7) and height of partition (h=0.1, 0.3, 0.5H) are studied. Based on the results, independent of nanoparticle shape, the streamlines and isotherms are extremely affected by Rayleigh number and height of partition. For a fixed amount of the partition height, average Nusselt number increases as the Rayleigh number rises.

KEYWORDS: *Cavity; Nanofluid; Nanoparticle shape; Natural convection; SiO_2*

INTRODUCTION

The natural convection is the dominant mechanism of heat transfer that is mostly encountered in various engineering applications, so augmentation of this problem is an essential topic of heat transfer as we can observe in most of researches nowadays. An appropriate method to improve the heat transfer is using the particles with nanometer-scale in the base fluid. A suspension of fluids with nanoparticles is called nanofluid. This technology has been widely used in industries since nanofluids cause fluid thermal conductivity enhancement with distribution of nanoparticles in the base fluid. At first, Choi [1] used the term of nanofluid. Different works have been already studied to investigate the performance of the nanofluids. Patel et al. [2] showed that adding just 0.00026 vol% of Ag particles to the base fluid, leads to 5-21% increase in the thermal conductivity of the nanofluid. Zhu et al. [3] analyzed the dispersion behaviors and thermal conductivity of Al_2O_3-H_2O nanofluids in water under different pH values and different sodium decylbenzenesulfonate (SDBS) concentration. Anoop et al. [4] investigated two nanofluids according to their particle sizes. It was observed that both nanofluid with 45 nm particles showed a higher heat transfer coefficient than that with 150 nm particles. Masuda et al. [5] indicated that adding 4.3% of TiO_2 and g- Al_2O_3, increases the thermal conductivity11 and 32%, respectively. Eastmann et al. [6] showed that Cu-ethylene glycol with φ=0.3% causes a 40% increase in thermal conductivity. Sivasankaran et al. [7] illustrated that the type of nanoparticles considered is very important on the convective heat transfer application. A 100% enhancement in the thermal conductivity of the base fluid was achieved by Grimm [8] for using aluminum particles with a volume fraction varying between 0.5-10%. Khanafer et al. [9] investigated heat transfer enhancement in a two-dimensional enclosure utilizing nanofluids for various important parameters. They found that the suspended nanoparticles substantially increase the heat transfer rate at any given Grashof number. The thermal characteristics of natural convection in a rectangular cavity heated from below with Al_2O_3 nanofluids with Jang and Choi's model for predicting the effective thermal conductivity of nanofluids and various models for the effective viscosity was investigated by Hwang et al. [10]. The results showed that water-based Al_2O_3 nanofluids is more stable than base fluid in a rectangular cavity. Abu-nada and chamkha [11] studied the natural convection heat transfer characteristics in a differentially heated enclosure filled with a CuO-EG-Water nanofluid for different variable thermal conductivity and variable viscosity models. According to the results, the effects of the viscosity models are predicted to be more predominant on the behavior of the average Nusselt number than the influence of the thermal conductivity models.

In another study, Abu-nada and Oztop [12] numerically

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Nomenclature

		x,y	Cartesian coordinates (m)
C_p	specific heat at constant pressure (J/kg K)		**Greek Symbols**
C_k	thermal conductivity ratio	α	thermal diffusivity (m^2/s)
d	distance of partition from hot wall (m)	β	thermal expansion coefficient (K^{-1})
g	gravitational acceleration (m/s^2)	φ	nanoparticle volume fraction
H	cavity hight (m)	ρ	density (kg/m3)
h	partition height (m)	μ	dynamic viscosity (m^2/s)
k	thermal conductivity (W/m K)		**Subscripts**
p	pressure (N/m^2)	c	cold
Pr	Prandtl number = $\upsilon_{nf}/\alpha_{nf}$	bf	base fluid
Ra	Rayleigh number = $g\beta\Delta TH^3/\alpha\upsilon$	h	hot
T	temperature (K)	nf	nanofluid
u,v	x and y components of velocity (m/s)	p	particle
w	partition width (m)	eff	Effective thermal conductivity of nanofluid

analyzed the effect of the inclination angle on the natural convection heat transfer and fluid flow in a two-dimensional enclosure filled with Cu nanofluid. They showed that at high Rayleigh numbers, the percentage of the heat transfer enhancement decreased. Anilkumar and Jilani [13] studied the natural convective heat transfer in a partitioned cavity utilizing nano fluids for various pertinent parameters. The results illustrated that the nano particle solid volume fraction, leads to the increase in nanofluid heat transfer rate. Sayehvand et al. [14] numerically analyzed natural convection heat transfer in a partitioned square cavity using water/Al_2O_3 nanofluid. They studied the influence of partitions height on heat transfer and showed that the average Nusselt number decreases as partition height rises. Jahanshahi et al [15] studied numerical simulation of free convection based on measure conductivity in a square cavity using water/sio_2 nanofluid. They showed the Nusselt number increases with volume fraction of nanoparticle for the whole range of Rayleigh numbers. Kefayati et al. [16] simulated Natural convection in enclosures using water/SiO_2 nanofluid with Lattice Boltzmann method (LBM). The thermal conductivity of nanofluids was obtained on basis of experimental data. The comparisons show that the average Nusselt number increases with volume fraction for the whole range of Rayleigh numbers and aspect ratios. Mahian et al. [17] studied first and second law of for a flat plate mini-channel where the working fluid was the suspension of boehmite alumina nanoparticles in a mixture of water and ethylene glycol. They present the results of outlet temperature and entropy generation for different shape of nanoparticles including blades, platelets, cylindrical, bricks. They indicated that the heat transfer reduces with an increase in volume fraction of nanoparticles and this reduction was higher for platelet shaped particles. Vanaki et al. [18] presented a numerical investigation to study the effects of different nanofluids on the thermal and flow fields through transversely wavy wall channels. It was found that the SiO_2-EG nanofluid with platelets nanoparticle shape gives the highest heat transfer enhancement compared with other tested nanofluids. Douglas et al. [19] described the numerical simulation of natural convection heat transfer of Cu–water nanofluids in a square enclosure. Their results showed that the Nusselt number for nanofluids was basically the same as that obtained for the base fluid. Therefore, the enhancement observed in the heat transfer coefficient was significant due to the augmentation in the thermal conductivity. Hemmat et al. [20] numerically studied the effects of nanoparticles type and volume fraction on natural convection in a squred cavity with a cylindrical block in and improved that increasing volume fraction and Ra number enhance the rate of heat transfer.

