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Effects of an Enclousure Inclination Angle and It's Walls Movement Direction on Variable Properties Nanofluid Mixed Convection

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ABSTRACT

In this paper, the effects of inclination angle and two different cases of movement direction of top and bottom walls of an enclosure on the nanofluid mixed convection have been investigated. In the first case, the natural and forced convection effects are in agreement, whereas in the second case they are opposed. Simulations have been performed for the temperature dependent as well as the temperature independent thermal conductivity and viscosity of water-Al_2O_3 Al_2O_3 nanofluid. The volume fractions of nanoparticles between 0 and 0.08 and the inclination angle of the cavity between 0 and 90° have been considered. To solve the governing equations, the SIMPLE algorithm and a finite volume based method have been used. The results show that by increasing the enclosure inclination angle, which enhances the forced convection, the three convective cells, observed at low inclination angles, change to one cell. The trend for change of average Nusselt number with increasing volume fraction is different for the temperature independent cases compared to that of the temperature dependen t cases. Therefore, in order to obtain accurate simulation results, the temperature dependency of the properties should be considered.

KEYWORDS

Square Enclosure, Nanofluid, Inclination Angle, Variable Properties, Nanoparticles Volume Fraction.

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1- INTRODUCTION

The thermophysical limitations of the usual heat transfer fluids have led to the introduction of nanofluids. Some recent experimental studies have shown that the nanofluids properties depend on the temperature as well as nanoparticles volume fraction [1, 2]. The properties of nanofluids affect the convection heat transfer characteristics; however, in the mixed convection studies undertaken yet, the variation of the properties with temperature, particularly the viscosity and conductivity, have not been considered. Therefore, unlike previous works, in this study the effects of properties variations of Al_2O_3-water nanofluid with temperature on mixed convection in a square enclosure, oriented at different inclination angles, have been investigated. For this purpose, two different cases of the enclosure top and bottom walls movement directions have been considered.

2- METHODOLOGY

The considered enclosure is shown in Fig. 1. The top and bottom walls are insulated but the left and right walls are having two different constant hot and cold temperatures, respectively. In the first case, the top wall moves from the left toward right and the bottom wall moves from the right toward the left, whereas in the second case, they move vise versa. For the orientation of the enclosure, four different inclination angles of zero, 30, 60 and 90 degrees have been considered. The enclosure is filled with Al_2O_3-water nanofluid, which is assumed to be Newtonian. The flow is laminar and at any location in the enclosure, the base fluid and the nanoparticles are considered at thermal equilibrium with the same velocity. The governing equations are the continuity, the momentum in the x and y directions as well as the energy equation. For the variable properties cases, the conductivity of the nanofluid, variable with temperature and volume fraction of nanoparticles, is evaluated through the correlation proposed by Nguyen et. al [1] as:

$$\frac{k_{nf}}{k_f} = 1 + 64.7\varphi^{0.4076}\left(\frac{d_f}{d_p}\right)^{0.3690}\left(\frac{k_p}{k_f}\right)^{0.7476}\mathrm{Pr}_T^{0.9955}\,\mathrm{Re}^{1.2321} \quad (1)$$

in which:

$$\mathrm{Pr}_T = \frac{\mu_f}{\rho_f \alpha_f} \quad (2)$$

$$\mathrm{Re} = \frac{\rho_f k_b T}{3\pi\mu_f l_f} \quad (3)$$

Also the viscosity of the nanofluid, variable with temperature and volume fraction of nanoparticles, is evaluated via the correlation proposed by and Chon et. al [2] as:

$$\mu_{nf} = \exp(3.003 - 0.04203T - 0.5445\varphi + 0.0002553T^2 + 0.0524\varphi^2 - 1.622\varphi^{-1}) \times 10^{-3} \quad (4)$$

For the constant properties cases, the conductivity and the viscosity of the nanofluid have been obtained through the correlations proposed by Maxwell-Garnett [3] and Brinkman [4], respectively.

