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Natural Convection of Turbulent Al_2O_3-Water Nanofluid with Variable Properties in a Cavity with a Heat Source and Heat Sink on Vertical Walls

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ABSTRACT: Natural convection heat transfer of Al_2O_3-water nanofluid with variable properties in the turbulent flow inside a cavity with a heat source and heat sink on the vertical walls is studied numerically. Base fluid viscosity, thermal conductivity, and viscosity of nanofluids, are a function of temperature and volume fraction. The governing equations in the two-dimensional space are discretized using the control volume method. Turbulence computations are performed using the k-w-SST model. The results show that change in the placement of heat source and heat sink and Raleigh number have the effect on streamlines and isotherms. For Rayleigh numbers 10^7 and 10^8, the Nusselt number increases with increasing volume fraction of nanoparticles to 1%, and then decreases with increasing volume fraction of nanoparticles. Also, for some cases it is observed that the Nusselt number of nanofluids is less than the base fluid and therefore in these cases using nanofluids for enhanced heat transfer is not proposed. For Rayleigh numbers 10^7 and 10^8, the least Nusselt number occurs in top-bottom case, and the most Nusselt number occurs in bottom – bottom case.

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1- Introduction

Modeling of heat transfer phenomena has significant importance, especially convection heat transfer in nature and many industrial phenomena. As this process of heat transfer is more considered in the cavities, different solutions have been presented by researchers for improving it. These solutions include improving the thermal properties of the base fluid with adding nanoparticle, changing the investigated geometry, and using turbulent flow regime [1-3].

In this study, the effect of the mentioned methods has been investigated for improving heat transfer in presented geometry. This investigation has been done using turbulent flow model k-w-SST for Rayleigh numbers 10^7 and 10^8 and volume fraction of Al_2O_3-water nanofluid is considered 0 to 4%. So far, in previous researches, the hot and cold source was not on walls that have thickness and turbulence models k-w-SST have been used. Also, turbulent flow with variable properties have not investigated in the geometry in which variable condition of placing the hot and cold source had been studied on vertical walls of the cavity.

2- Geometry and Governing Equations

This geometry configuration has been shown in Fig. 1. A hot and cold source with constant temperatures Th and Tc is on the left and right walls of the cavity. The other walls are adiabatic. The length of hot and cold sources is half of the cavity height and the width of them is 0.1 of cavity height. The flow is turbulent, steady, and incompressible.

This type of placing the hot and cold sources that are shown in Fig. 1 is briefly defined as middle-middle. The other types are created with changing the place of hot and cold sources on the walls. Thermal conductivity coefficient and viscosity of nanofluid are calculated with Corsione relations [4]. The viscosity of base fluid obtains with fitting a curve on the existing value in the reference [5]. Finite Volume Method (FVM) is used to solving the governing equations. CFX software is used to solving equations. The second-order upwind method and coupled algorithm are used to discrete the equations.

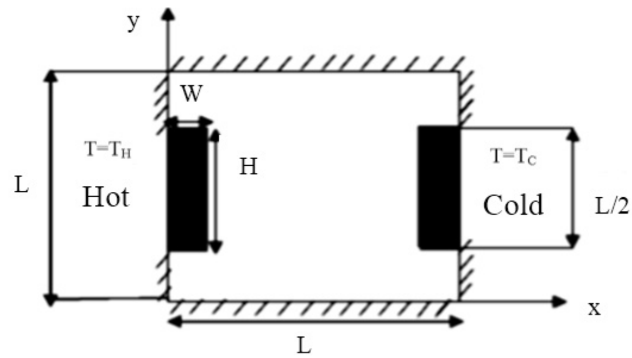

Fig. 1. Geometry and boundary conditions for the square enclosure with the source and the sink on the wall

3- Results and Discussion

Streamline has been shown in Figs. 2 and 3 for three types of placing hot and cold sources on vertical walls of the cavity. In these figures, the volume fraction is 0.03 and the Rayleigh number is 10^7 and 10^8. As it is obvious from the figures, in all types, a main clockwise vortex is created. Also, in some types, the secondary vortex is created in the central vortex. The location of placing the hot and cold source has the significant effect on streamlines.

