



Natural convection on an open square cavity containing diagonally placed heaters and adiabatic square block and filled with hybrid nanofluid of nanodiamond - cobalt oxide/water



K. Kalidasan^{a,*}, P. Rajesh Kanna^b

^a Department of Civil Engineering, Arulmigu Palaniandavar Polytechnic College, Palani, Tamilnadu 624 601, India

^b Department of Mechanical Engineering, Velammal College of Engineering and Technology, Madurai, Tamilnadu 625 009, India

ARTICLE INFO

Available online xxxx

Keywords:

Natural convection

Hybrid nanofluid

Adiabatic block

Partial heaters

Nusselt number

ABSTRACT

A finite difference based two dimensional simulations on laminar natural convection inside the open square cavity containing diagonal heaters and a central adiabatic square block is presented by vorticity – stream function approach. The enclosure is filled with hybrid nanofluid of Nanodiamond - Cobalt Oxide/Water. The top and bottom walls are considered as adiabatic and the vertical walls have diagonal heaters. The inlet port is placed on the left end of the top wall and the outlet is placed at the bottom of the right wall. The variables considered are Rayleigh number (10^4 to 10^6) and volumetric fraction of Nanodiamond - Cobalt Oxide (0 to 6%) particles. The results of fluid flow with single phase model are elucidated with streamlines, Isotherms and Average Nusselt number. The strength of the primary vortex depreciated with the increasing percentage of nano composites for all the Rayleigh numbers. Intensity of heat transfer is high in the right wall than the left wall.

© 2016 Elsevier Ltd. All rights reserved.

1. Introduction

Demand on energy is increasing every year due to the mushroom growth of industries. Energy conservation is preferred over energy generation as the latter evoke political and financial issues. Natural convection is used in many applications like solar collectors, crystal growth, energy efficient buildings, nuclear reactor, double pane windows and electronic cooling devices.

Obstacles in the form of blocks, cylinders and partitions are unavoidable in many industrial applications.

Studies on natural convection with obstacles using nanofluid were reported by [1,2]. Mahmoodi and Sebdani [3] numerical studies on natural convection with adiabatic block and nanofluid reported that when $Ra = 10^3$, 10^5 and 10^6 , the average Nusselt number increases with the increase in the volume fraction of the nanoparticles. At $Ra = 10^4$, the average Nusselt number decreases. Kalidasan et al. [4] studied the effect of nanofluid on natural convection inside the enclosure with diagonally constructed twin adiabatic blocks and reported an 11% increase in time averaged Nu on nanofluid when compared with pure water. Obstacles not only provide the hydrodynamic blockage to the flow of fluid but also reduced the momentum of flows which results the retardation in convective heat transfer. Also, they consume more thermal energy. It

is mandatory to search the alternate ways to overlook the effect of obstacles on the natural convection during the thermal design of the system. Heat transfer is enhanced by many ways viz. differentially heated walls [5], time - variant temperature [6], partial heaters [7] and high thermal conductive fluid [8,9].

Oztop and Abu - Nada [10] numerically investigated the natural convection on a cavity with partial heaters and nanofluid. They indicated that the heat transfer is increased with the increasing height of heater and more pronounced at low aspect ratio than at high aspect ratio. Aminossadati and Ghasemi [11] performed the research on the natural convection of a heat source embedded on the bottom wall of an enclosure filled with nanofluid and concluded that the length and location of the heat source significantly affected the heat source maximum temperature. Purusothaman et al. [12] performed 3D natural convection with an array of isothermal heaters mounted on one vertical wall of the nanofluid filled enclosure and observed that the fluid on top of the each heater receives additional heat energy from the bottom heaters through the buoyancy mechanism. Recently, Biswas [13] conducted the experimental and numerical studies on heater aspect ratio on natural convection. They found that the heat transfer increases with the increase of aspect ratio of heater at higher Ra but reduces at lower Ra due to the change in the thermal boundary layer thickness. Rahman et al. [14] numerically analyzed the natural convection on a cavity with inclined heater at the bottom corner of the right wall and reported that the flow strength decreases with increase in CNT volume fraction for all values of Rayleigh number.

* Corresponding author.

E-mail address: kalidasank@gmail.com (K. Kalidasan).

Nomenclature

H	Height of the system in m
L	Length of the system in m
T	Temperature in °C
ΔT	Temperature difference in °C
t	Dimensionless time

Greek symbols

α	Thermal diffusivity, m ² /s
β	Thermal expansion coefficient of the fluid, 1/K
μ	Dynamic viscosity, kg/m-s
ν	Kinematic viscosity, m ² /s
ω	Dimensionless vorticity,
ϕ	Volumetric fraction of nanoparticles,
ψ	Dimensionless stream function,
ρ	Density, kg/m ³
θ	Dimensionless temperature,

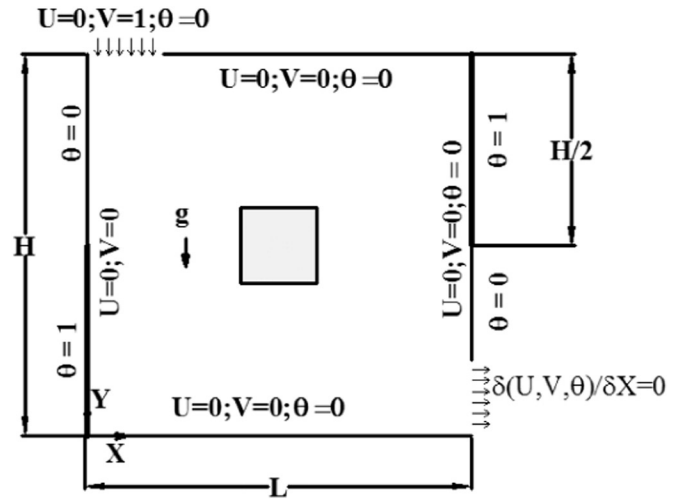


Fig. 1. Geometry of the system.

