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Nanofluid Effects On Heat Transfer By Natural Convection

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Abstract: This work deals with a numerical study on natural convection problem in a rectangular cavity, two-dimensional, differentially heated: the left vertical wall is heated to a constant temperature T_H, while the right vertical wall is kept at a cold temperature T_C such as ($T_H > T_C$) filled with nanoparticles at different concentrations φ. The fluid is considered incompressible, Newtonian and obeys the Boussinesq approximation. The influence of nanofluid, on the structure of the flow and heat transfer in the cavity was examined for a Rayleigh number Ra varies between $10^3 \leq Ra \leq 10^6$ and concentration of nanoparticles ranging from $0\% \leq \varphi \leq 4\%$ in order to examine the best average heat transfer rate through the cavity. The results show, in particular, that the increase of the volume fraction of the nanoparticles (φ) increases the average heat transfer rate.

Key words: Natural convection, nanoparticles, Nusselt number, Rayleigh number.

1. Introduction

The nanofluid has known many applications in industry which prompted several researches such experimental research. Heris et al. [1] examined copper oxide nanoparticles (CuO) and of aluminum trioxide (Al_2O_3), dispersed at various concentrations in water. Wen and Ding [2] have studied a flow nanofluid between two horizontal discs, one of which is uniformly heated. Nanofluid comprises of nanoparticles in water, typically (TiO_2) having a diameter between 30 and 40 nm, suspended in water. Oztop and Abu-Nada [3] have conducted numerical studies to analyze the effect of using different nanofluids on the distribution of temperature field in an enclosure height (H) and length (W) filled with a mixture of water and nanoparticles. Different types of nanofluids (Cu, Al_2O_3 and TiO_2) and different volume fractions (φ = 0.1, φ = 0.2) were investigated. They showed that the value of Rayleigh number and the size of the heater and the volume fraction of nanofluids affect heat transfer force. F. H. Lai et al. [4] have simulated natural convection in a cavity driven vertically and containing solid particles of Al_2O_3 undergoing movement with an incompressible fluid (water) with the Lattice Boltzmann method (LBM). The results indicate that the average Nusselt number increases with the increase of the Rayleigh number and the volume concentration of the particles. They showed that the concentration of the particles greatly affects the movement of the fluid in the cavity. When a numerical study, K.Khnafer et al. [5] studied the improvement of heat transfer in a two-dimensional enclosure using nanofluids.. Aminossadati S. M. et al. [6] performed a numerical study to analyze the natural convection cooling an integrated heat on the bottom wall in enclosure filled nanofluid. The upper chamber and the vertical walls are maintained at a relatively low temperature. The results indicate that the addition of nanoparticles in pure water improves cooling performance.

2. Description of the physical model

2.1 Geometrical configuration

The Studied physical model is shown in “Fig.1”. There is a rectangular cavity, two-dimensional, of height H and width L, differentially heated: the left vertical wall is heated to a constant temperature T_H,

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while the right vertical wall is maintained at the cold temperature T_C as ($T_H>T_C$). The other two horizontal walls are kept adiabatic. We consider the case of a square cavity and we take as reference temperature T_C temperature.

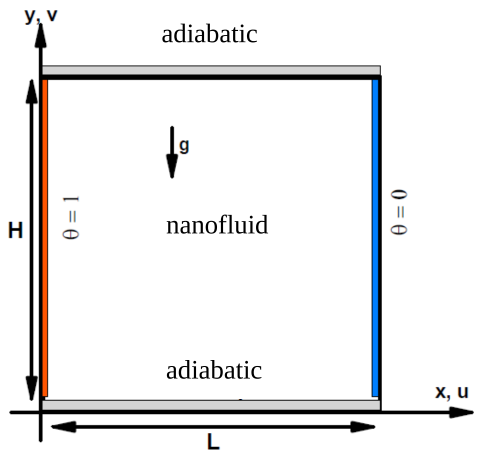

Fig.1: Differentially heated cavity filled with a nanofluid.

2.2 Validation of the code

The numerical simulations were conducted using a house code named "NASIM". This code is based on finite volumes, the projection method and uses a multi accelerated technical grid. In order to validate the code of calculation, numerical simulations were performed to Rayleigh numbers ($10^3 \leq Ra \leq 10^6$) for fluid consistent of pure water, corresponding to a void volume fraction ($\varphi = 0$) or ($1\% \leq \varphi \leq 4\%$). The results for Some reference variables such as the average Nusselt number Nu hot on the left wall, the maximum stream function Ψmax, and maxima of the components of u_{max} and v_{max} speed show good agreement with our results those in references [4] and [5].