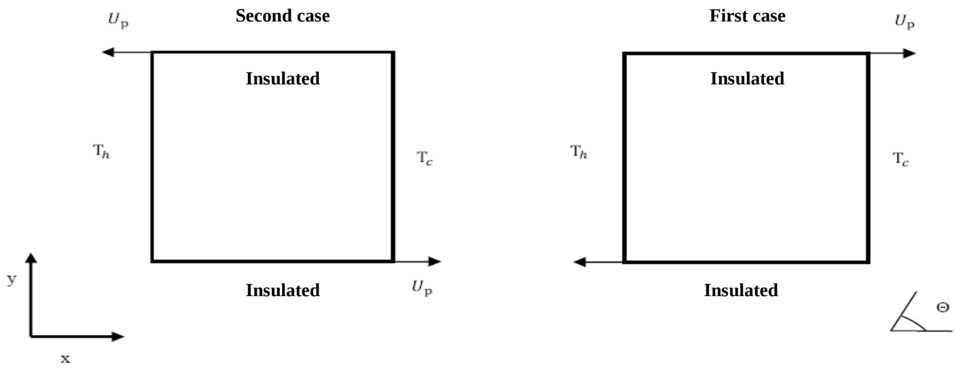

Figure 1: The geometry and boundary conditions of the enclosure.

The governing equations have been solved using the SIMPLE algorithm and a finite volume based method. After solving the flow and temperature fields, the local and average Nusselt numbers on the hot wall have been obtained. In all of the simulations performed the Grashof and the Richardson numbers have been considered constant equal to 10^4 and 10, respectively. Also different volume fractions of nanoparticles between 0% and 8% have been assumed.

3- RESULTS AND DISCUSSION

To make sure of the validity of the results, simulations were performed for the natural convection geometry and boundary conditions of Abu-Nada et. al [5]. The results presented in Fig. 2 show that there is good agreement between the average Nusselt numbers obtained in this study and those of Abu-Nada et. al [5].

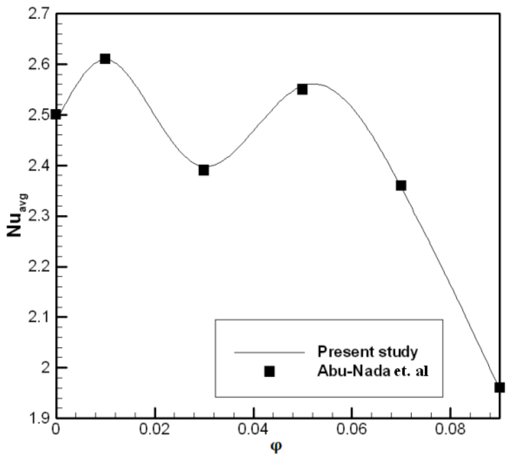

Figure 2: The average Nusselt numbers on the hot wall obtained in this study and those of Abu-Nada et. al [5].

For the first and the second cases, by increasing the inclination angle, the natural convection weakens. This is more pronounced in the first case, in which both the natural and force convections are in agreement. The isotherms show that by increasing the volume fraction of nanoparticles, the flow strength increases, such that at zero inclination angle, the weak convective cells at the center of the cavity vanish.

For the first case when the properties are variable with temperature, as the inclination angle increases, the local Nusselt number on the hot wall decreases slightly. This is due to the reduction of the effect of natural convection and the enhancement of the thermal boundary length on the hot wall. In this case, the volume fraction increase at higher inclination angles leads to more enhancement of the average Nusselt number. This is due to the fact that it enhances the force convection, which is prominent at the higher inclination angles.

For the second case, when the properties are variable with temperature, as the inclination angle increases, irrespective of the volume fraction of the nanoparticles, the average Nusselt number enhances. However, for the same inclination angle and volume fraction of nanoparticles, the average Nusselt number for the second case is less than that of the first case. This is due to the contradictory effects of the natural and force convections in this case.

4- CONCLUSION

In this study, the effects of properties variations of Al_2O_3-water nanofluid with temperature on mixed convection in a square enclosure have been studied. For this purpose, different inclination angles and two different cases of the enclosure top and bottom walls movement directions have been considered. The results for the first and the second cases showed that, as the inclination angle increases, the natural convection weakens. This is more pronounced in the first case, for which both the natural and force convections are in agreement. Also by increasing the volume fraction of nanoparticles, the flow strength increases such that at zero inclination angle, the weak convective cells at the center of the cavity vanish. The results also show that, if the viscosity and the conductivity are only functions of the nanoparticles volume fraction, with the volume fraction increase the average Nusselt number always enhances. However, for the temperature dependent condition, the trend is different, such that the volume fraction increase does not necessarily leads to Nusselt number enhancement. This emphasizes that if accurate results are expected from the simulations performed, the temperature dependency of the properties, such as conductivity and viscosity, should be considered.

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