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Numerical Study of Heat Transfer Enhancement by using Nanofluids in Convection over a Flat Plate

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Abstract—*In this paper, the problem of Convective heat transfer using nanofluid is numerically investigated. Thermal Conductivity, Viscosity of water-based nanofluid (Al_2O_3) has been calculated. Numerical Investigation shows that there is an enhancement of about 25% in heat transfer coefficient in case of forced convective heat transfer whereas in case of free convection, the heat transfer coefficient first increases upto 10% at a volume concentration of 1% and then decreases as the volume fraction of nanoparticles increases. This enhancement is observed due to high conductivity of nanoparticles and nanoconvection due to Brownian motion of particles in the suspension.*

Keywords*: Nanofluid, Heat transfer coefficient.*

1. INTRODUCTION

Convection heat transfer is being used in more and more fields, for example, in cooling of electronic equipment, in heat exchangers, in refrigeration etc. Almost all the conventional heat transfer fluids, like ethylene glycol, water, etc. have a limit on their thermophysical properties, which in turn put a restriction on several heat transfer applications. These thermophysical properties can be improved by forming a colloidal suspension and the idea dates back to study performed by Maxwell in 1873 [1]. In 1995, Choi [2] performed study on nanoparticle suspension in conventional heat transfer fluid based on Maxwell's study in which he found that thermal conductivity of fluid is enhanced without any agglomeration. Since then nanofluids have become a topic of interest for researchers in field of heat transfer. The goal of nanofluids is to achieve the highest possible thermal properties at the smallest possible concentrations (preferably <5% by weight) by uniform dispersion and stable suspension of nanoparticles (preferably < 50 nm) in host fluids. In order to get better heat transfer results from nanofluid there must be sufficient data on thermophysical properties of such colloidal suspension.

Eastman et al. [3] observed that with 3% volume concentration of Copper nanoparticle in ethylene glycol, thermal conductivity is enhanced by 40%. Das et al. [4] found that there is an increase of 10-25% in thermal conductivity of alumina nano-suspension in water with 1-4% volume concentration.

Several experimental and theoretical relations have been proposed but no universal correlations have been developed till date to calculate the thermophysical properties of all types of nanofluids at different concentration.

In the present work, the heat transfer enhancement of nanofluid (Al_2O_3- water) in case of natural and forced convection over a horizontal flat plate is numerically studied. The results show good agreement with the experimental studies performed by several other researchers.

2. MATHEMATICAL MODELLING

2.1 Assumptions

No theory has been formulated till date that could predict the actual behavior of nanofluids. Nanoparticle have an extremely reduced dimensions and thus they can be easily fluidized and as a result nanoparticle can be considered to behave like fluid [11]. Nanofluid can be treated as a single-phase fluid, if we assume that there is no slip between particle and continuous phase.

2.2 Geometrical configuration and governing equations

Fig. 1 shows the geometrical configuration of problem which is under consideration. It consists of a steady forced and natural convection flow and heat transfer of nanofluid over it (i) *Case 1* forced convection heat transfer is analyzed on a flat plate using nanofluid. (ii) *Case 2* Natural convective heat transfer behavior is observed over a flat plate using nanofluid. In both of the above cases length and width of plate are kept long enough so that fully developed flow conditions prevail at the outlet section.

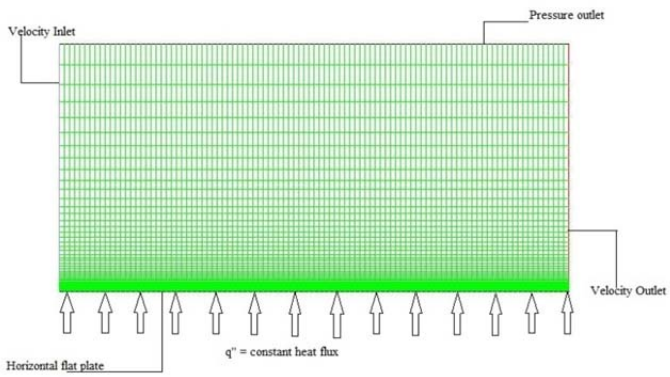

Fig. 1: Control volume under consideration

In present study, a single phase fluid approach to observe the thermal behavior of nanofluids. It is assumed that nanofluid is incompressible with constant physical properties. Under above assumptions, general conservation equation becomes as follows:

- ***Conservation of mass***

$$div(\rho V) = 0 \quad (1)$$

- ***Conservation of momentum***

$$div(\rho VV) = -grad\ P + \mu\nabla^2 V \quad (2)$$

- ***Conservation of Energy***

$$div(\rho V C_p T) = div(k\ grad\ T) \quad (3)$$

Where, in above equations P, T and V are respectively fluid pressure, temperature, and velocity vector. Also all fluid properties are evaluated at the reference temperature that is the fluid inlet temperature T_o.