Although a lot of studies have been carried out to investigate the performance of nanofluids in cavities, most of them have presented the influence of nanofluids on heat transfer enhancement without considering the shape of nanoparticles. To our research, little studies have been done on nanoparticles shape, so the aim of this study is to analyze the effects of SiO_2 nanoparticle shapes on natural convection. Therefore, we considered five different shapes of nanoparticles in order to demonstrate the performance of them comparing with each other, in a partitioned cavity. Also present work evaluates the effects of different heights of the partition for two values of nanoparticles volume fraction (2%, 4%). In addition, the effects of Rayleigh number and partitions height on the Nusselt number are studied.

PROBLEM DESCRIPTION AND MATHEMATICAL FORMULATION

A schematic view of the differentially heated square cavity, considering in two-dimensional, is shown in Figure 1. Two adiabatic vertical partitions are attached to the top and bottom walls at a fixed distance from the vertical walls (d=0.3H). the top and the bottom walls are assumed to be adiabatic as the same. The vertical left and right walls are considered as the hot and cold walls, respectively. The hot wall is at constant temperature T_h=305K at X =0, and the

cold wall temperature is at T_c=295K at X =1. the enclosure is filled with a mixture of water as the base fluid and SiO_2 nanoparticles, that we have considered them as a single phase nanofluid.

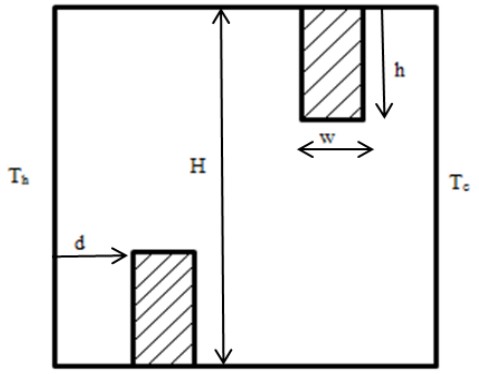


Fig. 1. Schematic of the partitioned square cavity

It is treated that the nanofluid is Newtonian, incompressible and laminar and the base fluid and the nanoparticles are in a thermal equilibrium state. the properties of the nanofluid are considered constant, except for the density of the nanofluid which is governed by Boussinesq approximation.

The thermophysical properties of the base fluid and the nanoparticles are given in Table 1.

Table 1
The thermophysical properties of SiO_2 , Al_2O_3 and base fluid (water) at T = 300 K [21].

Thermophysical properties	water	SiO_2	Al_2O_3
ρ (kg/m^3)	998.2	2200	Al_2O_3
cp (J/kg-K)	4182	703	3970
k (W/m-K)	0.6	1.2	765
μ (Ns/m^2)	0.001003	-	25

According to the above assumptions, the following formulas are obtained [14]:

Continuity equation:

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

x-momentom equation:

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{\partial p}{\partial x}+Pr_{bf}\left(\frac{c_{p,nf}\mu_{nf}}{k_{nf}}\right)\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right) \tag{2}$$

where Ra and Pr number defined as:

$$Ra=\frac{g\beta\Delta TH^3}{\alpha\upsilon},\quad \Pr=\frac{\upsilon_{nf}}{\alpha_{nf}} \tag{3}$$

Y-momentom equation:

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{\partial p}{\partial y}+Pr_{bf}\left(\frac{c_{p,nf}\mu_{nf}}{k_{nf}}\right)\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+Ra_{bf}\ \Pr_{bf}\ \beta_{nf}\left(\frac{\rho_{nf}c_{p.nf}}{k_{nf}}\right) \tag{4}$$

energy equation:

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_{nf}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \tag{5}$$

The effective density of the nanofluid is given by:

$$\rho_{nf}=(1-\varphi)\rho_{bf}+\varphi\rho_p \tag{6}$$

The heat capacitance of the nanofluid is expressed as:

$$(\rho c_p)_{nf}=(1-\varphi)(\rho c_p)_{bf}+\varphi(\rho c_p)_p \tag{7}$$

The thermal expansion coefficient of the nanofluid is expressed by:

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

MODEL VALIDATION

A numerical study was performed to investigate the natural convection in a nanofluid-filled (water-Al_2O_3) partitioned square cavity with isothermal vertical walls and adiabatic horizontal walls.

All the simulations was performed for Ra=10^5 and 10^7, φ=20%, d=0.3H, w=0.1H and different partition height (h=0.1, 0.3, 0.5H).

In Figure 2, The results of average Nusselt number for partitioned cavity using base fluid (water) in compare with using nanoparticles of Al_2O_3 with volume fraction of 20%, in base fluid, are presented.

As it is showed in Figure 2, average Nusselt number increases for case of using Al_2O_3 nanoparticles. For validation, numerical results for average Nusselt number in a square cavity are compared with previous works. The comparison is shown in Table 2, which shows a very good agreement.

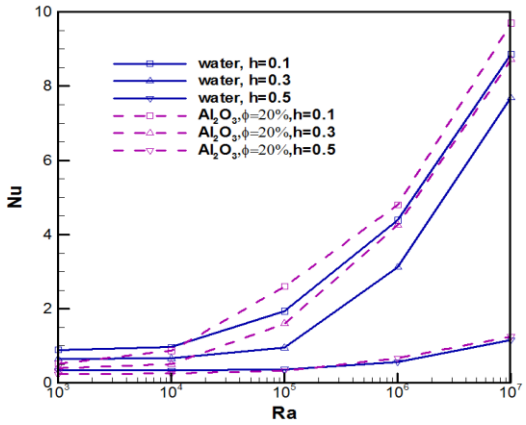


Fig. 2. comparison of average Nu number in different height of partitions for using (water) base fluid and mixture of (water-Al_2O_3 20%)

Table 2

Model validation of present study comparing with previous work for cavity concluding partitions utilizing water- Al_2O_3 nonofluid.

Height of partition	Average Nu number			
	Present work		Sayehvand et al. [14]	
	$Ra=10^5$	$Ra=10^7$	$Ra=10^5$	$Ra=10^7$
h=0.1H	2.6	9.7	2.61	9.76
h=0.3H	1.6	8.72	1.67	8.79
h=0.5H	0.33	1.25	0.354	1.25

Furthermore the computed results are presented in Figure 3 in compared with the results of Sayehvand et al. [14].

