EFFECT OF VOLUME CONCENTRATION OF FE_3O_4 NANOFLUID ON NATURAL CONVECTION INSIDE A CYLINDRICAL ENCLOSURE

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Abstract— Natural convection in enclosures, also known as internal convection, takes place in rooms and buildings, furnaces, solar energy collection, cooling towers as well as electronic cooling systems. This Work is focused on numerical simulations of natural convection heat transfer of Water-Fe_3O_4 nano fluids in cylindrical enclosure using computational fluid dynamic approach to study the effect of volume concentration of nano fluid on heat transfer enhancement. For the volume fractions considered in the analysis, the Nusselt number decreased with the increase of volume concentration.

Index Terms—Natural convection, nanofluids, heat transfer enhancement, numerical method.

I. INTRODUCTION

The mechanism of heat transfer in which the fluid motion is produced due to change in density resulting from temperature gradients is called free or natural convection. Natural convection in closed cavities is of great importance in many engineering and scientific applications such as energy transfer, boilers, nuclear reactor systems, energy storage devices among others. Natural convection in an enclosure is referred to as internal convection, which is different from the external natural convection from a heated or cooled vertical plate.

Nanofluid is a new kind of heat transfer medium, containing nanoparticles (1–100 nm) which are uniformly and stably distributed in a base fluid. These distributed nanoparticles, generally a metal or metal oxide observe to greatly enhance the thermal conductivity of the nanofluid, increases conduction and convection coefficients, allowing for more heat transfer. Many different particle materials are being used for nanofluid preparation, viz., Al_2O_3, CuO, TiO_2 SiC, TiC, Ag, Au, Cu, and Fe nanoparticles which are frequently used in nanofluid research. Carbon nanotubes are also utilized due to their extremely high thermal conductivity in the longitudinal (axial) direction.

Base fluids that are widely used in the preparation of nanofluids are the common working fluids of heat transfer applications; such as, water, ethylene glycol and engine oil. In order to improve the stability of nanoparticles inside the base fluid, some additives are generally added to the mixture in small amounts.

II. LITERATURE REVIEW

Putra N et al. [1], investigated Natural convection of nanofluids inside horizontal cylinder heated from one end and cooled from the other end. They reported heat transfer deterioration with the increase of particle volume fraction.

C.J. Ho et al. [2] investigated Natural convection heat transfer of alumina-water nanofluid in vertical square enclosures of different dimensions. The experimental results showed systematic heat transfer degradation for the nanofluids containing nano particles of 2 vol.% over the entire range of the Rayleigh number considered. However, for the nanofluid containing much lower particle fraction of 0.1vol.%, a heat transfer enhancement of around 18% compared with that of water was found to arise in the largest enclosure at sufficiently high Rayleigh number. Such enhancement cannot be explained simply based on the net influence due to relative changes in thermo physical properties of the nanofluid containing such low particle fraction, thus strongly suggesting other factors may come in to play.

Khanafer et al. [3] investigated the heat transfer enhancement in a two-dimensional enclosure utilizing nanofluids for various pertinent parameters. It is found that the suspended nanoparticles substantially increase the heat transfer rate at any given Grashof number.

Jou and Tzeng [4] used nanofluids to enhance natural convection heat transfer in a rectangular enclosure. They conducted a numerical study using Khanafer's model. They indicated that volume fraction of nanofluids cause an increase in the average heat transfer coefficient.

Santra et al. [5] studied heat transfer rate in a differentially heated square cavity using Cu-water nanofluid for volume fraction ranging from 0.05 % to 5%. It is observed that heat transfer decreases with increase in particle fraction for a particular Ra, While increases with Ra for a particular particle fraction

Hwang et al. [6] investigated the buoyancy-driven heat transfer of water-based Al_2O_3 nanofluids in a rectangular cavity. They showed that the ratio of heat transfer coefficient of nanofluids to that of base fluid is decreased as the size of nanoparticles increases, or the average temperature of nanofluids is decreased.

With regards to the CFD Simulations using FLUENT software, Jafari et al. [7] studied the effect of gravity on sedimentation and clustering of nano Ferro-fluids on natural convection heat transfer. They used both the single phase approach and mixture model.

Buoyancy driven heat transfer of nanofluids is studied by Ismail et al. [8] using FLUENT. Effect of volume fraction and Rayleigh number is studied in their work using single phase approach.

Li and Xuan [9] have experimentally investigated the convective heat transfer features of the aqueous magnetic fluid flow over a fine wire under the influence of an external magnetic field.

Review of the pertinent literature on the heat transfer characteristics of nanofluids shows that, over the years, considerable efforts have been given to investigate this problem experimentally, however, very few studies relates to numerical investigations on natural convection heat transfer. Therefore, the objective of this work is to numerically simulate natural convective heat transfer of Fe_3O_4-water nanofluids in comparison with that of pure water. The numerical simulations were carried out using the computational fluid dynamic (CFD) approach, with Fe_3O_4 nanofluid as the working fluid.

