Numerical Simulation of Natural Convection Within an Inclined a Cavity Filled with Ionanofluid [C4mim][Ntf2]-Al2o3

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NUMERICAL SIMULATION OF NATURAL CONVECTION IN AN INCLINED CAVITY FILLED WITH IONANOFLUID [C4mim][NTf2]-Al_2O_3

Abstract: *This work consists of a numerical study of natural convection heat transfer in a cavity filled with ionanofluid.The equations governing the problem are solved using the finite volume method and the Simplec algorithm. The objective of this study is to analyze the effects of the main factors influencing flow structure and heat transfer, such as the Rayleigh number Ra, the volume fraction (φ), the impact of the angle of inclination and the effect of the base fluid.*

The results show that the increasing the volume fraction (φ) foster heat transfer and the ionic fluid over water as the base fluid. Also the transfer reaches its maximum at a specific angle.

Key words*: Ionanofluid, natural convection, finite volume.*

1. Introduction :

The limitations of conventional liquids such as oil, ethylene glycol and water have led researchers to use a new fluid called a nanofluid. The nanofluid invented by Choi [1] is a suspension of nanomaterials uniformly dispersed in a conventional fluid. Nanofluids provide a significant improvement in convection [2] thanks to their high thermal conductivity.

A numerical analysis of nanofluids in free convection was carried out by Khanafer et al [3]. They showed that whatever the Grashof number, the addition of nanoparticles increases the rate of heat transfer.

Unlike two-dimensional natural convection, three-dimensional free convection in cavities filled with nanofluids has only been studied by a few researchers. Ravnik et al [4] used the boundary element method to study free convection in a cube filled with nanofluids. An analysis by Selimefendigil and Oztop [5] of the effects of the angular velocity of the cylinders on the average variation of the Nusselt number in a cubic tube filled with nanofluid. They found that the average Nusselt number is influenced by the direction of rotation of the inner cylinder.

A three-dimensional mesoscopic simulation of natural magnetohydrodynamic (MHD) convection was carried out by Sajjadi et al [6] using the Boltzmann lattice method. The results show that an increase in the Hartmann index leads to a decrease in heat transfer, which is explained by the decrease in Nuavg.

The aim of our work is to study numerically the phenomenon of two-dimensional, laminar and permanent natural convection in a closed, inclined square cavity filled with an ionanofluid.

2. Mathematical modeling:

The physical problem studied is that of two-dimensional natural convection flow of ionanofluid in an inclined square cavity. The fluid confined in the cavity is subjected to a horizontal temperature gradient. We consider a square cavity inclined on side H Figure 1. The top and bottom walls of the cavity are maintained at temperatures of T_F and T_C respectively, with $\Delta T = T_C - T_F > 0$, and the left and right walls are adiabatic.

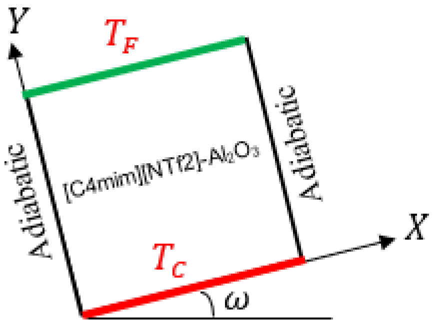


Figure 1 : Studied geometry

The governing dimensionless equations are :

$$\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0 \qquad (1)$$

$$U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}=-\frac{\partial P}{\partial X}+\frac{\mu_{nf}}{\rho_{nf}\alpha_f}\left(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right)+\frac{Ra.Pr.\theta(\rho\beta)_{nf}.cos(\omega)}{\rho_{nf}\beta_f} \qquad (2)$$

$$U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}=-\frac{\partial P}{\partial Y}+\frac{\mu_{nf}}{\rho_{nf}\alpha_f}\left(\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right)+\frac{Ra.Pr.\theta(\rho\beta)_{nf}.sin(\omega)}{\rho_{nf}\beta_f} \qquad (3)$$

$$U\frac{\partial \theta}{\partial X}+V\frac{\partial \theta}{\partial Y}=\frac{\alpha_{nf}}{\alpha_f}\left(\frac{\partial^2 \theta}{\partial X^2}+\frac{\partial^2 \theta}{\partial Y}\right) \qquad (4)$$

