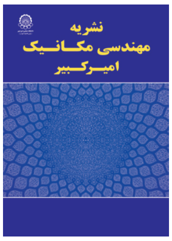

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Effects of Sedimentation of Nanoparticles on Flow, Heat and Mass Transfer of Al_2O_3-water Nanofluid in a Cavity

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ABSTRACT: In this study, effects of transport mechanisms of nanoparticles such as: sedimentation, Brownian motion, and thermophoresis in natural convection of Al_2O_3-water nanofluid as a two-component mixture on flow field, heat transfer and mass transfer during a period of thirty days have been investigated numerically. Left and right walls of the cavity are hot and cold, respectively. The temperature difference between two vertical walls is 8 K. In order to consider the variations of the volume fraction of nanoparticles versus time, an experimental model during a period of thirty days have been applied. The momentum, energy and mass transfer equations have been solved using the finite volume method. The initial volume fractions of nanoparticles are 0.0025, 0.0077 and 0.013, the ultrasonicator dispersion time is 1, 2 and 3 hours, and Rayleigh number range is from 10^2 to 10^5. The results show that in low Rayleigh number (10^2 and 10^3), during a period of time and sedimentation of nanoparticles, the heat transfer enhancement coefficient (*E*) is reduced. In $Ra=10^4$ and 10^5 with $\varphi_b=0.0025$, *E* is decreased as time passed. In $\varphi_b=0.0077$, the value of the E has a critical point due to the increasing thermal conductivity and viscosity coefficient, so that before the critical point, the *E* has increased and then has decreased. In $\varphi_b=0.013$, the *E* is increased over time. It is also observed that including the effect of sedimentation velocity is increased the thickness of mass boundary layer and the Nusselt number are reduced.

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1- Introduction

Nanoparticles are added to common fluids because they increase thermal conductivity and enhance heat transfer. The main problems in the use of nanoparticles, are agglomeration and sedimentation of nanoparticles over time.

Up to now, many analytical and numerical models have been presented for nanofluids convective heat transfer, which can be divided into homogeneous and non-homogeneous models. In the homogeneous model, nanofluid is assumed as a common fluid, but in the non-homogeneous model, due to relative velocity between nanoparticles and the base fluid, nanoparticles transport is considered. Nanoparticles transport may lead to non-homogeneity in nanofluid and distribution of nanoparticles in the base fluid can not be uniform because of mechanisms like Brownian motion, thermophoresis and sedimentation.

Sedimentation of nanoparticles is one of the interesting topics for research, but a few studies are done about it because of complexity in describing the interaction of nanoparticles. Ho et al. [1] investigated numerical simulation and experimental natural convection heat transfer of Al_2O_3-water nanofluid in a rectangular cavity with considering the Ludwig–Soret effect and sedimentation. They found that the comparisons between experimental data and numerical results unfold that when Ludwig–Soret effect, Brownian motion and sedimentation of nanoparticles are considered in the numerical model, the predicted Nusselt number is very close to experimental data.

In this study, combined effects of transport mechanisms such as Brownian motion, thermophoresis and sedimentation on laminar natural convective heat transfer Al_2O_3-water nanofluid as a two-component mixture in a square enclosure are investigated numerically and for changing in volume fraction of nanoparticles, an experimental model during a period of thirty days are applied.

2- Methodology

Geometry studied in this problem is a square enclosure that the left side wall of it is hot and the right side wall of it is cold. Difference of temperature between two vertical walls is 8 K. The horizontal walls are adiabatic. The enclosure is filled with Al_2O_3-water nanofluid that initial volume fractions of nanoparticles are 0.0025, 0.0077 and 0.013. They put the samples for period of 1, 2, and 3 hours inside the ultrasonicator. According to the initial volume fraction of nanoparticles and dispersion time based on experimental results by Rahman et al. [2], for example: at $\varphi_b=0.013$ sedimentation pattern is shown in Fig. 1.