By assuming the nanoparticles are well dispersed within the base fluid, thermophysical properties of nanofluids are computed using relations provided by Buongiomo [6].

$$\rho_{nf} = \varphi\rho_{np} + (1-\varphi)\rho_{bf} \quad (4)$$

For calculating specific heat of nanofluid we will be using the equations presented by Buongiomo [6].

$$C_{p_{nf}} = \frac{\varphi\rho_{np}C_{p_{np}} + (1-\varphi)\rho_{bf}C_{p_{bf}}}{\rho_{nf}} \quad (5)$$

For calculating thermal conductivity we will be using the most common equation proposed by Hamilton and Crosser [7].

$$\frac{k_{nf}}{k_{bf}} = \frac{k_p + (n-1)k_{bf} + (n-1)\varphi_p(k_p - k_{bf})}{k_p + (n-1)k_{bf} - \varphi_p(k_p - k_{bf})} \quad (6)$$

Where, in the above equation 'n' is the shape factor and is equal to 3 for spherical nanoparticles.

In this work, the relative viscosity of nanofluid is predicted by Einstein–Batchelor model [9].

$$\frac{\mu_{nf}}{\mu_{bf}} = 1 + 2.5\varphi_p + 6.2\varphi_p^2 \quad (7)$$

2.3 Numerical method

The system of general governing equations has been subjected to their appropriate boundary conditions of both the cases as described above. The computational fluid dynamics code Fluent was used to solve these set of governing equations. The First order upwind scheme was used to discretize the diffusion, convection terms coming from the governing equations. Staggered grid scheme has been used to calculate velocity terms at center of control volume interface and pressure terms are computed at the center of control volume. Pressure and velocity were coupled using Semi Implicit Method for Pressure Linked

Equations (SIMPLE) [12]. During iterative calculation process the residuals were carefully monitored as residuals are the indicator of convergence.

2.4 Boundary conditions

The general conservation equations mentioned above are highly complex, non-linear. There is also coupling of both fluid and thermal properties. Hence to solve these equations proper boundary conditions must be used. For *Case 1* (i.e. Forced Convection heat transfer) at the inlet of control volume, uniform velocity and temperature conditions are used. At the exit section, and top of control volume pressure outlet conditions prevail (i.e. all axial derivatives are zero). On the plate wall, no slip condition is used and also, thermal boundary conditions is considered in this study, which is the uniform wall heat flux at plate. For *Case 2* (i.e. Free Convection heat transfer) in control volume, velocity is assumed zero, and fluid is maintained at uniform temperature. On the plate wall, the usual no-slip conditions are applied. Also, thermal boundary condition is applied, which is adiabatic walls at both left and right hand of control volume, constant heat flux on the plate at the bottom and pressure outlet conditions on top of control volume. A 'back-flow' fluid temperature has been specified as well for case where an inflow occurs through the outlet section.

