BEHAVIOUR OF VARIOUS NANOFLUIDS USING A HEATER MOUNTED IN A CAVITY WALL TO DETERMINE FORCED CONVECTION HEAT TRANSFER

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ABSTRACT

The relation between the nanofluids properties is determined by using a heater mounted on a cavity wall. The base fluid is considered as water. The present study is focused on forced convection heat transfer from square heater subject to inflow and outflow inside a square cavity. The behaviorial physics will be reported in connection with volume fraction, Reynolds number and nanomaterial properties. It is noted that the local heat transfer is increased for a particular Reynolds number when nanomaterial is introduced.ConstantNusselt number attributed by the wall vortex. It is also found that we get high Nusselt number when the heater wall is subject to combination of vortex and main stream fluid rather than heat transfer due to wall attached vortices. For the same Reynolds number,nano fluid results high Nusselt number.

KEYWORDS:

Naofluids;
Forced convection;
Square heater;
Square cavity;
Reynolds number.
Nusselt number;

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1. INTRODUCTION

Forced convection heat transfer from heater mounted in a cavity wall is investigated to reveal the effect of nano material properties during forced convection. The base fluid is considered as water. Saeidi and Khodadadi [1] investigated the forced convection heat transfer from a cavity for different inlet and exit ports. They found that the position of outlet port affects significantly the local Nusselt number and strength of the vortex. In [2] AhmetKoca has reported the Conjugate heat transfer in partially open square cavity with a vertical heat source. The cavity has an opening on the top with several lengths and three different positions while the otherwallsof cavity were assumed adiabatic. It was found that ventilation position has a significant effect on heat transfer. Poochinapan [3] has solved cavity flow for comparison of explicit and implicit scheme used for simulating nonlinear convective terms by streamfunctionvorticity formulation. Esfe and Saedodin

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[4] have studied numerically the effect of nanoparticle diameter on heat transfer. They found that the nanoparticle diameter has inverse relationship with average Nusselt number. Sheikholeslamia and Vajravelu [5] have reported the effect of variable magnetic field on nanofluid heat transfer in a cavity. They reported that the main vortex moves downward however when the Lorentz force is increased and the heat transfer rate is also increased. Sheikholeslami [6] have conducted forced convection heat transfer in a cubical cavity using nanofluid under the presence of magnetic field. Their results depicted that forced convection reduces with enhance of Lorentz forces. Kalidasan et. al. [7] have reported natural convection from a C shaped cavity using nanofluid. A isothermal block was placed inside the cavity and Copper – Titania hybrid nanofluid were tested. They found that When Rayleigh number increases, the strength of the primary vortex diminishes and heat transfer increased monotoniously for a particular Rayleigh number. It is found that from the open literature the there is no study reveals the forced convection using nanofluid to reveal the heat transfer from a heater mounted in cavity wall with inflow and outflow condition. The present study is focused on forced convection heat transfer from square heater mounted on a cavity wall. The interesting physics will be reported in connection with volume fraction, Reynolds number and nanomaterial properties.

MATHEMATICAL FORMULATION AND NUMERICAL PROCEDURE

Figure 1 shows the schematic of the problem considered for computation. Incompressible two-dimensional laminar flow is considered for the computation. The governing Navier-Stokes equations are solved by stream function-vorticity formulation. The transient non-dimensional governing equations in the conservative form are,

Stream function equation

$$\nabla^2 \psi = -\omega$$

Vorticity equation

$$\frac{\partial \omega}{\partial t} + \frac{\partial (u\omega)}{\partial x} + \frac{\partial (v\omega)}{\partial y} = \frac{1}{Re(1-\phi)^{2.5}[(1-\phi)+\phi\frac{\rho_s}{\rho_f}]}\nabla^2\omega$$

Energy equation

$$\frac{\partial \theta}{\partial t} + \frac{\partial (u\theta)}{\partial x} + \frac{\partial (v\theta)}{\partial y} = \frac{(k_{nf}/k_f)}{RePr[(1-\phi)+\phi\frac{(\rho Cp)_s}{(\rho Cp)_f}]}\nabla^2\theta$$

The effective thermal conductivity of the nanofluid is approximated by Maxwell-Garnetts (MG) for fluid containing a spherical nano particle.

$$\frac{k_{nf}}{k_f} = \frac{k_s + 2k_f - 2\phi(k_f - k_s)}{k_s + 2k_f + \phi(k_f - k_s)}$$