2. Mathematical formulation

✓ *Equation of continuity*

$$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0 \tag{1}$$

✓ *Equation of conservation of momentum*

$$\frac{\partial U}{\partial t} + U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial Y} = -\frac{\partial P}{\partial X} + \frac{\mu_{NF}}{\rho_{NF}\alpha_F}\Pr\nabla^2 U \tag{2}$$

$$\frac{\partial V}{\partial t} + U\frac{\partial V}{\partial X} + V\frac{\partial V}{\partial Y} = -\frac{\partial P}{\partial Y} + \frac{\mu_{NF}}{\rho_{NF}\alpha_F}\Pr\nabla^2 V + \frac{(\rho\beta)_{NF}}{\rho_{NF}\beta_F} Ra\Pr\theta \tag{3}$$

✓ *Equation of energy conservation*

$$\frac{\partial \theta}{\partial t} + U\frac{\partial \theta}{\partial X} + V\frac{\partial \theta}{\partial Y} = \frac{\alpha_{NF}}{\alpha_F}\nabla^2\theta \tag{4}$$

3. Study of the natural convection in the case of the base fluid (water Pr = 6.2)

3.1 Qualitative Study

Regarding the thermal aspect, the presentation of profil of the axial temperature (y = 0.5) on water at different Rayleigh numbers in the 10^3-10^6 range is plotted on Figure 2.

Clearly observed from this figure a linear decrease of the dimensionless temperature of the central axis for the cavity (y = 0.5) of 0.5 to -0.5) for a Rayleigh number of 10^3. This gradual cooling of the temperature along the x-axis is due to the conductive regime dominates it. When Ra goes to higher values, we note that the lower half of the cavity cools and the contrary it is the upper half which heats up gradually with increasing Rayleigh number. This is related to the stratification phenomenon that begins to manifest from Ra = 10^5.

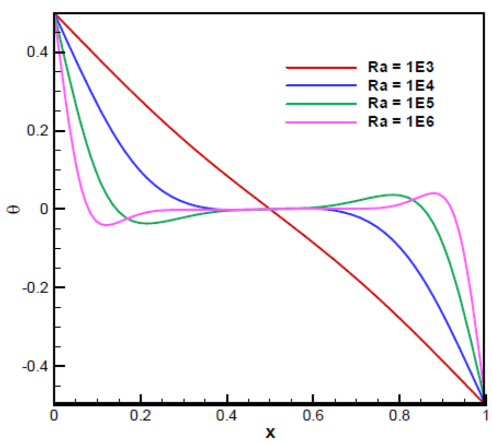

Fig.2 : Profile of the axial temperature (y = 0.5) on the water at different Rayleigh numbers in the range 10^3-10^6.

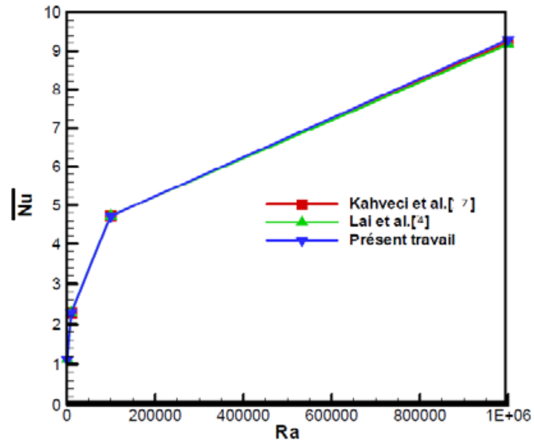

Fig.3 .Variation to the average Nusselt number on water at different Rayleigh numbers in the range 10^3-10^6.

3.2 Transfer Rate

Figure 3 shows the variation of the average Nusselt number on water at different Rayleigh numbers in the 10^3-10^6 range. It is clear that from this figure, the results of our code and those in the literature (ref.[5] and ref.[7]) are similar. This justifies the robustness of the numerical scheme implemented in our code.

4. Natural convection of a nanofluid

We will begin by studying the effect of the Rayleigh number "Ra" on natural convection in differentially heated cavity filled with water (Pr = 6.2) which are added alumina nanoparticles to a volume concentration of solid particles (φ = 4%).

Table1. Thermo-physical properties for water and nanoparticles.

