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Numerical Analysis on Convective Heat Transfer of water Based Hybrid Nanofluid (Alumina-Copper) In a Horizontal Annulus

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ABSTRACT

Numerical inspection of natural thermally induced flow in horizontal annulus has been carried out. The annulus taken under consideration is the circular annulus. By applying heat flux to the inner tube, the inner wall of the annulus is kept at high temperature and the outer wall of the annulus is maintained at constant low temperature. The numerical simulations were accomplished by varying concentrations of the hybrid nanofluid of a hybrid alumina-copper various for each Rayleigh number (4 x 104 < Ra < 4 x l05). Heat transmission through natural convection using air as convective fluid, in the body of horizontally placed annulus resided between two same hollow cylinders, is calculated. The influence of the Rayleigh number along with particle concentration on heat transmission characteristics, change in fluid flow and effective thermal conductivity of an annulus has been studied. The results showed a proportional rise in the heat transfer performance and effective thermal conductivity with the increasing particle concentration and Rayleigh numbers.

1. Introduction

A brief introduction has been carried out about the natural convection phenomenon in enclosures and their applications. Amongst the most significant engineering applications one is the investigation of thermally induced flow of coolants inside the eccentric and concentric horizontal annuli. These have gained a lot of interest among researchers over the last decades as a result of its wide-ranging and significant uses together with electronic equipment's cooling, nuclear reactors, heat exchangers, thermal energy storage, solar power utilization, building component (usually thermal insulation), air conditioning systems and various several power and energy transmit applications. Therefore, the purpose of such a design is just to improve the heat transfer rate through free convection. However, most engineering implementations need to reduce the transfer of heat through free convection.

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An accountable work has been performed on thermally induced flow in horizontal annulus which is having a numerous application in engineering Science. Various Researchers probe the flow regime and the pattern of heat transfer by natural convection from many two-dimensional closed curves like a triangle, rectangle, ellipses, etc. The present literature review focuses on the works reported on natural convection occurring in systems horizontal annulus has been discussed in detail.

Khalaf [1] compared theoretically and practically, the role of rotational Reynolds's number, radius, aspect ratio, and Rayleigh numbers for calculating naturally convected heat transfer and the change in fluid flow in the air, for a horizontal annulus. Based on the analysis, the average Nu number was declared as a function of Ra only for pure natural convection and dependent on both Re and Ra for mixed convection.

Bouras *et al.,* [2] theoretically analyzed the heat transfer by natural convection in an elliptical cross-sectioned horizontally placed, rotating outer cylinder annulus at a various combination of the Rayleigh number and Prandtl number. They observed that heat transfer rise with increasing Ra and Prandtl number doesn't have major role on heat transfer at lower Ra value.

Waleed *et al.,* [3] theoretically studied the thermally induced flow in a horizontal annulus in a flat tube placed centrally and concentrically. The simulation was performed on the 2D model angle of the flat tube for the variety of hydraulic radius ratios and orientation. The conclusion made was that the proportionality of the Nusselt number with the enhancement of orientation angles, Raleigh number, and hydraulic radius ratios.

Yu *et al.,* [4] analyse unsteady thermally induced flow inside a horizontal concentric annulus surrounded by inner circular cylinder and an outer triangular cylindrical enclosure. The investigation was carried out for various inclination angles of the triangular enclosure, Grashof number, and aspect ratios. The changes of the average Nusselt number recognized during the course of flow growth. The time- average Nusselt number and the flow development time in the inner circular wall have been projected and measured with Grashof number.

Nada [5] carried out an experimental analysis of thermally induced heat and fluid flow in horizontal as well as inclined annuli around concentric tubes. The effect of Rayleigh number for various widths of the annulus gap to outer diameter ratio with the variety of annulus inclinations was observed. The results give the increase of heat transfer rate with the width of the annulus gap. Also, the heat transfers marginally reduced with the increment of horizontal inclination.

Chmaissem *et al.,* [6] numerically studied the heat transfer in a horizontal annular area surrounded by a circular and elliptical isothermal cylinder. If the enclosure restricts the fluid circulation, even if the Rayleigh number is lower, it becomes possible to detect multicellular flows.