The following boundary conditions are assumed for simulation. The cavity dimensions are assumed as $W = H = 1$ and $w = 0.25$. The heater is also assumed as square of size as w and maintained at constant wall temperature. Hence the non-dimensional temperature $\theta = 1$ along all sides (A-B-C-D) of heater and inlet it equals to zero. The side walls of the cavity are maintained at adiabatic condition. Figure 2 shows the typical mesh used for the simulation. Table 1 shows the thermophycical properties of copper and silver nanomaterials. To ensure laminar flow the Reynolds number is restricted to maximum of 200. The nanomaterial volume fraction are computed for $\varphi = 0$, 5% and 10%. The detailed numerical procedure for nanofluid simulation and validation can be found from Kanna et al. [8].

Table 1
Thermophysical properties of base fluid and nanoparticles

Property	Pure water	Ag	Cu
ρ	997.1	1,0500	8933

K	0.613	429	400
C_p	4179	235	385

Table 2
Average Nusselt number from heater walls

Re	Pure water, φ=0	Ag, φ = 5%	Cu	
			φ = 5%	φ = 10 %
50	19.75	-		
100	22.80	30.15	26.20	28.90
200	27.79	-	-	-

RESULTS AND DISCUSSION

Two dimensional laminar incompressible flow is simulated for forced convection heat transfer from a heater which is maintained at constant temperature. The fluid enters at inlet port and exit at the exit port located at the bottom of the square cavity. The side walls are maintained at adiabatic condition. Figure 3 shows the validation of flow through square cavity. The streamline contour and isothermal contor for Re=500 is compared and found good agreement among them. Figure 4 and 5 show the effect of Reynolds number on forced convection for pure fluid. It is noticed that when Reynolds number is increased from 50 to 200 the primary vortex center is shifted towards main stream of fluid. This is due to increase of inertia force at higher Reynolds number. Alos secondary vortices are formed at the bottom of the wall particularly cavity between heater and left side wall and top right corner of the cavity. Tertiary vorex is tend to appear at the top right corner where adverse pressure gradient is higher. It is found that when flow reaches steady state at higher Reynolds number the isotherm is more denser near the heater cavity rather than main stream. This is mainly due to the strong secondary vortex appears in the vicinity of heater and side walls.