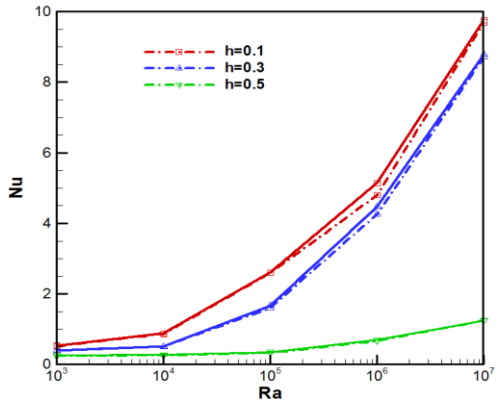


Fig. 3. Validation of average Nu number for present work (dashed line) and Sayehvand et al. [14](continued line)

A grid independence test was done for the cavity using water as a working fluid and SiO_2 nanoparticles (bricks shape), to analyze the effects of grid sizes on the results. Different grids, including 70×70, 80×80, 90×90 and 100×100 were tested for $Ra=10^7$ and h=0.1H. It is observed that a 90×90 grid, is accurate enough to be chosen as the appropriate grid for all calculations.

Different shape of nano particles

In the present work a numerical research of flow and heat transfer in a cavity with two adiabatic partitions, in order to illustrate the influence of main parameter such as Ra number, partitions height and the shape of nanoparticles on heat transfer is studied. For this purpose, the results of five different particle shapes such as spherical, platelets, blades, cylindrical and bricks are compared in this study. Furthermore the influence of Ra number and partitions height on average Nusselt number are presented and discussed. Average Nu number for different grid numbers used in grid independence study is shown in Table 3.

Table 3

Average Nu number for different grid numbers used in grid independence study.

Grid size	Average Nu number	Difference
70×70	8.8189	
80×80	8.8465	0.02
90×90	8.8574	0.01
100×100	8.8991	0.04

For this simulation we have considered Rayleigh number ($Ra=10^3$ to 10^7), height of partition (h=0.1, 0.3, 0.5H) at a fixed distance from the walls (d=0.3H). by means of considering the effects of particle shapes on thermophysical properties of nanofluids, the following equations (9-12) were obtained by Timofeeva et al. [21]:

Effective thermal conductivity:

$$\frac{k_{eff}}{k_{bf}} = 1 + \left(C_k^{shape} + C_k^{surface}\right)\varphi = (1 + C_k)\varphi \qquad (9)$$

The effective thermal conductivity of nanofluid can be obtained by using the available data from Table 4.

Table 4

Contribution of particle shape effect and surface resistance to thermal conductivity of nanoparticle suspensions [21].

Type	Aspect ratio	C_k	C_k^{shape}	$C_k^{surface}=C_k-C_k^{shape}$
Platelets	1:1/8	2.61	5.72	-3.11
Blades	1:6:1/12	2.74	8.26	- 5.52
Cylindrical	1:8	3.95	4.82	- 0.87
Bricks	1:1:1	3.37	3.72	- 0.35

For spherical shape of nanoparticles equation 10 is used:

$$\frac{k_{nf}}{k_{bf}} = \frac{k_p + 2k_{bf} - 2\varphi\left(k_{bf} - k_p\right)}{k_p + 2k_{bf} + \varphi\left(k_{bf} - k_p\right)} \qquad (10)$$

For dynamic viscosity of nanoparticles we have used equation 11 with the presented data in Table 5:

$$\mu_{eff} = \mu_{bf}\left(1 + A_1\varphi + A_2\varphi^2\right) \tag{11}$$

Table 5
Viscosity coefficient for different nanoparticle shapes[21].

Coefficient	platelets	blades	cylindrical	bricks
A_1	37.1	14.6	13.5	1.9
A_2	612.6	123.3	904.4	471.4

For spherical nanoparticle we have used equation 12:

$$\mu_{nf} = \frac{\mu_{bf}}{(1-\varphi)^{2.5}} \tag{12}$$

Another important dimensionless paramater in the study of convection heat transfer is the Nusselt number (Nu), which is defined as:

$$Nu = \frac{hl}{k} \tag{13}$$

where the convection heat transfer coefficient, h, is given as the ratio between the higher temperature wall heat flux and the temperature difference. Thus, one can rewrite Nu as:

$$Nu = \frac{q''}{\Delta T}\frac{l}{k} = -\left(k\frac{\partial T}{\partial x}\right)\frac{l}{\Delta T k} \tag{14}$$

RESULTS AND DISCUSSION

A problem of natural convection is numerically analyzed in a nanofluid-filled water-SiO_2 partitioned square cavity with isothermal vertical walls and adiabatic horizontal walls.

All the simulations are presented for Ra=10^5 and 10^7, d=0.3H, w=0.1H and different partition height (h=0.1, 0.3, 0.5H), with considering the effect of various nanoparticle shapes and the volumetric fraction of SiO_2 nanoparticle, which was investigated in two values of φ=2%, 4%. In all cases, two partitions are placed at d=0.1H, distance from the isotherm walls, in other expression, the bottom baffle is located near the hot wall, and the top baffle is located near the cold wall. The contours of isotherms and velocity vectors of the studied partitioned cavity for water-SiO_2 nanofluid in different partition heights, is shown in Figures 4 and 5.

In Figure 4, as the considered Rayleigh number (Ra=10^5) is attenuate, both convection and conduction mechanisms are effective and should be introduced as two considerable mechanisms in this moderate Ra number.

From the velocity vectors one can see large clockwise circulations.

When the partition height is little, an elliptical vortex is formed, and the velocity vectors are uniformly distribute, except near the partitions, where a deflection occurs to pass them.

However, as the height increases, the single vortex breaks down into two separate vortexes, and the centers move towards the hot and cold walls, even though we can see just one circulation yet. Moreover, the flow circulation is intensely affected by deflection of flow that is more evident in higher heights.

Usually, it is found that, partition height increasing, restricts the fluid flow and cause the temperature gradient decrease also with increasing partitions height, the velocity magnitude decreases and it is because of the two vortexes which appear in higher height.

It is noteworthy that near the isotherm walls and partitions, velocity magnitude has the most value. For lower heights, the isotherms near the hot and cold walls are vertical, but they are horizontal at the other parts. By increasing partition height, the isotherms tend to be more skewed.