III Problem Definition

A cylindrical enclosure of length to diameter ratio as 1 and diameter of cylinder as 0.04m is selected for CFD simulations. Since the nanoparticles in the base fluid are easily fluidized, the nanofluid mixture is considered as a single phase. It is also assumed that the nanoparticles and the base fluid are in thermal equilibrium with each other and thus the relative velocity is negligible or equal to zero. Thus, the well known equations of single phase flow, viz., equations of continuity, momentum and energy are applicable to the nanofluids as well.

The temperature of the left wall is maintained at three different temperatures 310K, 329K, 345K to study the natural convection at different Ra, while the right wall is constantly maintained at a temperature of 285K.

To investigate the behaviour of Fe_3O_4 -Water nanofluid for different volume concentration, viz., 1%, 2% and 4% during the natural convection heat transfer using CFD software, CFX 14.5.

III Numerical Simulation

The simulations are initially performed in 3D on the mesh model of cylindrical enclosure as shown in Fig.1.

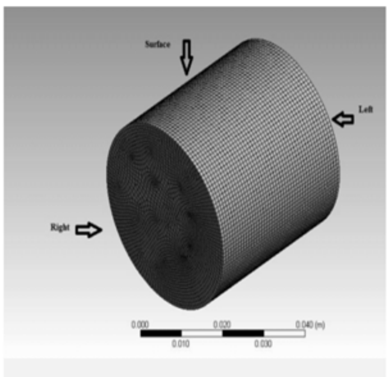

Fig.1 Mesh model of a Cylindrical Enclosure in CFX 14.5

A. Grid Independence Study

Prior to performing the actual simulations on nanofluid flow, grid independence study was carried out with three different mesh sizes with number of elements; 77330, 81877, 92000 and 113000 respectively. The hot and cold walls are maintained isothermally at temperatures of 310 and 285 K, respectively. Velocity profiles are plotted at the mid-section of the cavity and the same is shown in Fig.2 for different mesh sizes.

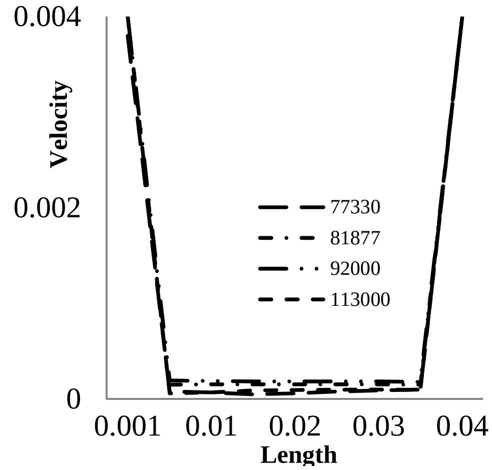

Fig.2 Grid independent study showing velocity magnitude at mid section of cavity.

The mesh with 113000 elements is used for all other simulations as the grid shows comparatively smaller deviation with that of grid with 92000 elements.

B. Material Properties of Nanofluids

Many models are available in literature for prediction of thermal conductivity of nanofluids. After thorough examination, stationary particle kinetic model is selected for calculation of thermal conductivity of nanofluid for different volume fractions as given in (1). Similarly, kinematic viscosity is evaluated using Brinkmann's model as mentioned in (2). Density and specific heat are evaluated using homogeneous model in (3) and (4).

$$k_{eff} = k_f[1 + \frac{k_p \Phi\, r_f}{k_f r_p (1-\Phi)} \quad (1)$$

$$\mu_{eff} = \frac{\mu_f}{(1-\Phi)^{2.5}} \quad (2)$$

$$\rho_{eff} = \rho_f(1-\varphi) + \varphi\rho_p \quad (3)$$

$$C_{peff} = \frac{(1-\Phi)\rho_f C_{Pf} + \Phi\rho_p C_{pp}}{\rho_{eff}} \quad (4)$$

C. Governing Equations

The governing equations of fluid flow as given in (5), (6) and (7) are numerically solved using segregated solver.

$$\frac{\partial(\rho u_j)}{\partial x_j} = 0 \quad (5)$$

$$\frac{\partial(\rho u_j \emptyset)}{\partial x_j} = \frac{\partial\left(\Gamma \frac{\partial \emptyset}{\partial x_j}\right)}{\partial x_j} + S \quad (6)$$

where Ø represents x and y directional velocities for momentum equations and temperature for energy equation. The subscript, j represents the coordinate direction.