To reveal the effect of nanomaterial in the base fluid *Ag* and *Cu* are used to investigate the heat transfer. The simulations are carried out for Re = 100 and volume fraction is fixed as 5 %. Figure 6 shows the streamline contours for pure base fluid and figure 7 and 8 show the steamline contour for Cu and Ag. It is found that at Re = 100 in addition to the primary vortex two secondary vortices are appeared in between the heater and side walls. When nano materials are introduced this two vortices size is increased and merged for high denser material. The isotherm contour for the corresponding cases discussed above are shown from figure 9 to 12. It is noticed that the main stream fluid separates the top primary vortex from the heater. However the bottom vorex involves intense forced convection heat transfer with the heater. To explore the effect of nanomaterial in the base fluid temperature distribution, temperature is plotted from y = 0.35 along *x* direction (fig. 13). It is found that when nanomaterial is introduced the temperature is increased significantly. The local Nusselt number distribution along the walls A-B-C-D for different cases are shown from figure 14 to 16. It is observed that the local Nusselt number from wall A-B shows a linear trend for maximum distance and decreases towards singular point. This is mainly due to the wall attached vortex at Re=100. The top wall of heater ie. B-C is subject to main stream of fluid and counter clockwise vortex. Hence the local Nu is continuously increasing upto the singular point. However a short kink is noticed due to the conjuction of bottom wall primary vortex and main stream acting on the B-C surface. Further local Nu from C-D wall shows similar to A-B wall a linear trend. The wall attached vortex attributes approximately constant Nu to this wall.   To summarise the various cases Table 2 shows the average Nusselt number. It is evident that increasing Reynolds number will increase Nu. When nano material is introduced in the base fluid will enhance the heat transfer. Particularly high density and low specific heat materials results high Nu for same Re and volume fraction. Also it is found that % of nanomaterial increase causes increase in Nu.
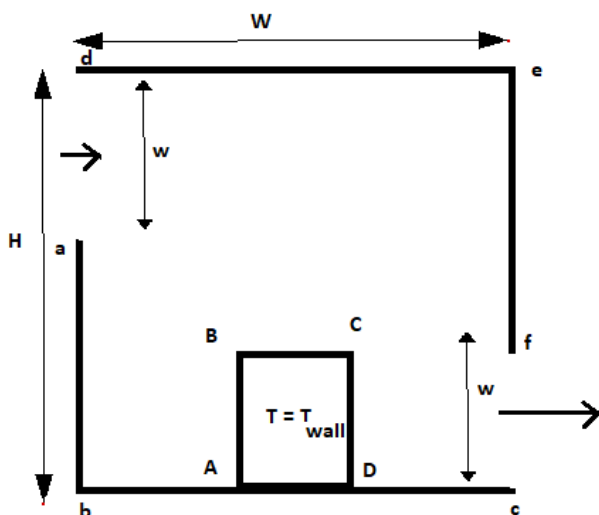
Fig. 1 Schematic diagram of the problem with boundary conditions.
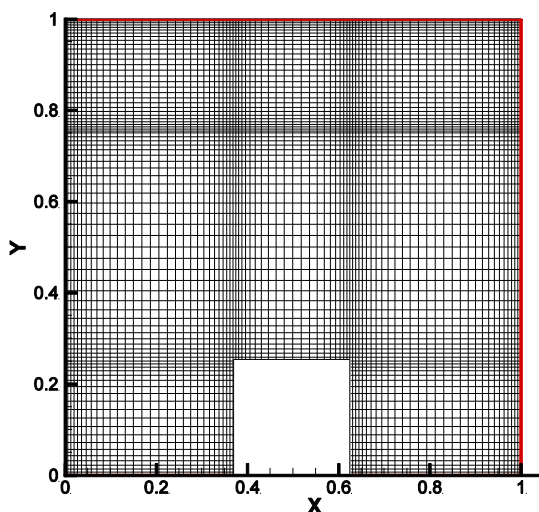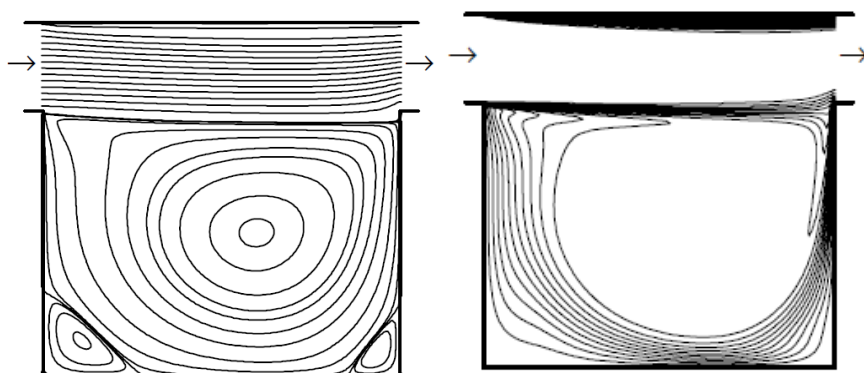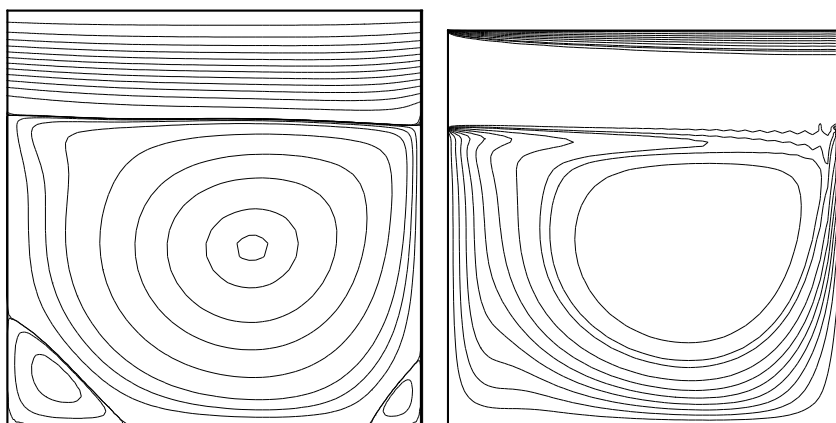