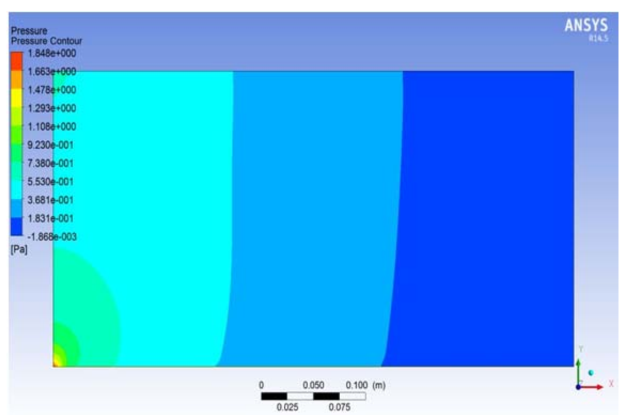

Fig. 2. Pressure contour for forced convection

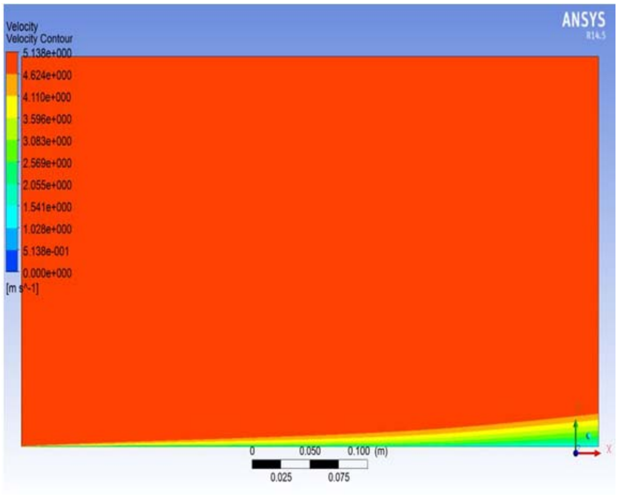

Fig. 3. Velocity contour for forced convection

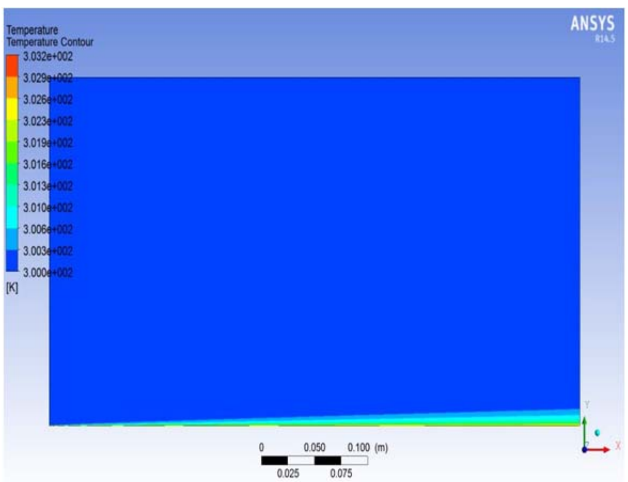

Fig.4. Temperature Profile for forced convection

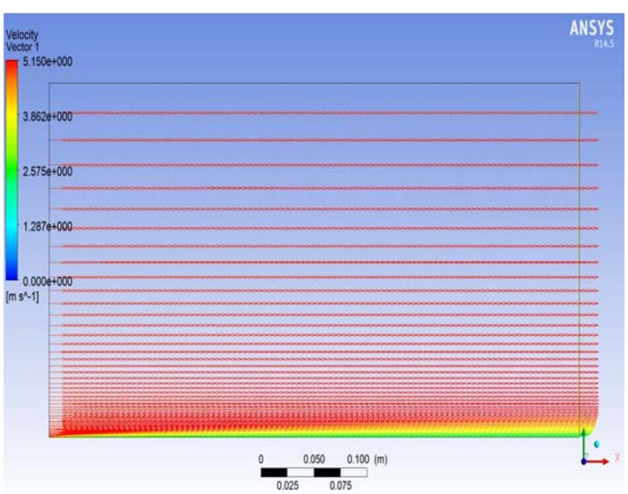

Fig.5. Velocity vector for forced convection

3. RESULTS AND DISCUSSION

3.1 Forced Convection

A detailed numerical simulations for *Case 1* considering nanofluid (water-Al_2O_3). The heated plate has a length of 0.5m. For the case of forced convection the parameters are as follows: (Reynolds number) *Re* = 10^3-10^6, (Wall heat flux) q" = 100W/m^2, (Inlet temperature ofnanofluid) T_o = 300K. The Nusselt number for fully developed flow for water based Alumina is compared with that of base fluid. The results of simulation are in good agreement with experimental work performed by Namburu et al. [13] which suggests that the computational model is generating correct results. Fig.6 shows the validation of present study. Here, Fig. 2 to Fig. 5 gives the details about the temperature, pressure and velocity in case of forced convection. Fig. 7 clearly depict that with increase in the volume concentration nusselt number is also increasing. Increase in Nusselt number and heat transfer coefficient is about 1.25 times with 3% volume concentration of nanoparticles over base fluid. This increase is due to the high conductivity of Aluminum oxide particles and the increased value of prandtl number.

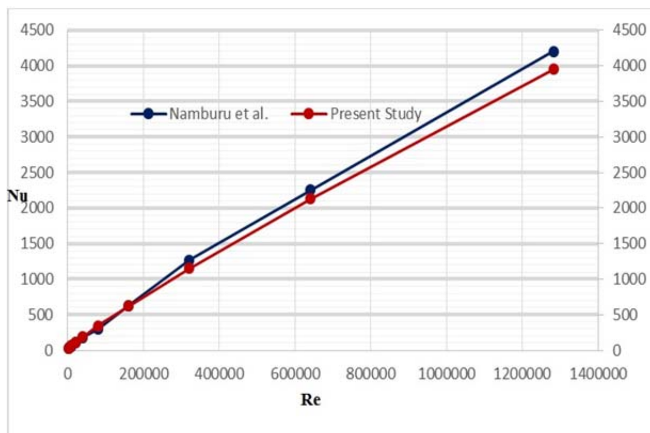

Fig. 6 Comparison of computed value of Nusselt number with results of Namburu et al.