Nevertheless, they are still horizontal between the two partitions, whereas the compression of isotherm lines, considerably become more between the two partitions. The reason is the natural convection which is vigorous at the top left and bottom right of the square cavity but this effect is not strong enough between the partitions, therefore horizontal lines are seen.

At Ra=10^7(figure 5), as the partition height rises, heat transfer occurs mainly because of the convection and conduction mechanism is weaker, also the primitive circulation is divided into two circulations, one circulation adjacent to the hot wall and the other circulation near the cold wall. Two vortexes are formed that move towards the walls.

The fluid flow is compacted at the distance between partitions and the walls. Predominance of the convection influences the isotherms as Rayleigh number increases, so with increasing Ra number from the value of 10^5 to 10^7, the isotherms form in flatter horizontal lines and also the velocity magnitude rises so the fluid flow circulates with rather more velocity in the cavity.

Once more, it is obvious that for low partition height, isotherms are horizontal at the center of the cavity and vertical isotherms are developed only inside the very thin boundary layers. As the height increases, the density of the isotherms near the boundary layer reduces and the horizontal isotherms become packed between the two partitions.

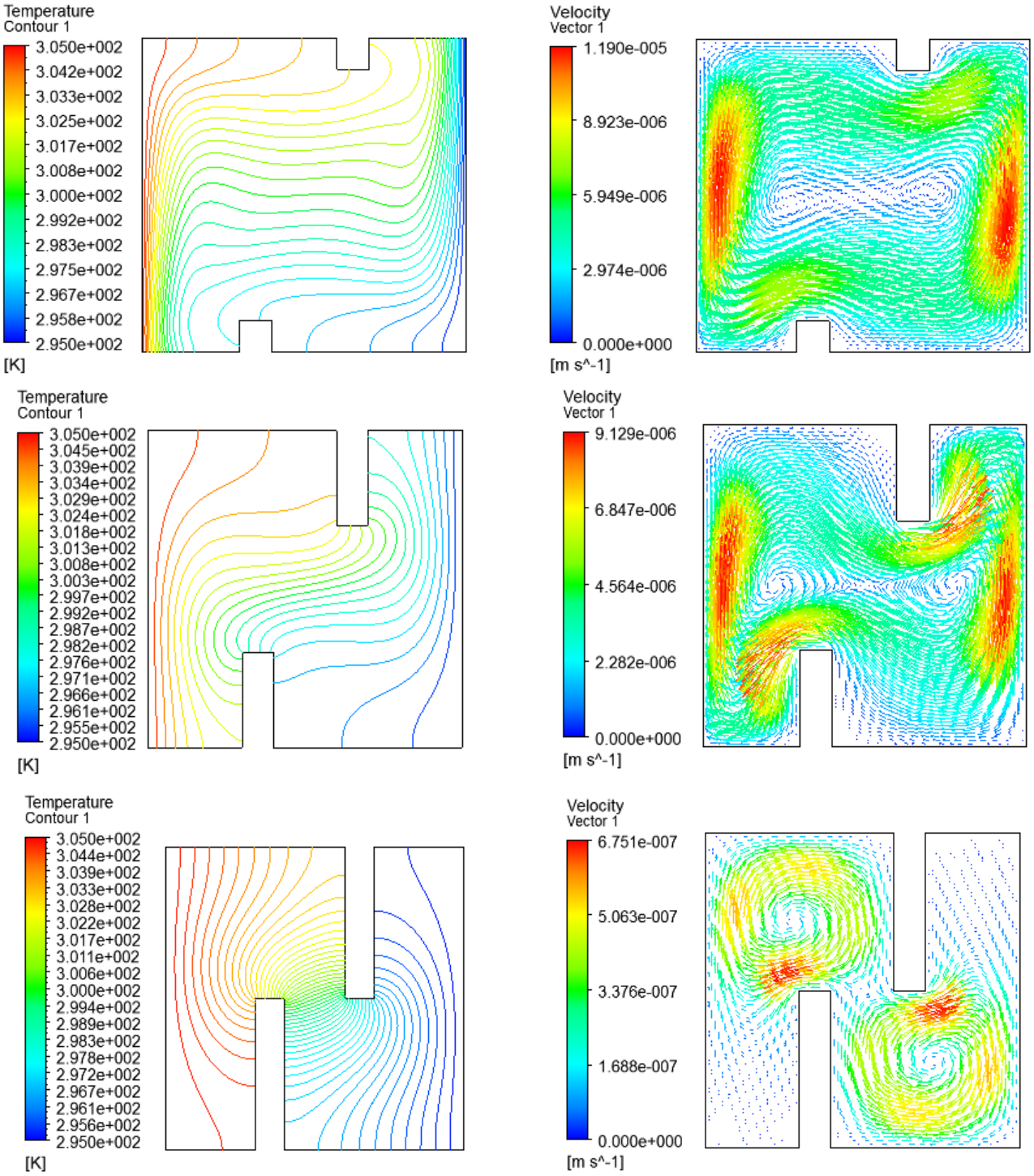


Fig. 4. Effect of partition height at Ra=$10^5$and d=0.3 left isotherms and right velocity vectors

