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ORIGINAL ARTICLE

INVESTIGATION OF HEAT TRANSFER ON A CAVITY CONTAINING A HEATED CIRCULAR FOR TWO TYPES OF NANOFLUIDS WITH DIFFERENT VALUES OF VOLUME FRACTION

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ABSTRACT: The present numerical study deals with natural convection in an enclosure with heated cylindrical block filled with nanofluid. The governing equations have been discretized using the finite volume method and the SIMPLE algorithm has been used to couple velocity and pressure fields.
KEYWORDS: Solid Volume Fraction, Natural Convection, Circular Cylinder, Nanoparticle.

INTRODUCTION

Research and study about free convection is an essential issue because of its applications in industry. Some of important applications of free convection include the following: Radioactive waste materials disposal (Bilgen, 2005a), nuclear reactors cooling (Bilgen, 2002), electronic devices cooling, heat transfers in buildings, solar thermal collector systems, fire control systems, chemical apparatuses, double glazed windows, ventilation systems, aerospace science.

Bilgen, (2005b) studied laminar and turbulent free convection heat transfer inside a cavity with small fins by numerical methods and solved 2-D conservation of mass, 2-D conservation of momentum and 2-D conversation of energy equations considering Boussinesq approximation and using SIMPLER method. He found out that choosing the proper geometrical parameters for the thin fins can increase amount of heat transfer by 38%. Sezai and Mohamad, (1999) investigated effects of devising fins with very low conduction heat transfer coefficient on warm vertical lids of the cavity.

Due to lack of extensive research on nanofluids heat transfer inside a cavity with a hot square cylinder, and also considering application this geometry in industrial application, purpose of this study is to investigate this geometry with respect to different effective factors like strength and weakness of buoyancy force, type of suspended particles, and volume fraction of nanoparticles. Results of this study are presented in the form of temperature and stream contours and different figures.

NUMERICAL MODELING

Schematic of the problem is shown in Figure 1. A hot cylinder with radius r and different positions at a high constant temperature (T_h) is considered to be located inside the cavity and the side lids are remained at a low constant temperature (T_c). The upper and lower lids are also insulated.

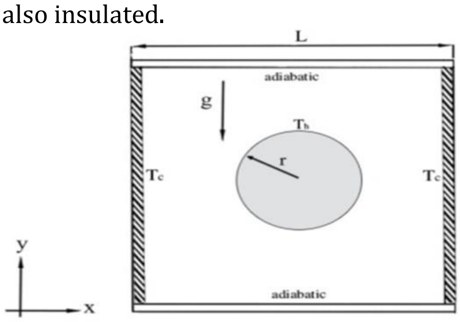

Figure 1: Schematic of the problem.

Nanofluids used in this problem are considered to be incompressible and Newtonian and the stream is laminar and steady in all areas of the cavity. Except for the density which varies according to the Boussinesq approximation, other thermophysical properties of water and nanofluid are assumed to be constant.

Continuum, momentum and energy equations for a laminar and steady free convective stream of nanofluid in a 2-D square cavity can be written as:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \quad (1)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho_{nf}}\frac{\partial p}{\partial x}+\upsilon_{nf}\nabla^2 u \quad (2)$$

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho_{nf}}\frac{\partial p}{\partial y}+\upsilon_{nf}\nabla^2 v+(\rho\beta)_{nf}\,g(T-T_c) \quad (3)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_{nf}\nabla^2 T \quad (4)$$

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Non-dimensionalized form of the governing equations is obtained using dimensionless parameters:

$$X = \frac{x}{L},\ Y = \frac{y}{L},\ R = \frac{r}{L},\ U = \frac{uH}{\alpha_f},\ V = \frac{vH}{\alpha_f} \quad (5)$$

$$\theta = \frac{T - T_c}{T_h - T_c} \qquad P = \frac{pL^2}{\rho_{nf}\,\alpha_f^2}$$

$$Ra = \frac{g\beta_f \Delta T L^3}{\upsilon_f \alpha_f},\quad Pr = \frac{\upsilon_f}{\alpha_f} \quad (6)$$