D. Method Of Solution

Time independent (steady state) solver was used for all the simulations. Laminar model is used to simulate the natural convection flow using SIMPLE scheme for pressure–velocity coupling and PRESTO is used for pressure. Iterations are performed until the residuals reaches $1*10^6$.

The total surface heat flux (q) is computed from hot wall in each case using surface integrals. Heat transfer coefficient is then calculated using the value of total surface heat flux as given in (7).

$$h = \frac{q}{(T_H - T_C)} \quad (7)$$

IV RESULTS AND DISCUSSIONS

A. Validation of Numerical Model

The numerical results of natural convection heat transfer with water are compared with that of experimental results [10] available in the literature in order to validate the model.

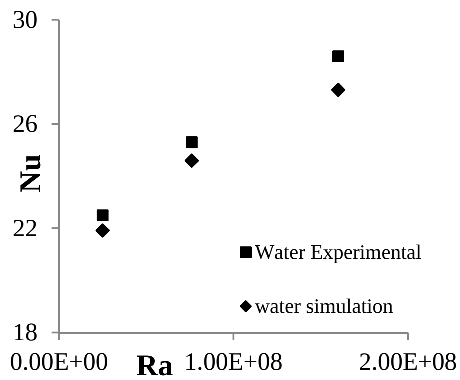

Fig.3 Validation of Numerical model

The results are represented in Fig. 3 shows that the numerical results predicted the trends and thus the numerical model is validated.

B. Comparison of Nu of Nanofluid with that of Water

Nusselt number is plotted for three different Rayleigh numbers corresponding to three different temperatures of 310, 329 and 345 K at hot wall and constant temperature of 285 K at cold wall for Fe_3O_4 nanofluid at volume fractions of 1%, 2% and 4% as shown in Fig. 4. The figure shows that at low Raleigh number, the variation in Nusselt number of nanofluid compared to pure water is not significant. The graph clearly shows that with the increase of volume fraction of nano particles, the Nusselt number has decreased. The results predicted the trends as reported in the literature. The results show that the decrease of Rayleigh number has dominant effect on the heat transfer by natural convection compared to the increase of Prandtl number.

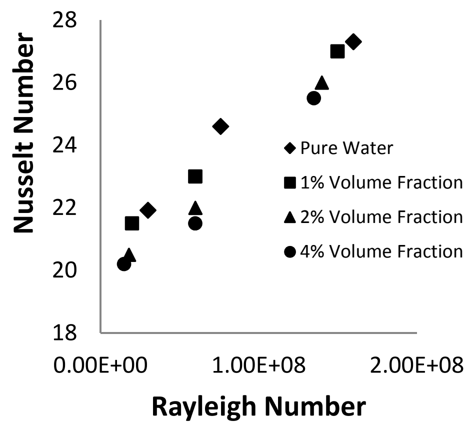

Fig.4 Variation of Nu with Ra for Nanofluid

Figure 5 shows the variation of the ratio of Nusselt number of nanofluid to that of pure water at different temperatures of hot wall. The graph is drawn in order to estimate the deterioration in the heat transfer of nanofluid in comparison with the water.

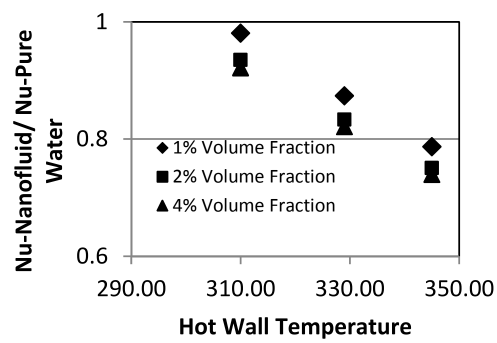

Fig.5 Comparative Graph of Nu of Nanofluid

The graph shows that the decrement in heat transfer by natural convection of nanofluid compared to that of water is more than 20% at high Rayleigh numbers. At the medium value of Ra among the three hot wall temperatures considered, the decrement is from 10% to 20%

with volume fraction changing from 1% to 4%. At low Ra, the decrement of Nu is almost negligible for nanofluid of 1% volume fraction and with increase of volume fraction, the decrement in Nu is upto 10%.

V CONCLUSIONS

Natural convection heat transfer of nanofluid is studied for Fe_3O_4-water nanofluid in a horizontal cylinder of L/D = 1.0 using CFD approach. The numerical results obtained for pure water showed excellent match when compared with the experimental results [10], thus validating the numerical model which considered the nanofluid as single phase fluid.

The comparison of numerical results for volume fractions of 1%, 2% and 4% of Fe_3O_4 nanofluid with that of water shows heat transfer decrement as reported by Ho et al. [2]. The highest decrement is obtained for 4% volume fraction at high Rayleigh number with more than 25%. The results clearly showed a decrement in heat transfer with the increase of natural convection.

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