The governing continuity, momentum, energy and mass transfer equations are given by [1,3]:

$$\frac{\partial \rho_{nf}}{\partial t}+\frac{\partial \rho_{nf} u}{\partial x}+\frac{\partial \rho_{nf} v}{\partial y}=0 \qquad (1)$$

$$\rho_{nf}\left[\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right]=-\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}\left(\mu_{nf}\frac{\partial u}{\partial x}\right)$$
$$+\frac{\partial}{\partial y}\left(\mu_{nf}\frac{\partial u}{\partial y}\right)+S_x \qquad (2)$$
$$S_x=-\rho_p\left[1-2\left(\frac{\rho_p}{\rho_{nf}}\right)\varphi\right]V_{s,x}\left(V_{s,x}\frac{\partial \varphi}{\partial x}+V_{s,y}\frac{\partial \varphi}{\partial y}\right)$$

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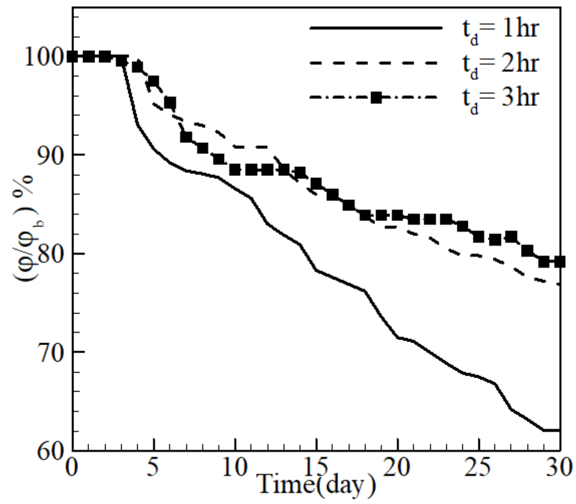

Figure 1. The rate of sedimentation nanoparticles for water-Al_2O_3 nanofluid and φ_b=0.013 [2]

$$\rho_{nf}\left[\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right]=-\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}\left(\mu_{nf}\frac{\partial v}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mu_{nf}\frac{\partial v}{\partial y}\right)+\begin{bmatrix}(1-\varphi_i)\rho_f(T-T_C)\beta_f g\\ -(\varphi-\varphi_i)(\rho_{nf}-\rho_f)g\end{bmatrix}+S_y \tag{3}$$

$$S_y=-\rho_p\left[1-2\left(\frac{\rho_p}{\rho_{nf}}\right)\varphi\right]V_{s,y}\left(V_{s,x}\frac{\partial\varphi}{\partial x}+V_{s,y}\frac{\partial\varphi}{\partial y}\right)$$

$$(\rho c_p)_{nf}\left[\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right]=\frac{\partial}{\partial x}\left(k_{nf}\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_{nf}\frac{\partial T}{\partial y}\right)+\rho_p c_p\begin{pmatrix}D_B\left(\frac{\partial\varphi}{\partial x}+\frac{\partial\varphi}{\partial y}\right)\left(\frac{\partial T}{\partial x}+\frac{\partial T}{\partial y}\right)\\ +D_T\left(\frac{\partial T}{\partial x}+\frac{\partial T}{\partial y}\right)\left(\frac{\partial T}{\partial x}+\frac{\partial T}{\partial y}\right)\end{pmatrix} \tag{4}$$

$$\frac{\partial\varphi}{\partial t}+\frac{\partial\varphi}{\partial x}+v\frac{\partial\varphi}{\partial y}=\left(\frac{\partial}{\partial x}\left(D_B\frac{\partial\varphi}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_B\frac{\partial\varphi}{\partial y}\right)\right)+\left(\frac{\partial}{\partial x}\left(D_T\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_T\frac{\partial T}{\partial y}\right)\right) \tag{5}$$

In the above equation, the values D_B, D_T and V_s are calculated using Eqs. (6) to (8):

$$D_B=\frac{\rho_p k_B T}{3\pi\mu_f d_p} \tag{6}$$

$$D_T=0.26\frac{k_f}{2k_f+k_p}\frac{\mu_f}{\rho_f T}\varphi \tag{7}$$

$$V_s=\frac{(\rho_p-\rho_m)gd_p^2}{18\mu_f}(1-\varphi)^{5.6}\overrightarrow{e_g} \tag{8}$$