	ρ (kg /m³)	*C_p (J/kg K)*	*k (W/mK)*	*β (K^{-1})*
Eau pure	997.1	4179	0.613	21×10^{-5}
Copper (Cu)	8933	385	401	1.67×10^{-5}
Silver (Ag)	10.500	235	429	1.89×10^{-5}
Alumin (Al_2O_3)	3970	765	40	0.85×10^{-5}
Titanium (TiO_2)	4250	686.2	8.9538	0.9×10^{-5}

4.1 Effect of the Rayleigh number Ra

In Figure 4 are shown the profiles of the longitudinal component of the velocity u in terms of the y on the central axis of the cavity (x = 0.5) for the case of alumina to 4% concentration of nanoparticles and different numbers of Rayleigh in the 10^3-10^6 range. From this figure we observe that the extrema of the u component of velocity increase significantly near the horizontal walls with the increase of Rayleigh. This means that the heat transfer provided by this component takes place from the left to the right and vice versa. This transfer is accelerated with the increase of Ra because the convective regime becomes dominant when Ra reaches high values. We note, moreover, that the u profiles remain symetrical and present the centro-symmetry property.

Regarding the thermal aspect, we start first by presenting the axial temperature profile (y = 0.5) on alumina 4% nanoparticles concentration and different numbers in the range of Rayleigh 10^3-10^6 in Fig.5. It is clear to see from this figure a linear decrease of the dimensionless temperature in central cavity (y = 0.5) of 0.5 to -0.5 for a Rayleigh number of 10^3. The gradual cooling of the temperature along the x-axis is due to the conductive regime dominates it.

When the number of passes Ra values above, we note that the lower half of the cavity cools and in the contrary it is the upper half which is heated gradually with the increase of Rayleigh. This is related to the stratification phenomenon that begins to magnifest for Ra = 10^5.

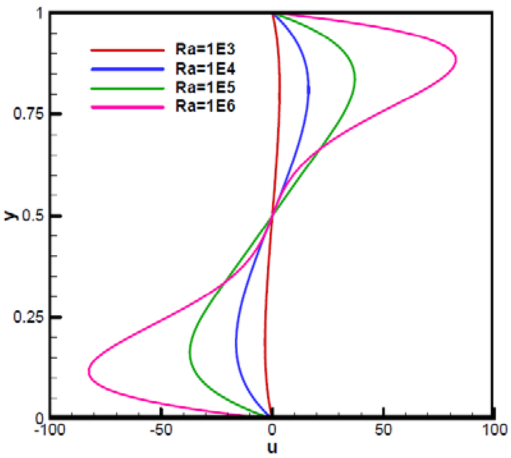

Fig.4 .Longitudinal component of the velocity u terms of y on the central axis of the cavity (x = 0.5) for the case of alumina and 4% of nanoparticle concentration and different Rayleigh numbers in the range 10^3-10^6.

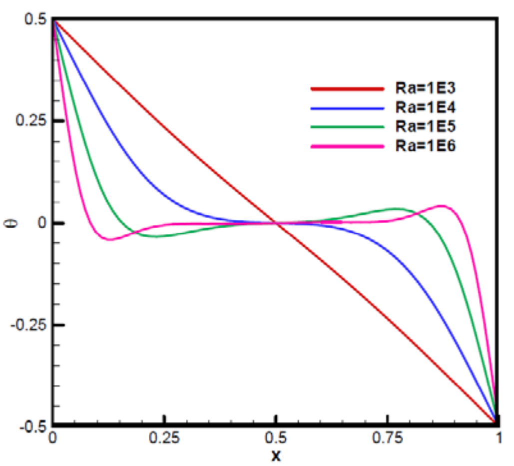

Fig.5 .Profile of the axial temperature (y = 0.5) on alumina for 4% nanoparticle concentration and at different Rayleigh numbers in the range 10^3-10^6.

4.2 Effect of the percentage of nanoparticles concentration

Figure 6 shows the change in average Nusselt number "Nu" on alumina according to the concentration of nanoparticles (1%≤φ≤4%) and different numbers of Rayleigh (10^3 ≤Ra≤10^6). In this figure, we see that when (Ra <10^5) the variation of Nu is very low with the solid volume fraction. At Ra = 10^5, Nu increases with the solid volume fraction with a lower gradient compared to that of Ra = 10^4. At Ra = 10^6, a slight increase was observed for Nu with the volume fraction of solid for alumina Al_2O_3. The difference between the results is proportional with the increase of Rayleigh and the concentration of alumina.

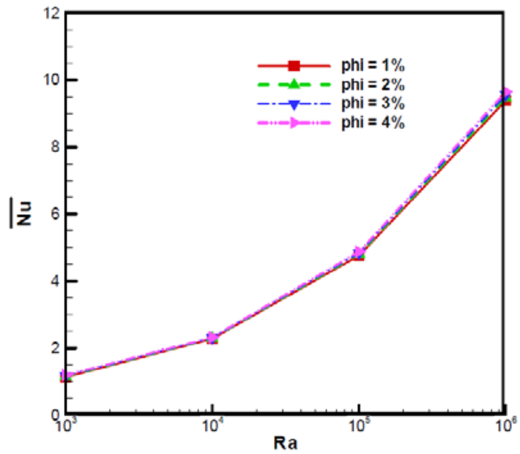

Fig.6 .Variation to the average Nusselt number on alumina according to the concentration of nanoparticles (1%≤φ≤4%) and at different Rayleigh numbers (10^3≤Ra≤10^6).