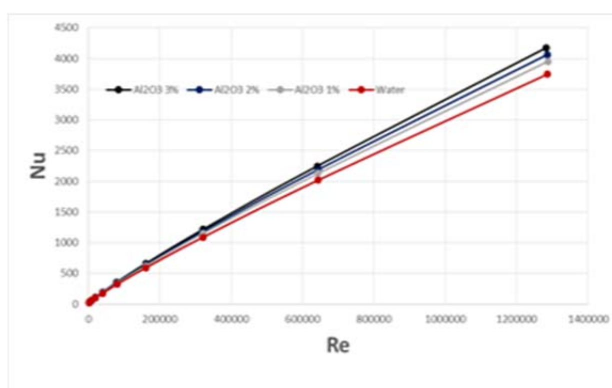

Fig. 7. Variation of Nusselt number with change in volume concentration and Reynolds number

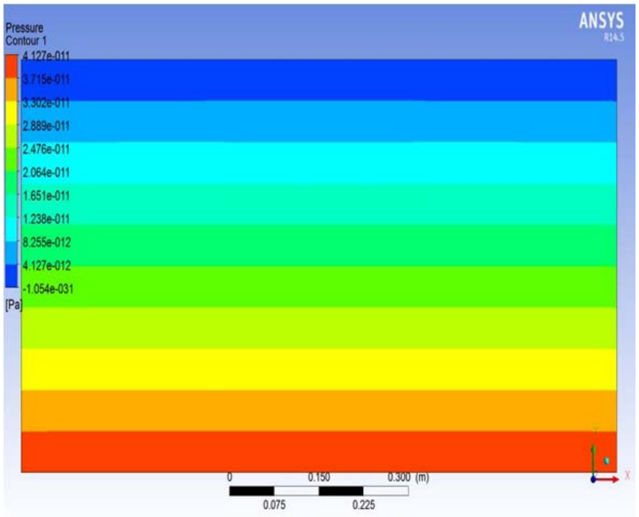

Fig. 8. Pressure variation in control volume in natural convection

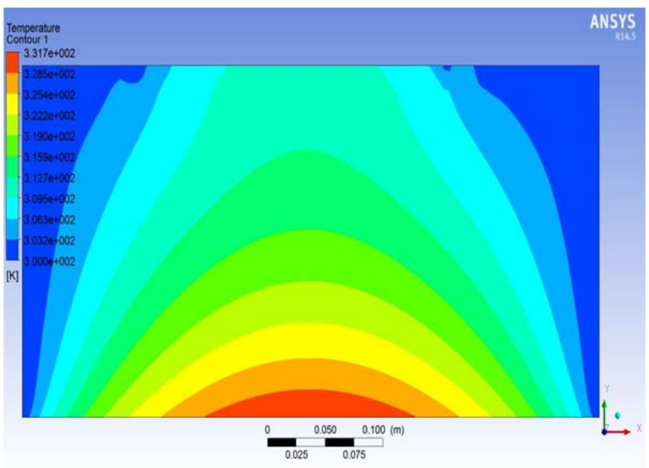

Fig. 9. Temperature variation in control volume in natural convection

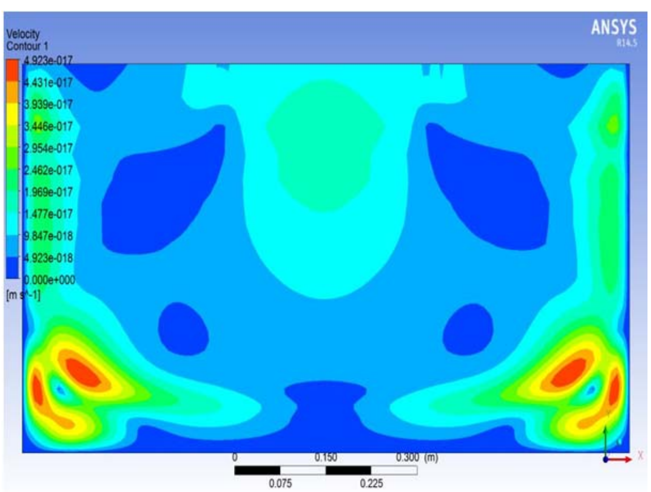

Fig. 10. Velocity contour for natural convection

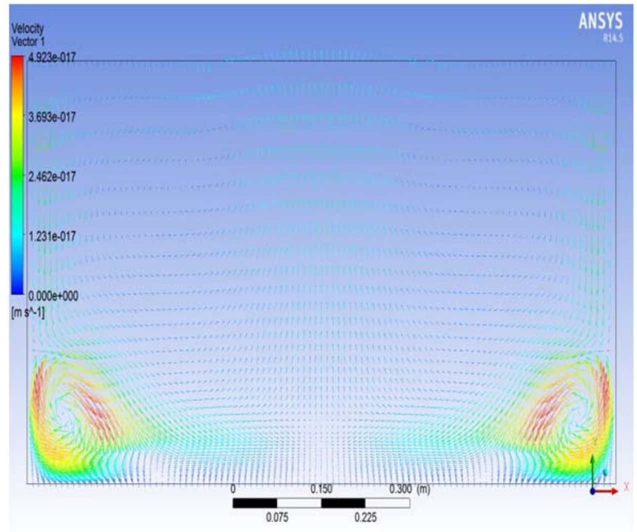

Fig. 11. Velocity vector for natural convection

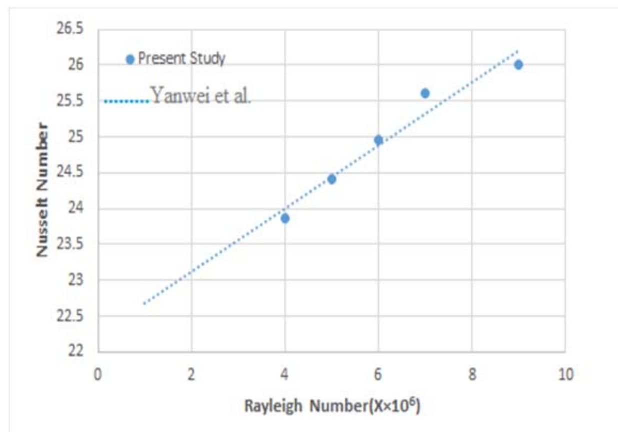

Fig. 12. Comparison of computed Nusselt number with results of Yanwei et al.

3.2 Natural Convection

Detailed study and extensive simulations have been performed in natural convection case considering water-based alumina nanofluid. For the case of forced convections the parameters are as follows: (Rayleigh number) Ra = 4E6 – 8E7, (Wall heat flux) q''= 100W/m^2

(Inlet temperature of nanofluid) T_o = 300K. In order to validate this computational model, results of this model is compared with the numerical results by Khanafer et al. [14] and experimental results by Yanwei et al. [15] as shown in fig.12. It is found that the results are in good agreement. Fig.8 –Fig.12 gives detail description about velocity, temperature and pressure in control volume. Fig. 13. Shows the variation of