The dimensionless parameters of the previous equations are:

$$(X,Y)=\frac{(x,y)}{L_{réf}} \qquad ; L_{réf}=H \qquad (5)$$

$$(U,V)=\frac{(u,v)}{V_{réf}} \qquad ; V_{réf}=\frac{\alpha_f}{H} \qquad (6)$$

$$\theta=\frac{T-T_{réf}}{\Delta T_{réf}} \qquad ; \Delta T_{réf}=T_C-T_F \qquad (7)$$

$$P=\frac{p}{P_{réf}} \qquad ; P_{réf}=\frac{\rho_{nf}{\alpha_f}^2}{H^2} \qquad (8)$$

$$Pr=\frac{\nu_f}{\alpha_f} \qquad (9)$$

$$Ra=\frac{g\beta_f H^3(T_C-T_F)}{\alpha_f\nu_f}=Gr\times Pr \qquad (10)$$

Equations (1)–(4) obtained are solved with the following boundary conditions:

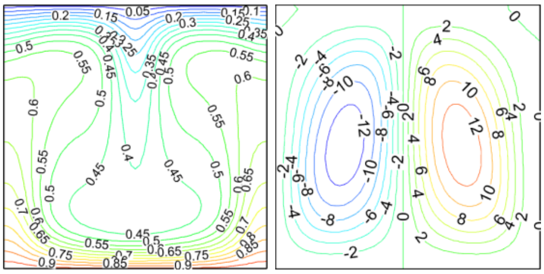
Left wall	$X=0$	$0\leq Y\leq 1$	$\frac{\partial\theta}{\partial X}=0$
Right wall	$X=1$	$0\leq Y\leq 1$	$\frac{\partial\theta}{\partial X}=0$
Bottom wall	$0\leq X\leq 1$	$Y=0$	$\theta=1$
Top wall	$0\leq X\leq 1$	$Y=1$	$\theta=0$

The calculation of the average Nusselt number is based on the following relation:

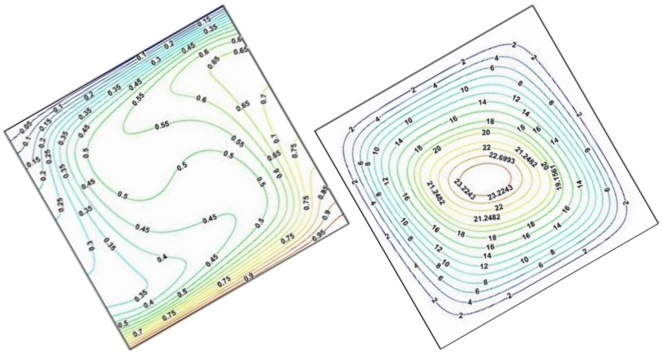
$$\overline{Nu_c}=-\frac{k_{nf}}{k_f}\int_0^1\left(\frac{\partial\theta}{\partial Y}\right)_{Y=0}dX \qquad (11)$$

$$\overline{Nu_f}=-\frac{k_{nf}}{k_f}\int_0^1\left(\frac{\partial\theta}{\partial Y}\right)_{Y=1}dX \qquad (12)$$

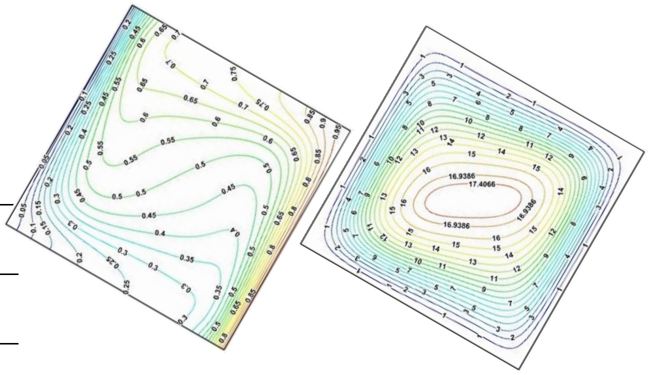
3. Results:



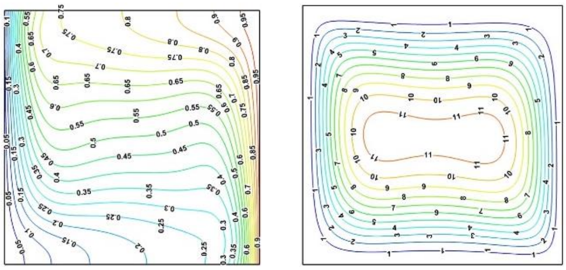
$\omega=0°$



$\omega=30°$



$\omega=60°$



$\omega=90°$

Figure 2: *Streamlines and isotherms for different inclination angles (ionanofluid, $Ra=10^5$, φ = 0.04)*

Figure 2 shows the isotherms and current lines for an ionanofluid with Ra = 10^5 and φ = 0.04 depending on the angle of inclination. The thermal field is marked by horizontal stratification and strong gradients on the active walls, meaning that heat transfer is by convection. The current lines form a single vortex, and become stronger as the angle of inclination increases.