Only limited researches were performed in the past on convective heat transfer with ventilated ports and heaters. Bilgen and Balkaya [15] studied the natural convection on discrete heaters with ventilated enclosure with air and recommended to keep the heaters closer to each other near the cavity bottom, corresponding to the location of the lower ventilation port. They also emphasized the importance of the Rayleigh number on the configuration of heaters. Mehrizi et al. [16] studied the effect of outlet port on mixed convection using nanofluid with hot obstacle and reported that the maximum heat transfer rate occurs when the outlet port on the right wall is located at middle.

Many fluid like water used in the industrial applications has low thermal conductivity. Due to which, the capital and operation costs of thermal systems become uneconomical. Hence highly thermal conductive particles like nanoparticles are added to the base fluid for enhanced performance. Hybrid nanofluid is a new kind of nanofluid manufactured with two or more than two types of nanoparticles along with the base fluid [17]. The applications of hybrid nanofluid are electronic cooling, heat pipes, car radiators, coolant in welding and machining, nuclear plant, heat exchanger, solar heating, transformer, domestic refrigerator, grinding process and vehicle brake fluid [18]. The research on hybrid nanofluid was presented by [19–21].

Natural convection using hybrid nanofluid is an emerging area of research and is expected to yield good results, since the thermal performance of hybrid nanofluid is superior to the single - particle based nanofluid such as Al_2O_3 , TiO_2 and Fe_3O_4 [22]. Detonation Nanocrystalline Diamond popularly called as Nanodiamond (ND) is the carbon nanostructure produced easily with quantum satis [23]. Quantum satis is adding as much of the ingredient to achieve the desired result, but not more than that. Yarmand et al. [24] experimental analyze on heat transfer enhancement using Graphene nanoplatelets - silver hybrid nanofluid revealed a Nusselt number enhancement of 32.7% when $\phi = 0.1\%$ and $Re = 17,500$ when compared with distilled water. Shukla and Aiyyer [25] investigated the thermal conductivity enhancement of transformer oil using nanodiamonds and indicated that the thermal conductivity of base fluid is enhanced by 14.5% with 0.12% of nanodiamond at 40 °C and increased further with the increase in temperature. Suresh et al. [26] experimental findings on Al_2O_3 - Cu/water hybrid nanofluid indicated a Nu enhancement of 13.56% ($\phi = 0.1\%$) at $Re = 1730$ when compared to pure water. Sundar et al. [22] experimentally studied the heat transfer enhancement using MWCNT - Fe_3O_4 hybrid nanofluid and found that Nu is increased by 9.35% ($\phi = 0.1\%$) and 14.81% ($\phi = 0.3\%$) when Re is 3000 and increased by 20.62% and 31.10% respectively when Re is 22,000. Vasiliev et al. [27]

experimental research on nanodiamond indicated that the heat capacity of nanodiamond is 30% more than that of bulk diamond.

Literature studies indicated that research on the combined effects of open enclosure, adiabatic block, partial heaters and hybrid nanofluid on natural convective heat transfer is not carried out so far. Hence the present research is focused on the effect of adiabatic square block on the laminar natural convection inside the square enclosure containing two partial heaters placed diagonally on the vertical walls and filled with hybrid nanofluid of nanodiamond - cobalt oxide/water.

2. Mathematical formulation

The schematic representation of the problem is presented in Fig. 1. The flow is diagonally downward and opposed to buoyancy. An adiabatic square block of size $L/5 \times L/5$ is placed at the centre of the enclosure. The inlet port is placed at the left end of the top wall and the outlet port is constructed at the bottom of the right wall. The widths of both the ports are assumed as $L/10$. Two partial heaters of size $L/2$ are placed diagonally opposite to each other on the vertical walls. The remaining portions of the vertical walls are assumed as cold. The horizontal walls are considered as adiabatic. The working fluid is water - based hybrid nanofluid containing Nanodiamond - Cobalt Oxide (ND - CO_3O_4) with $Pr = 6.2$ [28].

The solid particles contain 67% Nanodiamond and 33% of Cobalt Oxide. The nanofluid is assumed as a Newtonian and the flow is two - dimensional, unsteady, laminar and incompressible. Boussinesq approximation is applied to ensure constant thermophysical properties of the hybrid nanofluid. The thermophysical properties of the base fluid (water) and solid phase are given in Table 1.

2.1. Governing equations

Dimensionless forms of the governing equations are obtained by using dimensionless variables. The governing equations for the problem are the continuity, momentum and energy equations. Using the stream

Table 1
Thermophysical properties of base fluid and hybrid nano particles.

Physical properties	Water	Nanodiamond	Cobalt Oxide
$\rho(\text{kg/m}^3)$	997.1	3000	6110
$C_p(\text{J/kgK})$	4179	509.1	460

Download English Version:

<https://daneshyari.com/en/article/4992979>

Download Persian Version:

<https://daneshyari.com/article/4992979>

[Daneshyari.com](https://daneshyari.com)