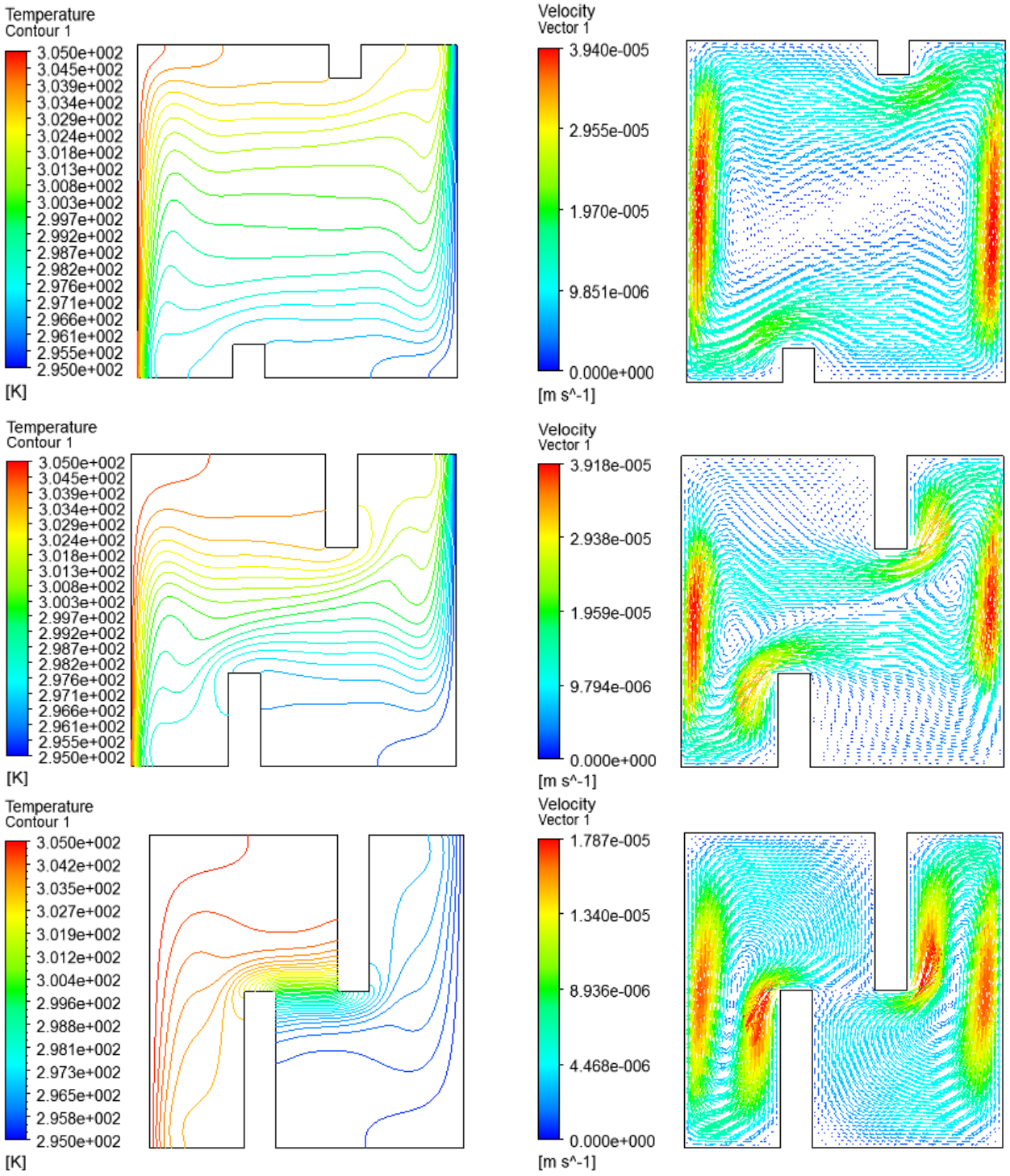


Fig. 5. Effect of partition height at Ra=10^7 and d=0.3 left isotherms and right velocity vectors

Effects of nanoparticle shapes on Nu number

Figure 6, shows the effect of SiO_2 nanoparticle shapes on average Nu number as a function of Ra number with values in range 10^3 to 10^7, and in different height of partitions, h=0.1H, h=0.3H, h=0.5H. it can be obtained that when the height of partition is little (h=0.1H, h=0.3H), considering type of different nanoparticle shapes has a little influence on Nu number because the difference between the results of Nu number is very little as Figure 6 can obviously confirmed this. Even though for the case of h=0.5H, it can

be discovered that in lower range of Ra (10^3-10^5), the effect of nanoparticle shapes on Nu number is negligible, but also, as Ra number increases, the buoyancy force appear stronger so the results can be distinct from each other and the effect of different shapes might be considered. In this case the platelets shape of nanoparticle has the high value of Nu number and therefore the most rate of heat transfer.