Figure 3 shows the distribution of temperature profiles at the vertical median plane of the cavity, with volume fraction φ = 0.04 for different Rayleigh numbers. The figure clearly illustrates that values between a maximum value corresponding to the temperature at the middle of the cavity and a corresponding low value at the end of the cavity.

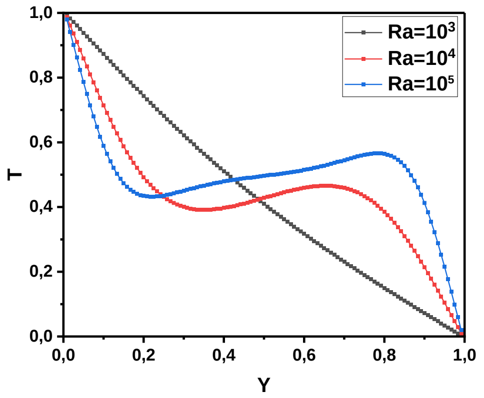


Figure 3 :Temperature profile along the mid-section of the enclosure (X = 0.5 H) for different Rayleigh numbers (Ra=105 and φ = 0.04)

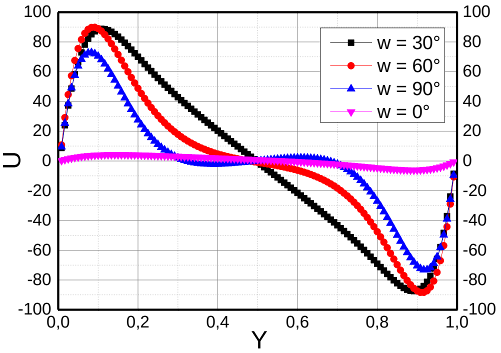


Figure 4 : Transverse velocity profile along the enclosure axis (Y) for different angles at (X=0.5 H) for Ra=10^5

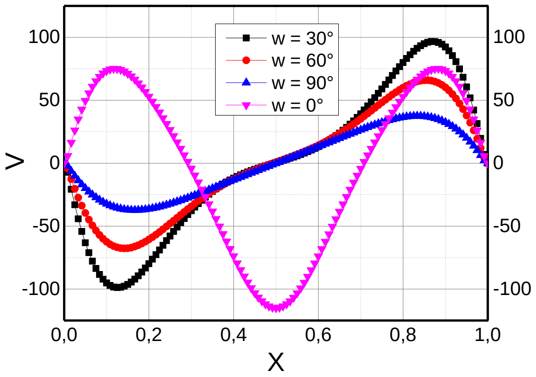


Figure 5 : Longitudinal velocity profile along the enclosure axis (X) for different angles at (Y=0.5 H) for Ra=10^5

Figures 4 and 5 show U and V velocity profiles as a function of inclination angle at the mid-section of the enclosure. In general, when the enclosure is tilted, velocities are lower in the center of the enclosure than near the walls. In addition, the addition of nanoparticles to the fluid is associated with random motion through the fluid, resulting in higher velocities for the ionanofluid.

Figure 6 shows the effect of inclination angle *w* on the average Nusselt number, with the cavity inclination angle proposed as a control parameter for fluid flow and heat transfer. We also note that the maximum value of the nusselt number occurs in the case of ω=60°, due to the increase in flow velocity at this angle.

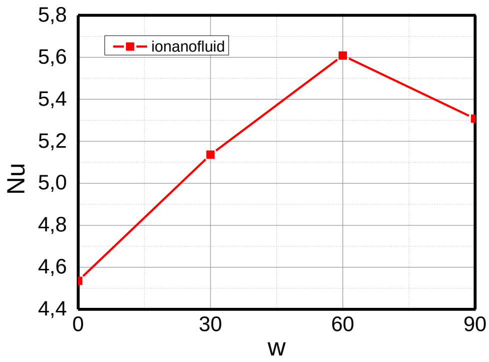


Figure 6 : Effect of tilt angle on mean Nusselt number for (Ra =10^5 and φ = 0.04)

4. Conclusion

We have presented a numerical study of heat transfer by natural convection in an inclined square cavity (2D) filled with ionanofluid [C4mim][NTf2]-Al_2O_3. The finite volume method is used to discretize the equations, while the SIMPLER algorithm is employed to solve the coupling between pressure and velocity.

The main results can be summarized as follows:

- Increasing the angle of inclination from ω=0° to ω=60° leads to an increase in the Nusselt number,
- An inclined cavity with a variable heating angle relative to the horizontal offers better thermal performance.
- Ionic nanofluid improves heat transfer compared with water-based nanofluid.

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