Yuan *et al.,* [7] conducted a numerical experiment on buoyancy induced flow in horizontal concentric annuli of various inner shapes. The outer surface has given the lower temperature whereas the inner surface at constant high temperature. The analysis was categorized by the shape of an internal entity form, which is either triangular, circular, elliptical, or cylindrical. Thermal fields and flow were pictured using streamlines and isotherms. The effects of surface radiation were also included in the analysis and overall heat transfer correlations were expressed in form of Nusselt number. When considering whole heat transfer activity due to natural convection at high temperatures, radiation has been found to play a drastic role.

The numerical and experimental studies concerning the thermally induced flow of water [8-10] and nanofluids [11-15] in vertical annulus reported in literature are large in number while there is scarcity of studies related to rotating horizontal annulus. Therefore, in present numerical work, numerical inspection of natural thermally induced flow of water based hybrid nanofluid (Alumina - copper) in horizontal annulus has been carried out.

2. Methodology

Figure 1 depicts the computational model in which the outer diameter of the annulus is kept constant by varying the inner diameter (12 to 25 mm), and the ends of the annulus are closed. Inner to Outer wall is the direction of heat transfer. During the numerical simulation, the warmth flux changes to regulate the temperature of the inner heated cylinder (TH) and Rayleigh number within annuli.

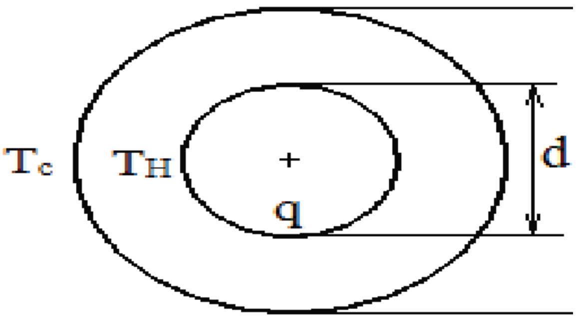


Fig. 1. Cross-sections of the studied annulus

In this section, the heat and fluid flow of hybrid nanofluid inside horizontal annuli are governed by equations that are discussed in this section along with the boundary conditions. Within the two-dimensional domain of the annulus, the governing equations and boundary conditions are solved numerically using finite volume method discretization. The governing partial differential equations are non-linear. This non-linearity results in the driving of the governing equations for control volume of the annulus. With computational methods and discretization techniques, the resulting (PDE) partial differential equations are transformed into algebraic equations.

For limited number of grid points, algebraic equations are solved to analyse the temperature distributions and therefore the fluid flow within the physical model of the matter. The radiation between surfaces has been considered and measured by radiosity and thus factors are incorporated in ANSYS Fluent simulation. The radiation effect on the answer is collected, instead, via its effect on the energy residual and therefore the energy field. However, normalized radiation error has been specified in ANSYS Fluent for each S2S (surface to surface) radiation iteration. Wherever for every time an S2S radiation iteration is carried out. The normalized radiation error has been well-defined. Since the temperature and velocities aren't alleged to differ with axial inclination of the various annulus cylinders, therefore, the problem was modeled as a two-dimensional problem. The standard-laminar viscous-flow model has been applied within the solution alongside surface to surface(S2S) radiation. The COUPLED algorithm has been used in the discretization to link the pressure-velocity coupling. The second-order upwind discretization scheme has been used to obtain precise and accurate results with an aim to validate the present numerical model. The convergences criteria used in the present study for the solution is to hold the normalized momentum, continuity, and energy residuals below 10-6, and 10-9, respectively. For the present standard-laminar model, the transient state solution has been used to acquire the temporal terms in the governing equations to be accelerated in time to reach a steady-state solution. Since a steady-state solution that typically exists with either high Rayleigh or low Prandtl numbers cannot be obtained accurately.

Rayleigh number (Ra) can be calculated as follows:

$$Ra = \frac{\rho g C_P \beta (T_H - T_C) D^3}{k\nu} \quad (1)$$

The stagnant air inside the annulus gives the given heat transfer at specific thermal conductivity that signifies as the effective thermal conductivity of air, which is represented as follows

$$K_{eff} = \frac{\dot{q}ln(D/d)}{2\pi(T_H - T_C)} \quad (2)$$

Where q stands for convective heat transfer of the annulus geometry per unit length. Calculation of thermal conductivity enhancement ratio as a result of thermally induced flow is done by using:

$$\frac{K_{eff}}{k} = \frac{\dot{q}ln(D/d)}{2\pi k(T_H - T_C)} \quad (3)$$

3. Model Validation

The computational model is validated with the numerical results of Nada and Said (2018). The present numerical model has been simulated for the same operational and geometric condition for the validation. Figure 2 shows the validation of the present solver with inner diameter of 12 mm of the circular annulus. Different heat flux (q) ranging from 100 W/m^2 to 1200 W/m^2 are applied at inner surface of annulus cylinder in order to produce high temperature at the inner surface of the geometry. Outer surface temperature is at 300 k. The inner surface temperature (Th) and outer surface temperature (Tc), the total rate of heat transfer (Qt) and rate of radiation heat transfer (Qr) are obtained for each different heat flux given to the inner cylinder of the annulus. The rate of convection heat transfer (Qr) is obtained by subtracting rate of radiation heat transfer (Qr) from the total rate of heat transfer (Qt) and effective thermal conductivity is calculated for respective heat flux boundary condition to obtain the Rayleigh number.

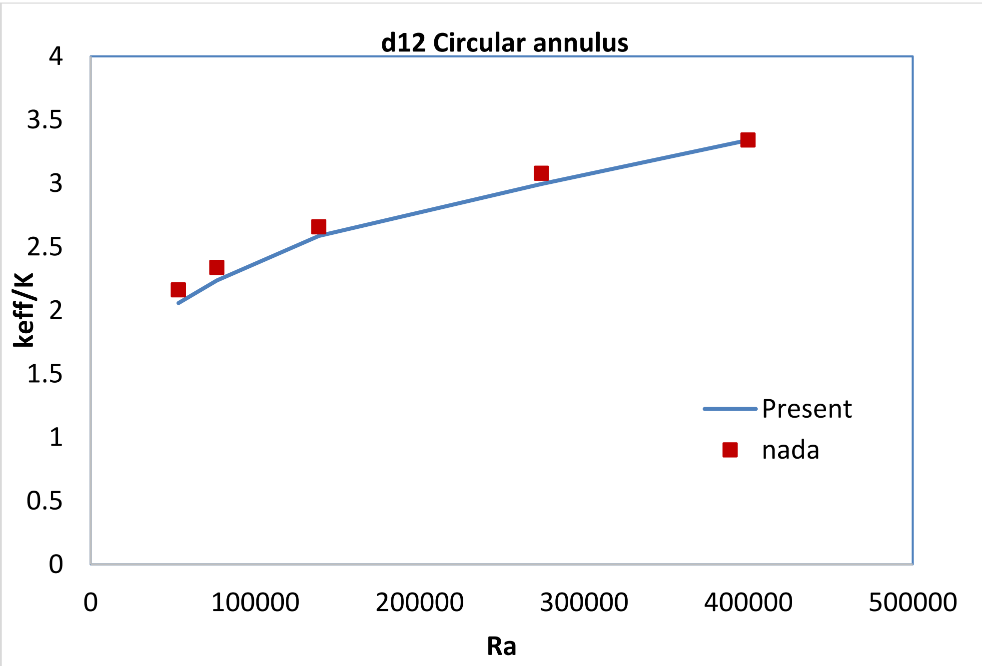


Fig. 2. Effective Thermal Conductivity Variation with Ra

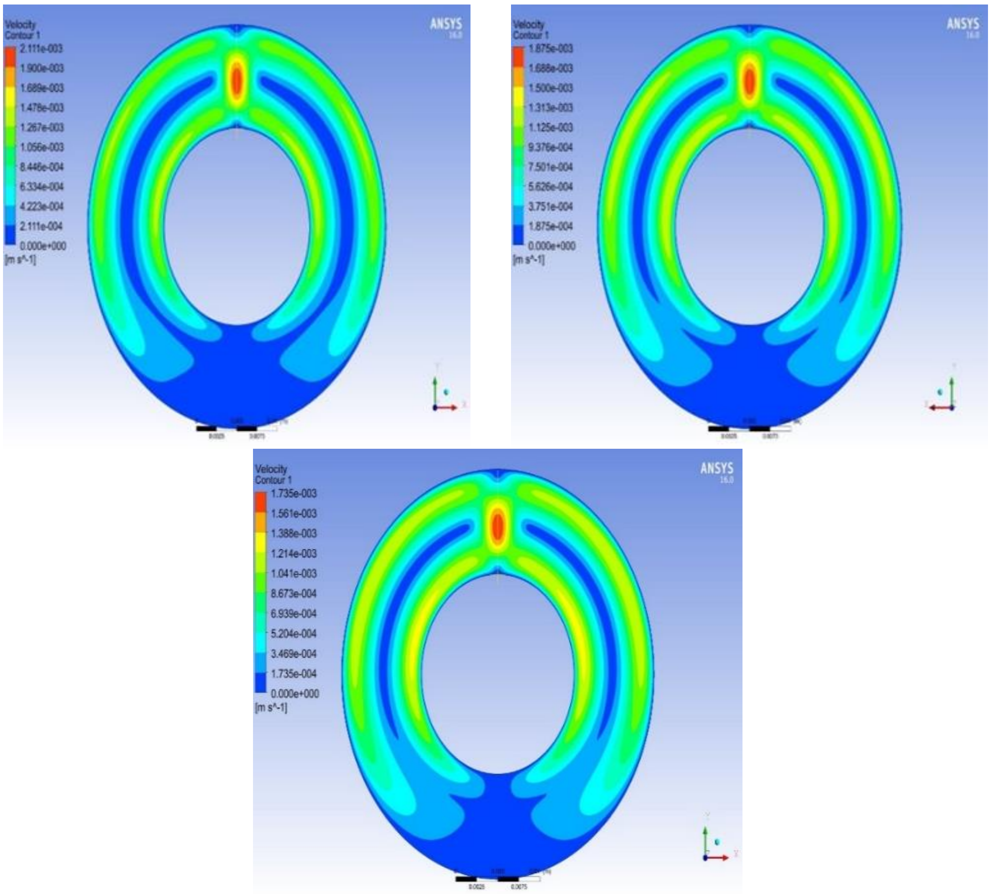
Table 1
Properties of Nanofluid for Different Volume Concentration