4.3 Effect of the type nanofluid

The Table 1 shows the thermo-physical properties of water and nanoparticles. It is clear to see from this table that the titanium (TiO_2) has the lowest thermal conductivity compared to other nanoparticles,

therefore it has the lowest values of Nu, in contrast, copper (Cu) and silver (Ag) have the highest values. In addition, the thermal conductivity of alumina nanoparticles is about one tenth of Cu and Ag, therefore, the Nusselt number for Al_2O_3 is lower than hat Cu and Ag

Figure 7 illustrates the profile of the average Nusselt number as a function of the concentration of nanoparticles on different Rayleigh numbers in the 10^3-10^6 range for four different nanofluids (Copper, Silver, Aluminum and Titanium). We note, low Rayleigh number (Ra = 10^3 and 10^4), the average Nusselt number increases almost monotonically with solid volume fraction for all nanofluids. At Ra = 10^5, the average Nusselt number increases with the concentration of nanoparticles with a lower gradient compared to that of Ra = 10^4. A Ra = 10^6, a slight increase was observed for the Nusselt number with the volume fraction of Cu and Ag nanoparticles.

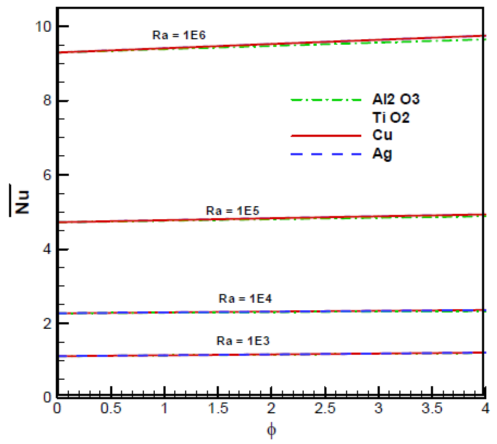

Fig.7 .Profile of the average Nusselt number as a function of the nanoparticle concentration on different Rayleigh numbers in the range 10^3-10^6 for four different nanoparticles.

4.4 heat transfer rate

Figure 8 exhibits the profile of the ratio of average Nusselt number on alumina with water according to different Rayleigh numbers in the range 10^3-10^6 and at different concentrations of nanoparticles in the range of 1%≤ φ≤4 %. We note, in this figure, that the transfer of heat at the side wall is more important compared to the middle of the cavity.

For $10^3 \leq$ Ra$\leq 10^4$ report decreases in a very important way for different concentrations of nanoparticles by cons when $10^4 \leq$ Ra$\leq 10^6$ report changes its appearance, it increases proportionally with the Rayleigh number and the volume fraction of nanofluids.

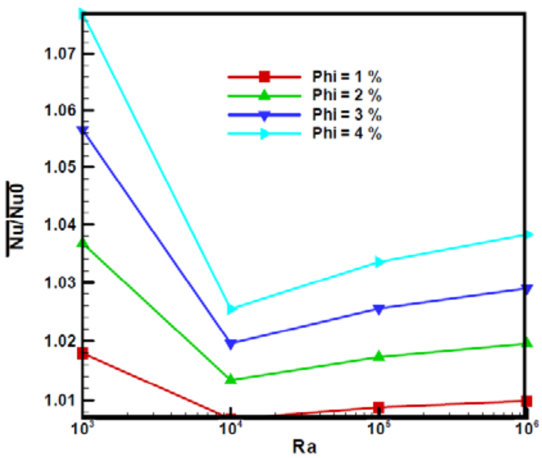

Fig.8 .Profile of the ratio of average Nusselt number on alumina with water according to different Rayleigh numbers in the range 10^3-10^6 and at different concentrations of nanoparticles in the range 1% ≤ φ≤ 4%.

6. Conclusions

This work is part of a research topic for the study of nanofluids flows in confined spaces. For this purpose, a numerical study with the objectives of the prediction convection and heat transfer in a rectangular cavity filled with a nanofluid was conducted. The effects of various parameters governing the flow; such that the Rayleigh number and the nanoparticle concentration; were predicted and analyzed. An increase in the volume fraction of the nanoparticles grown the heat transfer rate, was shown.

Different types of nanofluids were considered through two physical models evoking natural convection flows. We have presented the results for the flow of natural convection in a differentially heated cavity filled with a nanofluid. It was shown, in particular, that by varying the type of nanoparticles used, those of copper to provide better heat transfer.

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