The conductivity and viscosity of the nanofluid are evaluated through the correlation proposed by Corcione [4]:

$$\frac{k_{nf}}{k_f}=1+4.4Re^{0.4}Pr^{0.66}\left(\frac{T}{T_{fr}}\right)^{10}\left(\frac{k_p}{k_f}\right)^{0.03}\varphi^{0.66} \tag{9}$$

$$\frac{\mu_{nf}}{\mu_f}=\frac{1}{1-34.87\left(d_p/d_f\right)^{-0.3}\varphi^{1.03}} \tag{10}$$

where

$$Pr=\frac{\mu_f\rho_f}{\alpha_f} \tag{11}$$

$$Re=\frac{2\rho_f k_B T}{\pi\mu_f d_p} \tag{12}$$

3- Results and Discussion

The results show that in low Rayleigh number with considering the sedimentation of the nanoparticles over time, the heat transfer enhancement coefficient is reduced (Fig. 2). Also the effect of considering the sedimentation velocity on distribution of volume fraction of nanoparticles near the walls, is showed in Fig. 3. As can be seen, the gradient of volume fraction of nanoparticles between the cold and hot walls increases.

4- Conclusions

In this study, the effects of the transport mechanisms of nanoparticles such as: sedimentation, Brownian motion, and thermophoresis in natural convection of Al2O3-water nanofluid on flow field and heat and mass transfer during a period of thirty days have been investigated numerically using the finite volume method and the SIMPLER algorithm. Over time, the heat transfer enhancement coefficients reduced highly in low Rayleigh number.

Considering sedimentation velocity of nanoparticles increases the thickness of the mass boundary layer near the cold and hot walls.

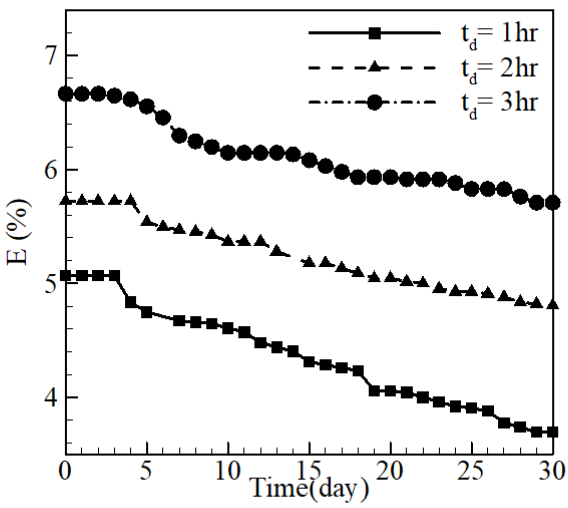

Figure 2. The heat transfer enhancement (*E*) over a period of 30 days for *Ra*=10^2 and φ_b=0.013.

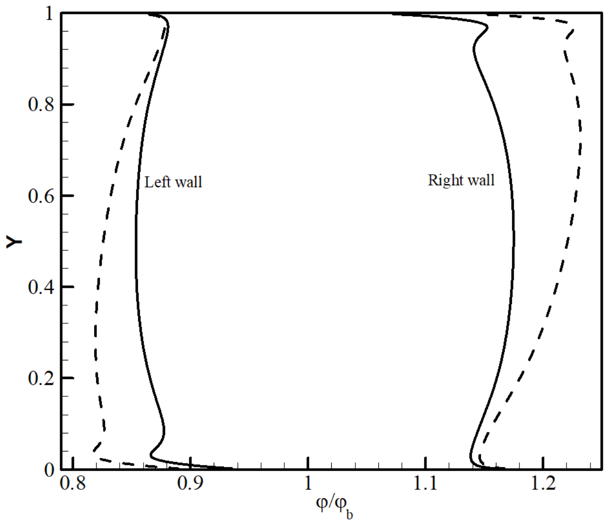

Figure 2. Distribution of volume fraction of nanoparticles near the walls without sedimentation velocity (___) and with it (------)

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