Volume Fraction(Φ)	Density(ρ) (Kg/m3)	Specific Heat (Cp) (J/kg-k)	Thermal Expansion Coefficient(β) (1/k)	Thermal Conductivity (K) (W/m-k)	Viscosity(μ) (Kg/m-s)
1.8	1083.75	3832.57	0.000191	0.6462	0.001175
2.7	1127.07	3679.33	0.000182	0.6633	0.001202
3.6	1170.4	3537.44	0.000174	0.6807	0.00123
4.5	1213.72	3405.68	0.000167	0.6984	0.00126

4. Discussion

In the present study, numerical simulations were carried out for annulus gap for circular annulus. The Particle Concentration have been varied from 1.8, 2.7, 3.6 and 4.5 to get the Rayleigh number varying from 4 x 10^4 to 4 x 10^5 to calculate the effective thermal conductivity. The effect of Rayleigh number and annulus gap width on heat and fluid flow of hybrid nanofluid are discussed in detail. The temperature contours and Velocity Contour has been discussed below.

The effect of nano-particles concentration on heat transfer is analysed by taking base fluid and concentration. The heat transfer of water and nano-fluids inside the annuli is studied using temperature and velocity contours. The velocity contours show the specific effect of applied different heat flux to produce different concentration on the flow field and heat transfer as shown in figure of velocity contours. Also, the temperature contours for same corresponding conditions are shown on figure of temperature contours.



(a)