Fig. 2 Computational mesh

a) Streamline contour[1]   b) Isothermal contour [1]

c) Streamline contour   d) Isothermal contour

Fig. 3. Validation simulation for Re=500 of [1] at a) and b) [1].
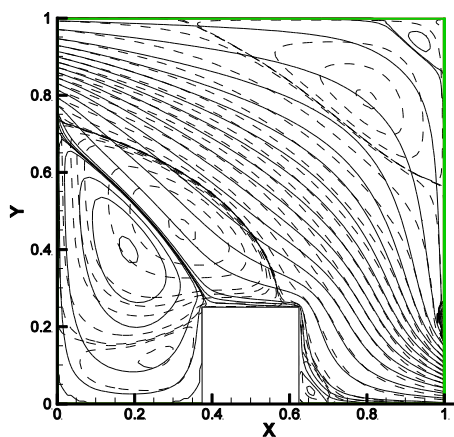   Present simulation are at 3.c) and d).
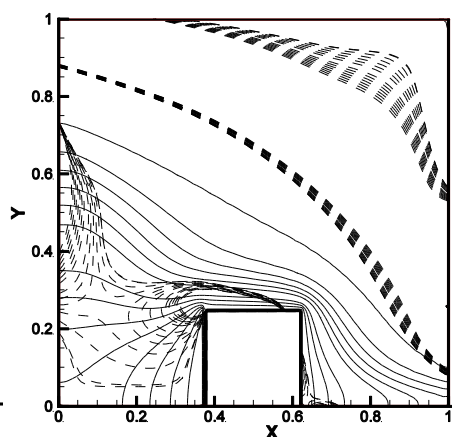

