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Laminar natural convection of Copper - Titania/Water hybrid nanofluid in an open ended C - shaped enclosure with an isothermal block

K. Kalidasan [a,*], R. Velkennedy [b], P. Rajesh Kanna [c]

[a] Department of Civil Engineering, Arulmigu Palaniandavar Polytechnic College, Palani, Tamilnadu 624 601, India
[b] Department of Civil Engineering, Thiagarajar College of Engineering, Madurai, Tamilnadu 625 015, India
[c] Department of Mechanical Engineering, College of Engineering and Computing, Alghurair University, Dubai, United Arab Emirates

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ABSTRACT

A finite difference based, two dimensional numerical analysis on the laminar natural convection inside the differentially heated C - shaped open cavity with an isothermal square block is presented using the vorticity - stream function approach. The enclosure is filled up with hybrid nanofluid of Cu - TiO_2/water. The left vertical wall is assumed as hot and the right wall is considered as cold wall. All the horizontal walls at the top and bottom are considered as adiabatic. The inlet port is located on the top right portion and the outlet is placed at the bottom right portion of the C shaped cavity. The square isothermal block of size L/5 is placed at the middle of the web of the cavity. The variables considered are Rayleigh number (10^4 to 10^6) and the solid hybrid particles (0 to 5%). The physics of the fluid flows with a single phase model are illustrated with streamlines, isotherms and average Nusselt number. When Rayleigh number increases, the strength of the primary vortex diminishes. Heat transfer enhanced monotically with the increase in percentage of hybrid nano composites at $Ra = 10^4$ and 10^5.

1. Introduction

Natural convection is the attraction of many researchers during the past few decades. Natural convection is an ideal tool for many practical applications due to enormous advantages it possesses like energy conservation, low noise and operating cost. The industries that demanding the natural convection are energy efficient buildings, nuclear reactor, cooling of electronic components, heat exchangers, solar collectors and double pane windows [1,2]. Obstacles in the form of blocks are essential elements in many industrial applications. Obstacles are either adiabatic or isothermal. The studies on natural convection using nanofluid with a block were reported by [3–6].

The low thermal conductivity possessed by the conventional fluid like water and oil decreased the thermal efficiency of the system particularly while encountering the hydrodynamic blockage by the obstacles. Due to the technological advancement, the thermal efficiency of the system needs to be enhanced by manifold. Also, the conventional fluid has a limitation during the cooling by natural convection. Hence, the conventional fluid is replaced by the nanofluid. Nanofluid has enormous advantages like high thermal conductivity, large surface area, more stability and improved abrasion related properties [7].

Studies with nanofluid were performed by [8–15]. Suresh et al. [16] experimentally analyzed the characteristics of CuO/water nanofluid under turbulent flow in a helically dimpled tube and found that both the relative viscosity and thermal conductivity of nanofluid increases remarkably with the increase of nanoparticles. Soleimani et al. [17] numerically analyzed the natural convection heat transfer in a CuO/water nanofluid filled semi - annulus enclosure and concluded that the effect of nanoparticles is more pronounced at low Rayleigh number than at high Rayleigh number. Titanium dioxide (TiO_2) is opted as one of the nano composites due to its excellent chemical and physical stability. Also, TiO_2 particles are cheap and easily available [18,19]. Studies performed using TiO_2 as a nano composite for the thermal enhancement were [20,21].

Recently, nanofluid is replaced by the hybrid nanofluid in many thermal systems [22,23]. Ghalambaz et al. [24] investigated the effects of hybrid nanoparticles on the melting process of a nano- enhanced phase - change material and indicated that the use of nanoparticles with a high thermal conductivity and a low dynamic viscosity improved the heat transfer rate of the thermal storage. Kalidasan and Rajesh Kanna [25] performed the research on hybrid nanofluid with partial heaters on the vertical walls and adiabatic block. They found that the strength of the primary vortex was depreciated with the increasing percentage of nano composites for all the Rayleigh numbers. Rahman et al. [26] indicated that thermal behavior of hybrid nanofluid was strongly influenced by the dominant nanoparticles of the hybrid nano composites. Ramachandran et al. [27] experimentally observed that hybrid nanofluid can be used as an alternative to the conventional working fluid in electronic cooling applications. Madhesh et al. [18]

* Corresponding author.
E-mail address: kalidasan@palaniandavarpc.org.in (K. Kalidasan).

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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^{-1}
μ	dynamic viscosity, kg/m-s
ν	kinematic viscosity, m^2/s
ω	dimensionless vorticity
φ	volumetric fraction of nanocomposites
ψ	dimensionless stream function
ρ	density, kg/m^3
θ	dimensionless temperature

experimentally investigated the convective heat transfer of Cu - TiO_2 hybrid nanofluid and informed that the hybrid nano composites (Cu - TiO_2) prepared and dispersed in the base fluid is distinct in class from other investigated nanofluid with respect to the heat transfer and rheological characteristics. Also, Cu - TiO_2 were effectively dispersed in to the base fluid without any surfactant. Surfactants reduced the interfacial tension between the base fluid and suspended nanoparticles [28]. Hence Cu - TiO_2/water hybrid nanofluid is opted in the present research.