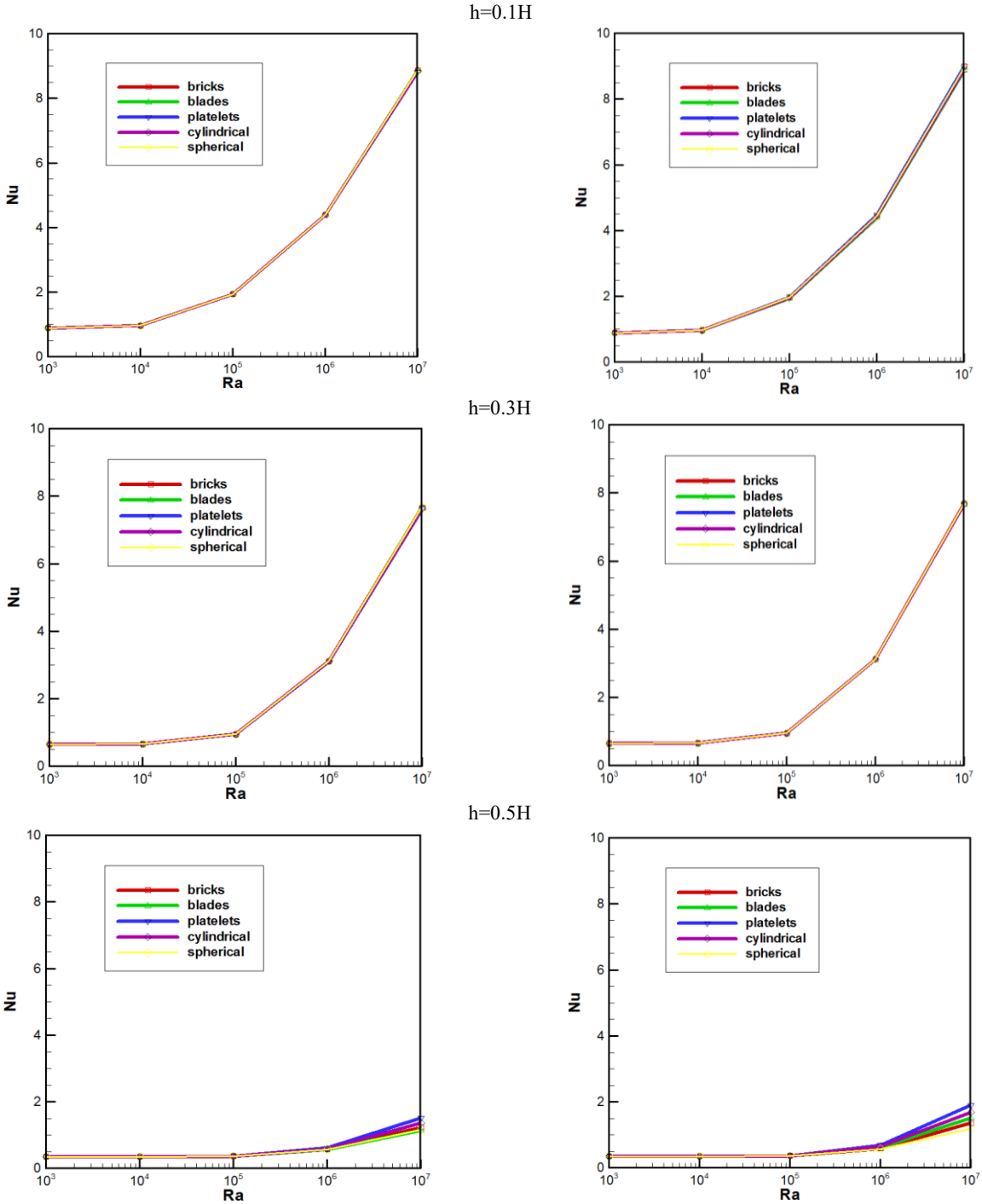


Fig. 6. effect of SiO_2 nanoparticle shape on average Nu number on hot wall at different height of partition; left φ=2% and right φ=4%

Effects of nanoparticle type (Al_2O_3 and SiO_2 nano particle)

Figure 7, presented comparison of average Nu number on the hot wall at different height of partition, in case of using different shape of SiO_2 nanoparticle (breaks, blades, platelets) with Al_2O_3 nonoparticle instead of using only the base fluid (water), which can show that how mixture of base fluid with nanoparticles would increase Nu number. It can be concluded that Al_2O_3 nonoparticle, has the high effect on Nu number because the thermal conductivity coefficient of Al_2O_3 is much greater than SiO_2 so the effective thermal conductivity (k_{eff}) which considered for nanofluid has a bigger value and this important factor could enhance heat transfer in the partitioned cavity as well.

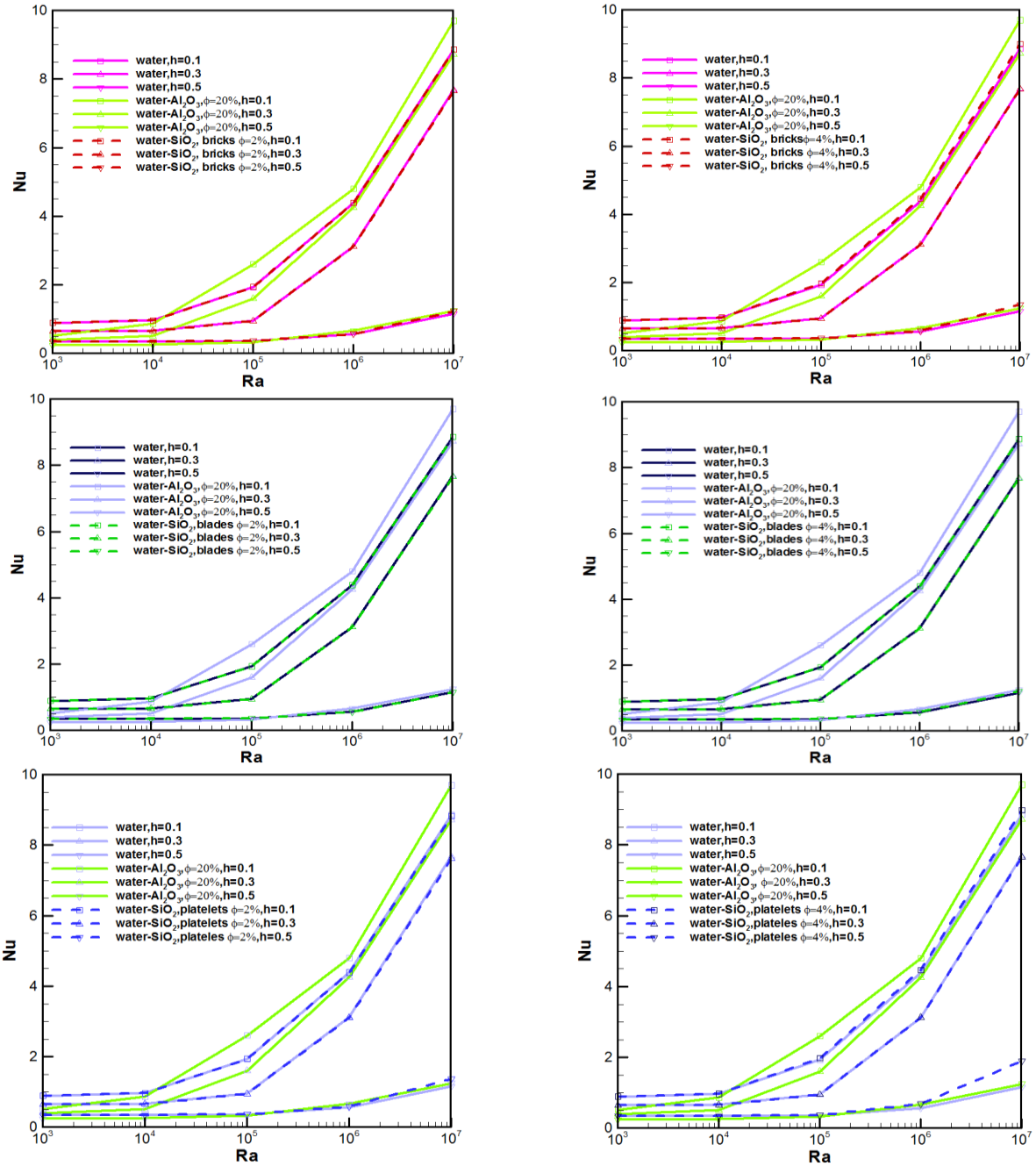


Fig. 7. Comparison of average Nu number on the hot wall at different height of partition, in case of using different shape of SiO_2 nanoparticle with Al_2O_3 nanoparticle

The effect of nanoparticle shape can be considered in high values of partition height (h=0.5H) more ever at Ra 10^5-10^7, and with increasing volume fraction from φ=2% to φ=4% the concentration of nanoparticles amplifies in base fluid so Nu number rises and we can see that the platelets shape has the most average Nu number in h=0.5H and Ra=10^5-10^7. From Figure 8 one can see the variation of Nu number on the hot wall in comparison of, using cylindrical and spherical shape of SiO_2 nanoparticle instead of Al_2O_3 nonoparticle, at different height of Partition. It can be concluded that, for case of cylindrical shape, as we increase the volume fraction 2% to value of 4%, the average Nu number rises and this effect is more clear in h=0.5H and also in Ra=10^5-10^7. For the case spherical shape, we can see just a little change in Nu number, although we increased the volume fraction.