Fig. 4 Streamline contour Re= 50(-)   Fig. 5 Isotherm contour Re= 50(-) and
         and 200(- -).φ=0   200(- -).φ=0
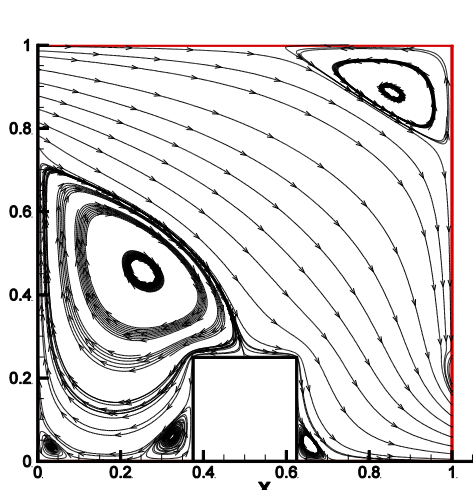
Fig. 6 Streamline contour Re = 100 & φ=0
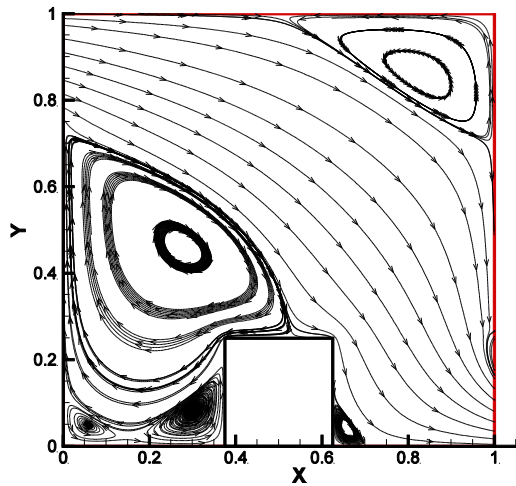
Fig. 7 Streamline contour Re = 100, Cu & φ=5%
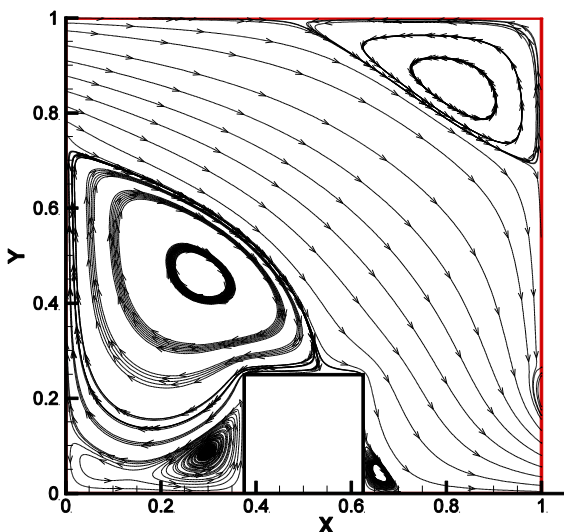
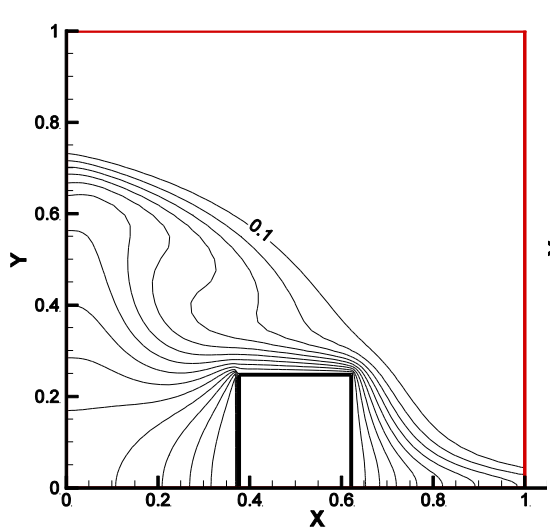Fig. 8 Streamline contour Re = 100, Ag & φ=5%
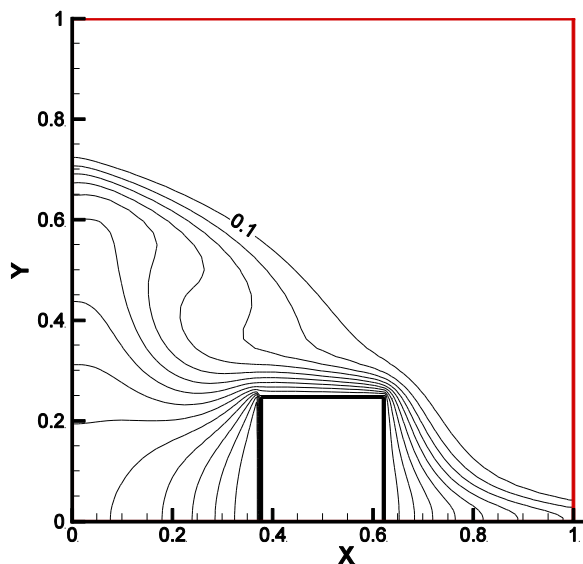
Fig. 9 Isotherm contour Re = 100. φ=0
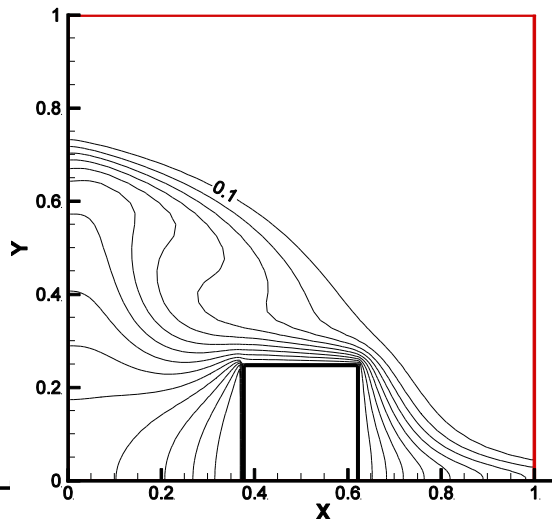
Fig. 10 Isotherm contour Re = 100. *Cu* nanomaterial, φ = 5%
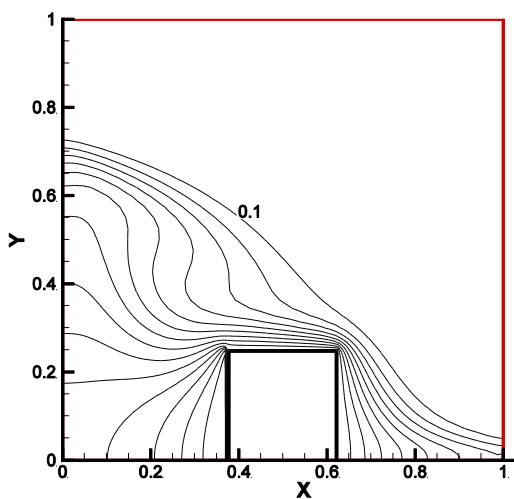
Fig. 11 Isotherm contour Re = 100. *Ag* nanomaterial, φ = 5%