C shaped geometry has been so far received less attention than the conventional square cavity. Mahmoodi and Hashemi [29] studied the natural convection on a C - shaped closed cavity with a nanofluid and informed that when the C - shaped enclosure becomes narrower, the rate of heat transfer increases. Also, the effect of nanoparticles on the enhancement of heat transfer is high at low Rayleigh numbers. Mansour et al. [30] performed the investigation on natural convection on a C - shaped enclosure with different nanofluid and mentioned that the rate of heat transfer increases when the Rayleigh number increases for the constant aspect ratio. Study on C cavity is essential to improve the cooling of electronic chips.

To the best of author's knowledge, open ended C cavity with a block is not considered for research in the past. Hence, open ended C - shaped cavity filled by hybrid nanofluid with an isothermal block is considered in the present research.

2. Mathematical formulations

The schematic model representing the problem with boundary conditions is presented in Fig. 1. The cold hybrid nanofluid enters the C - shaped enclosure through the inlet at the top - right flange. The flow is anticlockwise, downward and opposed to buoyancy. An isothermal square block of size L/5 × L/5 is placed at the centre of the web portion of the C - shaped enclosure. The left vertical wall is assumed as hot and the right vertical wall is assumed as cold. All The horizontal walls are considered as adiabatic. After heated up by the hot left wall and isothermal block, the fluid leaves the enclosure through the outlet port placed at the bottom - right flange of the C - shaped enclosure. The widths of both the ports are assumed as 0.3 L. The base fluid considered in this research is water with $Pr = 6.2$ [31]. The hybrid nanocomposites consists of 75% Copper (Cu) and 25% of Titania (TiO_2). The nanofluid is assumed as a Newtonian and the flow is assumed as two - dimensional, laminar, unsteady and incompressible. The assumed model is a single phase with nanocomposites and base fluid is assumed in thermal equilibrium and no slip motion occurs between the solid and liquid phases [25]. Boussinesq approximation is applied to ensure constant thermophysical properties of the hybrid nanofluid due to the variation of density by the temperature. The thermophysical properties of the base fluid and hybrid nanocomposites are given in Table 1.

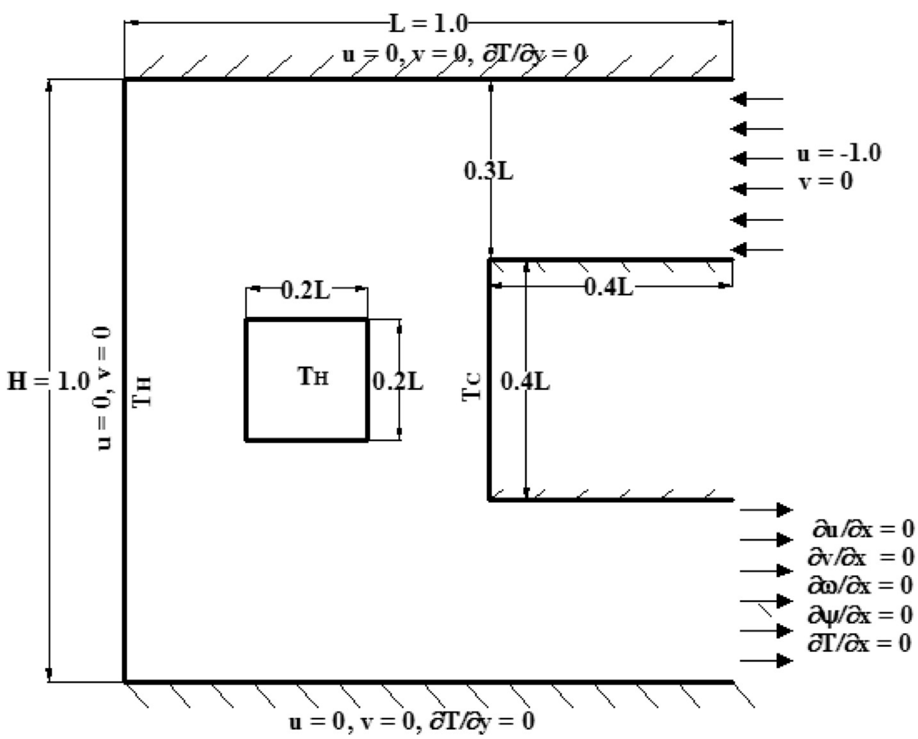

Fig. 1. Schematic model of the system.