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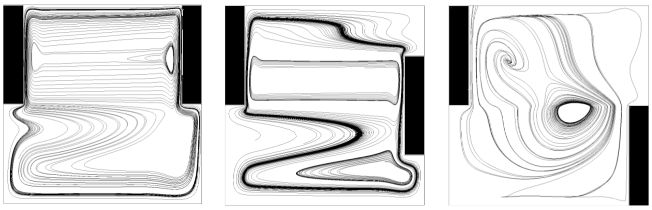
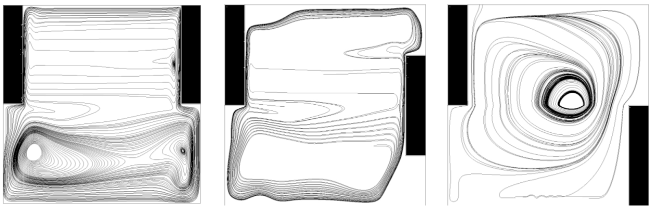


top-top top-mid top-bottom

Fig. 2. Streamlines for different position of the heat source and heat sink at $Ra=10^7$, $\varphi=0.03$



top-top top-mid top-bottom

Fig. 3. Streamlines for different position of the heat source and heat sink at $Ra=10^8$ and, $\varphi=0.03$

By comparing the similar states in Figs. 2 and 3 from the point of allocation of hot and cold source, it can be seen that in the higher Rayleigh number, due to the dominance of the heat transfer regime, the streamlines are more compact in the vicinity of the hot and cold source which indicates the strong convection in these areas.

In Fig. 4, the variations of the average Nusselt number on the hot source are shown versus of the volume fraction of nanoparticles for the different allocation of the hot and cold source for $Ra=10^7$ and $Ra=10^8$. In Fig. 4 it can be seen that for each $Ra=10^7$ and $Ra=10^8$, in all cases, with increasing volume fraction up to 1%, the average Nusselt number is increased, then Nusselt number decreases with increasing volume fraction.

4- Conclusions

Natural convection heat transfer of Al_2O_3-water nanofluid with variable properties in the turbulent flow inside a cavity with a gibbous heat source and heat sink on the vertical walls is studied numerically. Based on the results of this study, the following conclusions are made:

1. For $Ra=10^7$ and 10^8, the lowest value of the Nusselt number is for the top-bottom case and the most value is for the bottom-bottom case.
2. For $Ra=10^7$ and 10^8, in all cases, by increasing the volume fraction to 1%, the average Nusselt number increased, and then the Nusselt number decreased with increasing volume fraction. Also, in some cases, the Nusselt number of the nanofluid is less than the Nusselt number of the base fluid.

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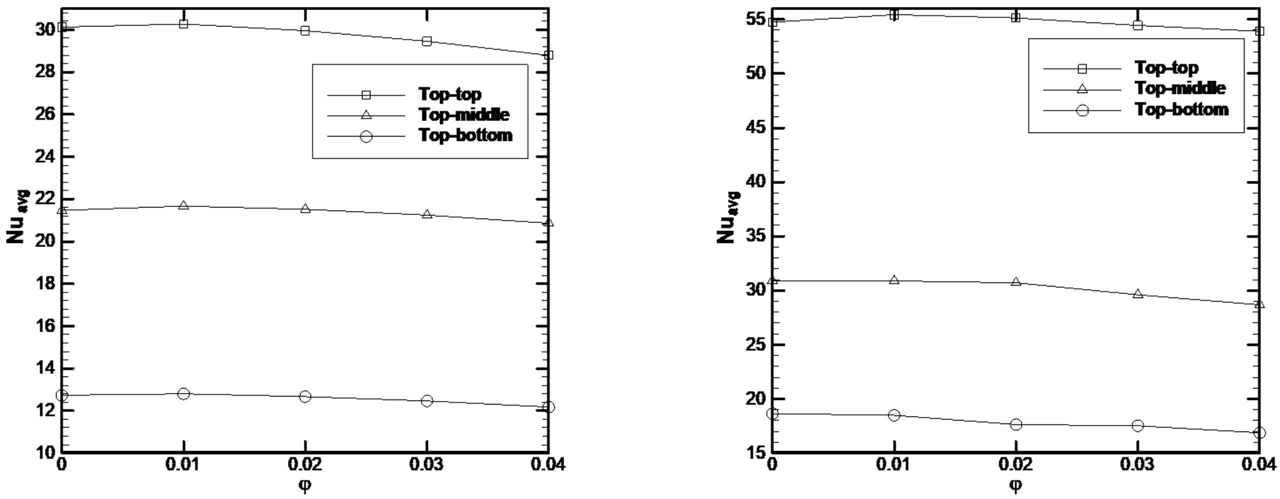

$Ra=10^7$ $Ra=10^8$

Fig. 4. Variations of the average Nusselt number of the heat source with respect to the volume fraction of the nanoparticles for different configurations of the source and the sink at $Ra=10^7$ and 10^8.

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