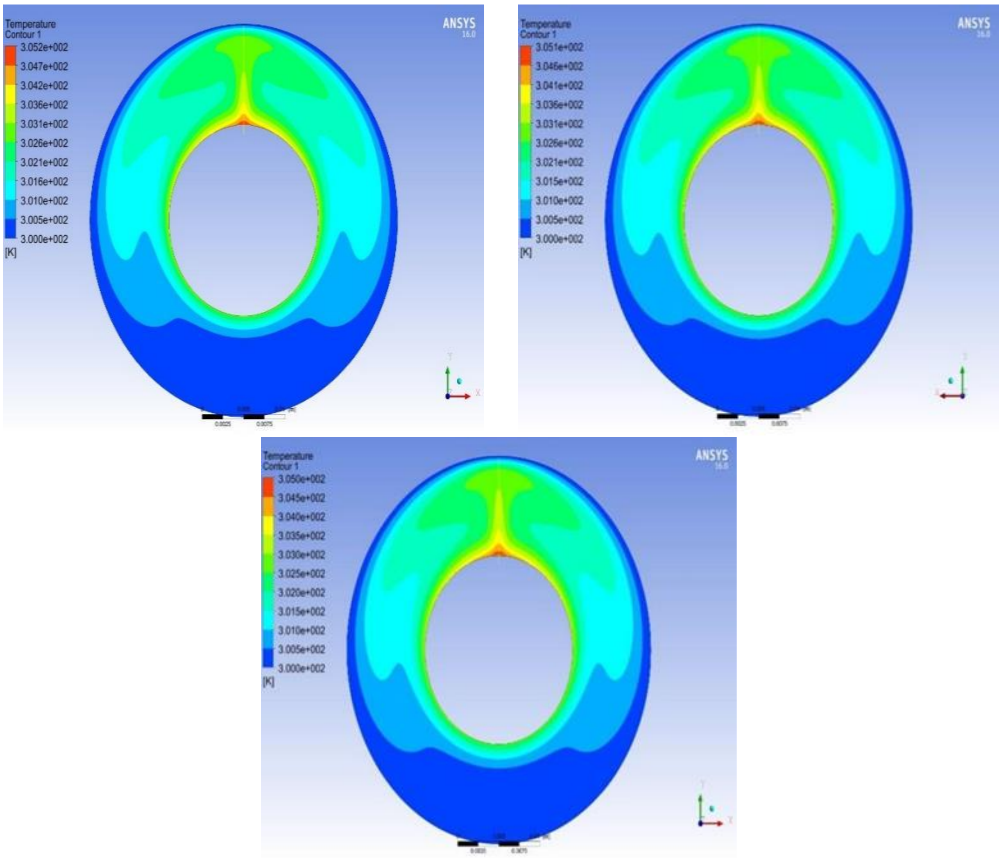


Fig. 3. (a) Velocity Contours for Particle Concentration (Φ =0,1.8,4.5) of the Studied at Annulus (b) Temperature Contours for Particle Concentration (Φ =0,1.8,4.5) of the Studied at Annulus

As seen in the diagram, the contours are symmetrical around the vertical axis of the annulus. The upper half of the annuli experiences higher temperature while lower temperature for lower bottom half of the annulus. It is also observed from the temperature contour that with increasing particle concentration, the temperature seems to decreases.

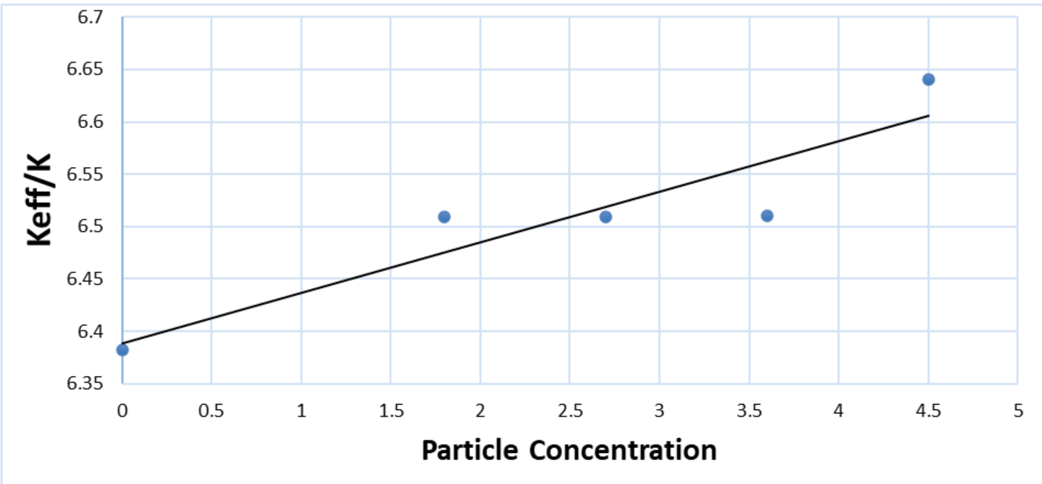


Fig. 4. Change in effective thermal conductivity with particle concentration

5. Conclusion

Numerical inspection of natural thermally induced flow in a horizontal annulus with different particle Concentrations was examined. The influence of the Keff/K, particle concentration annuli on the temperature contours, velocity contours were analyzed. And to compare the results the effective thermal conductivity was also calculated. Also, a comparative study was shown between heat transfer improvements of the circular annulus. The finding suggests that,

i. With increasing the particle concentration, the thermal performance and effective thermal conductivity of the annulus are improved.
ii. The velocity of the flow decreases with the enhancement of particle concentration

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