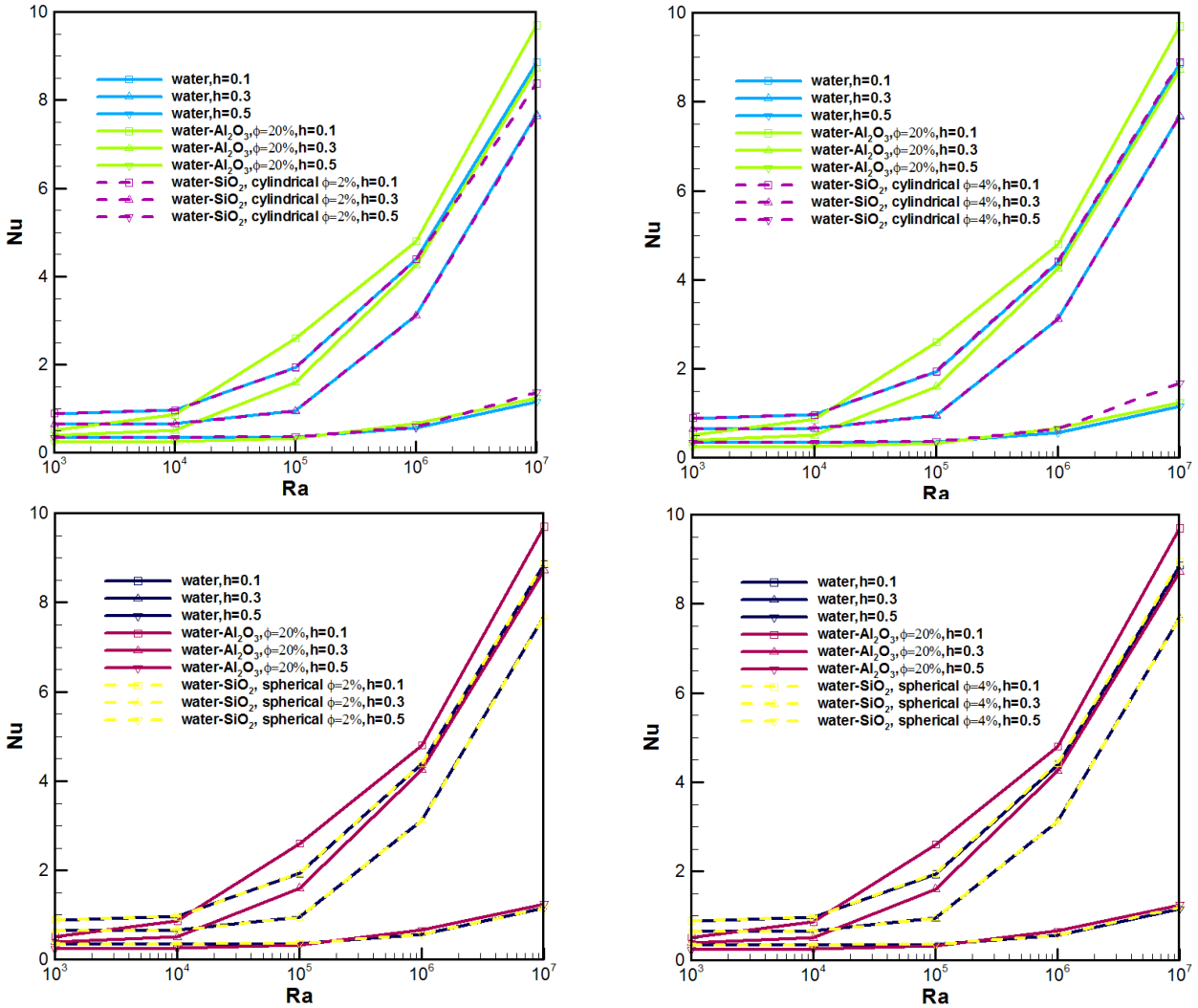


Fig. 8. comparison of average Nu number on the hot wall at different height of partition, in case of using cylindrical and spherical shape of SiO_2 nanoparticle with Al_2O_3 nanoparticle

Effects of partitions height

Figure 6, displays the variation between Nusselt number and Rayleigh number for different heights of the partitions. According to the graphs, at a fixed height of the partitions, increasing Rayleigh number induces to an increase in the Nusselt number. By rising Rayleigh number, heat transfer through convection conquers the conduction and therefore, Nusselt number increases. As the height of the partition increases, Nusselt number decreases and this reduction is the result of conduction heat transfer which is much greater than the convection, as the height of partitions increase the flow limitation between them rises so flow circulation comes weaker.

Effects of increasing volume fraction

From the overall Figures (6-8), one can find that, the average Nu number increases as nanoparticles volume fraction rises from φ=2% to φ=4%, and this is more effective in higher Ra number and the highest partition height (h=0.5H), this is because of an increase in

concentration of nanoparticles and much stronger flow circulation that occurs in high Ra. as it is indicated from the Figures (7-8), the heat transfer enhancement of using nanofluid is slightly observed for water- Al_2O_3 nanofluid at φ=20%.

Figure 7 comparison of average Nu number on the hot wall at different height of partition, in case of using different shape of SiO_2 nanoparticle with Al_2O_3 nanoparticle.