average nusselt number of nanofluid with varying Rayleigh number. It shows that at a particle concentration of 1% heat transfer characteristics is enhanced. As we increase the volume concentration enhancement weakens and at 2% it becomes approximately equal to that of base fluid. On increasing the volume concentration further heat transfer decreases.

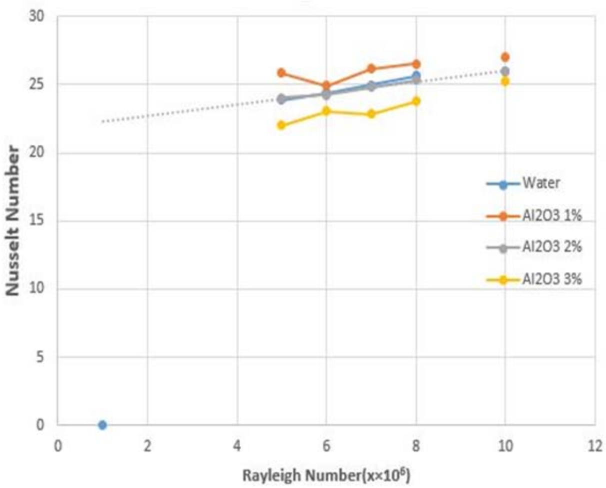

Fig. 13. Variation of Nusselt number with volume concentration and Rayleigh number

4. CONCLUSION

The flow and heat transfer of Al_2O_3-water nanofluid over a heated plate in numerically investigated. Following conclusions have been obtained:

In case of forced convection, about 25% of enhancement is observed in heat transfer coefficient when compared to that of base fluid. This mainly due to increased conductivity and high value of prandtl number at high particle concentration.

In case of natural convection, at low particle concentration (φ =1%) enhancement in heat transfer coefficient is observed. But as we increase the particle concentration any further heat transfer coefficient retards. This shows that in natural convection heat transfer coefficient is more dependent on viscosity rather that thermal conductivity. Another reason for this phenomena may be lack of nanoconvection due to Brownian motion of particle.

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