Nanofluid effective density, thermal diffusivity, specific heat capacity and dynamic viscosity are calculated by the following equations:

$$\rho_{nf} = (1-\varphi)\rho_f + \varphi\rho_s \quad (7)$$

$$\alpha_{nf} = k_{nf} / (\rho c_p)_{nf} \quad (8)$$

$$(\rho c_p)_{nf} = (1-\varphi)(\rho c_p)_f + \varphi(\rho c_p)_s \quad (9)$$

$$(\rho\beta)_{nf} = (1-\varphi)(\rho\beta)_f + \varphi(\rho\beta)_s \quad (10)$$

$$\frac{\mu_{nf}}{\mu_f} = \frac{1}{(1-\varphi)^{2.5}} \quad (11)$$

Maxwell equation is used to calculate nanofluid heat conduction coefficient:

$$\frac{k_{nf}}{k_f} = \frac{(k_s + 2k_f) - 2\varphi(k_f - k_s)}{(k_f + 2k_s) + \varphi(k_f - k_s)} \quad (12)$$

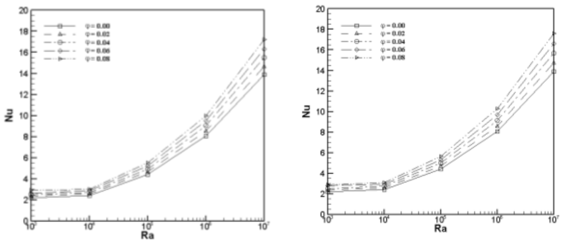
Where, k_p and k_f are nanoparticles thermal coefficient and base fluid thermal coefficient, respectively.

NUMERICAL APPROACH

In this study the governing equations (mass, momentum and energy) have been discretized using the finite volume method and the SIMPLE algorithm has been used to couple velocity and pressure fields.

RESULTS AND DISCUSSION

Figure 2 demonstrates Variation of Nusselt number with respect to Rayleigh number for different solid volume fractions for two types of nanoparticles. All the calculations are done for a square cavity with a hot circular cylinder with r = 0.3 inside it at location of c(x,y)=(0.5,0.5).



b *a*

Figure 2: Variation of Nusselt number with respect to Rayleigh number for different solid volume fractions. A: Cu-water nanofluid; b: Al2O3-water nanofluid.

It can be argued that amount of heat transfer in nanoparticles having lower volume fraction are the same and average Nusselt numbers of different nanofluids are also almost the same. On the other hand, as can be understood from comparison of the above figures, by increasing volume fraction of nanoparticles, effect of different nanoparticles becomes more obvious in a way that water-copper nanofluid which has a higher value of conduction heat transfer coefficient compared to water-allumina nanofluid, causes higher values of Nusselt number and consequently more heat transfer. Generally, when determining Nusselt number for nanofluids, two factors, temperature gradient and ratio of conduction heat transfer coefficient of the nanofluid to base fluid are very important. Increasing volume fraction of nanoparticles, conduction heat transfer and therefore thermal diffusivity increases. Hence, temperature gradient decreases. However, as was argued before, for determining Nusselt number, in addition to temperature gradient, ratio of conduction heat transfer coefficients is also important, and since increasing concentration of nanoparticles causes an increase in ratio of the conduction heat transfer coefficients and amount of this increase is more than reduction in temperature gradient, therefore it can be concluded that increase in nanoparticles concentration causes Nusselt number to increase. Also, for higher values of nanoparticles volume fraction, increase in average Nusselt number is higher for high Rayleigh numbers compared to low Rayleigh numbers.

CONCLUSION

In this article, free convection flow inside a square cavity and around a hot circular cylinder was investigated.

1) Addition of nanoparticles to the base fluid increases the amount of heat transfer in all points of the lid and amount of this increase is more at upper areas of the lids

2) Addition of nanoparticles to the base fluid increases the amount of heat transfer in all points of the lid and amount of this increase is more at upper areas of the lids.

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