CONCLUSION

CFD analysis of Natural convection heat transfer is studied in a partitioned square cavity. Simulation is done for $Ra=10^5$ to10^7, φ=2%, 4% and for different partition height of the water-SiO_2 nanofluid-filled cavity and different nanoparticle shapes. According to the consequences, Rayleigh number and height of the partition are important factors that actually affect the isotherms and velocity vectors. From the results we can conclude the following:

1. By increasing partition height, one vortex decomposes into two vortexes which move towards the top left hot and bottom right cold walls and also the density of the isotherms closed to the walls reduces, despite the isotherms between partitions that become more compressed. in addition, at high partitions, the isotherms are horizontal between two baffles.
2. At $Ra=10^7$ the flow is more limited in the distance between walls and partitions and in this condition increasing the height, cause the fluid flows in two clockwise circulations in the mentioned cavity.
3. For a fixed amount of the partition height, Nusselt number increases as the Rayleigh number goes up. In other words, for a fixed Rayleigh, with the increasing partition height, Nusselt number decreases along the hot wall and this is because of the fluid limitation that is caused by partitions.
4. Using various shapes of SiO_2 nanoparticle would increase average Nu number and it is more effective in height of partition, h=0.5H and the range of $Ra=10^5$-10^7.
5. The heat transfer augmentation is satisfied as well by using Al_2O_3 nanoparticle in the water as the base fluid, comparing with SiO_2 nanoparticle.
6. Average Nu number increases as volume fraction of nanoparticle rises from 2% to 4%, and it could be more effective in platelets and cylindrical shapes of nanoparticle which considerably occure in h=0.5H and the range of $Ra=10^5$-10^7.
7. by increasing Ra number from value of 10^5 to 10^7, the flow is more confined in the distance between walls and partitions. Furthermore, it can be concluded that, with increasing partition height, the isotherms seem to be more horizontal between two partitions.
8. The results indicate that Nu number increases as the concentration of nanoparticle rises from 2% to 4%, and it could be more obvious for platelets and cylindrical shapes of nanoparticle which considerably augments at h=0.5H and the range of $Ra=10^5$-10^7.

REFERENCES

[1] Chol SU. Enhancing thermal conductivity of fluids with nanoparticles. ASME-Publications-Fed. 1995 Nov 12;231:99-106.

[2] Patel HE, Das SK, Sundararajan T, Sreekumaran Nair A, George B, Pradeep T. Thermal conductivities of naked and monolayer protected metal nanoparticle based nanofluids: Manifestation of anomalous enhancement and chemical effects. Applied Physics Letters. 2003 Oct 6;83(14):2931-3.

[3] Zhu D, Li X, Wang N, Wang X, Gao J, Li H. Dispersion behavior and thermal conductivity characteristics of Al_2O_3–H_2O nanofluids. Current Applied Physics. 2009 Jan 31;9(1):131-9.

[4] Anoop KB, Sundararajan T, Das SK. Effect of particle size on the convective heat transfer in nanofluid in the developing region. International journal of heat and mass transfer. 2009 Apr 30;52(9):2189-95.

[5] Masuda H, Ebata A, Teramae K. Alteration of thermal conductivity and viscosity of liquid by dispersing ultra-fine particles. Dispersion of Al_2O_3, SiO_2 and TiO_2 ultra-fine particles.

[6] Eastman JA, Choi SU, Li S, Yu W, Thompson LJ. Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles. Applied physics letters. 2001 Feb 5;78(6):718-20.

[7] Sivasankaran S, Aasaithambi T, Rajan S. Natural convection of nanofluids in a cavity with linearlyvarying wall temperature.

[8] Grimm A. Powdered aluminum-containing heat transfer fluids. German patent DE. 1993;4131516:A1.

[9] Khanafer K, Vafai K, Lightstone M. Buoyancy-driven heat transfer enhancement in a two-dimensional enclosure utilizing nanofluids. International journal of heat and mass transfer. 2003 Sep 30;46(19):3639-53.

[10] Hwang KS, Lee JH, Jang SP. Buoyancy-driven heat transfer of water-based Al_2O_3 nanofluids in a rectangular cavity. International Journal of Heat and Mass Transfer. 2007 Sep 30;50(19):4003-10.

[11] Abu-Nada E, Chamkha AJ. Effect of nanofluid variable properties on natural convection in

enclosures filled with a CuO–EG–water nanofluid. International Journal of Thermal Sciences. 2010 Dec 31;49(12):2339-52.

[12] Abu-Nada E, Oztop HF. Effects of inclination angle on natural convection in enclosures filled with Cu–water nanofluid. International Journal of Heat and Fluid Flow. 2009 Aug 31;30(4):669-78.

[13] Anilkumar SH, Jilani G. Natural Convection Heat Transfer Enhancement in a Closed Cavity with Partition Utilizing Nano Fluids. InProceedings of the World Congress on Engineering 2008 Jan 1 (Vol. 2).

[14] Sayehvand H, Habibzadeh A, Mekanik A. CFD analysis of natural convection heat transfer in a square cavity with partitions utilizing Al2O3 nanofluid. International Journal of Nano Dimension. 2012 Mar 1;2(3):191-200.

[15] Jahanshahi M, Hosseinizadeh SF, Alipanah M, Dehghani A, Vakilinejad GR. Numerical simulation of free convection based on experimental measured conductivity in a square cavity using water/SiO_2 nanofluid. International Communications in Heat and Mass Transfer. 2010 Jul 31;37(6):687-94.

[16] Kefayati GR, Hosseinizadeh SF, Gorji M, Sajjadi H. Lattice Boltzmann simulation of natural convection in tall enclosures using water/SiO_2 nanofluid. International Communications in Heat and Mass Transfer. 2011 Jul 31;38(6):798-805.

[17] Mahian O, Kianifar A, Heris SZ, Wongwises S. First and second laws analysis of a minichannel-based solar collector using boehmite alumina nanofluids: effects of nanoparticle shape and tube materials. International Journal of Heat and Mass Transfer. 2014 Nov 30;78:1166-76.

[18] Vanaki SM, Mohammed HA, Abdollahi A, Wahid MA. Effect of nanoparticle shapes on the heat transfer enhancement in a wavy channel with different phase shifts. Journal of Molecular Liquids. 2014 Aug 31;196:32-42.

[19] Fontes DH, dos Santos DD, Padilla EL, Bandarra Filho EP. Two numerical modelings of free convection heat transfer using nanofluids inside a square enclosure. Mechanics Research Communications. 2015 Jun 30;66:34-43.

[20] Esfe MH, Arani AA, Karimiopour A, Esforjani SS. Numerical simulation of natural convection around an obstacle placed in an enclosure filled with different types of nanofluids. Heat Transfer Research. 2014;45(3).

[21] Timofeeva EV, Routbort JL, Singh D. Particle shape effects on thermophysical properties of alumina nanofluids. Journal of Applied Physics. 2009 Jul 1;106(1):014304.