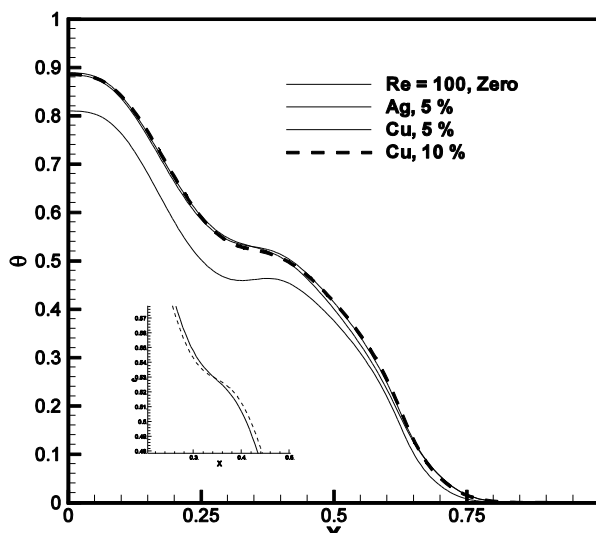Fig. 12 Isotherm contour Re = 100. *Cu* nanomaterial, φ = 10%
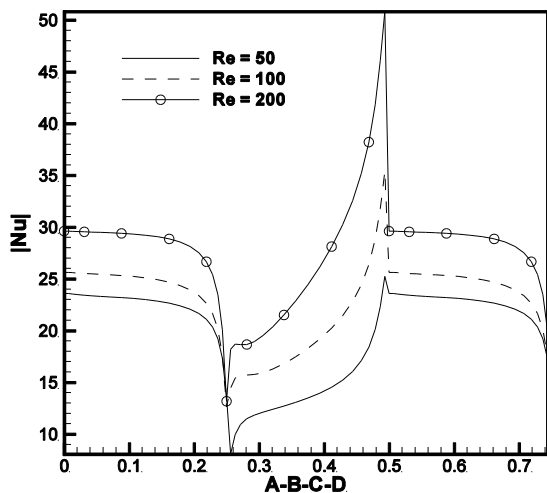
Fig. 13 Isoherm at *y* = 0.35

Fig. 14 Local Nusselt number: pure water.
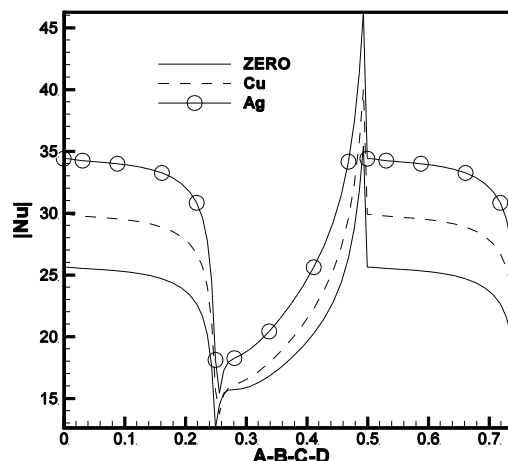

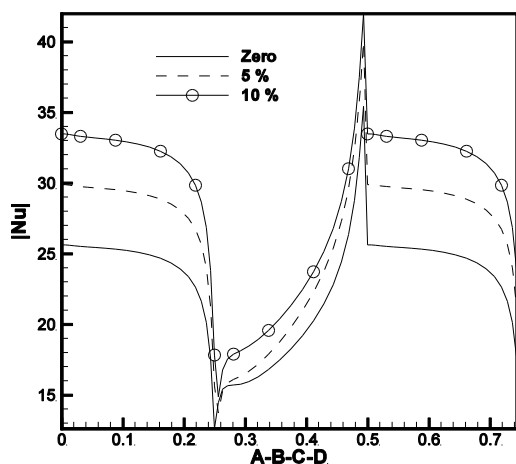Fig. 15   Local Nusselt number: Effect of material

Fig. 16 . Local Nusselt number: Effect of volume fraction

CONCLUSIONS

Two dimensional incompressible flow over heater mounted in a square cavity is simulated subject to inflow and outflow to understand the usage of nanofluid. Results are compared with basefluid. It is found that the increae in Reynolds number will also increase in heat transfer. The wall attached vortex results less variant in local Nusselt number. The high conductivity and low specific heat nanomaterials enhance the heat transfer than the bae fluid. When perentage of volume fraction is increased proportionately the Nusselt number is also increased. The heater top wall shows higher Nusselt number than rest of the two side walls.

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