



The investigation of simultaneous heat transfer of water/ Al_2O_3 nanofluid in a close enclosure by applying homogeneous magnetic field

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ABSTRACT

In this study, the heat transfer and laminar flow of Water/ Al_2O_3 nanofluid in a T-shaped enclosure with lid-driven under the influence of applying magnetic field have been numerically investigated. The numerical solving domain has been simulated two-dimensionally for Richardson numbers of 0.1, 1 and 10 for volume fractions of 0–6% of nanoparticles. In this paper, the effect of applying homogeneous magnetic field in Hartman numbers of 0, 30 and 60 on the natural and forced heat transfer parameters of nanofluid has been analyzed and compared. The results of this research revealed that, applying magnetic field has significant effect on the temperature domain and fluid flow and considerably reduces the circulation mechanisms of fluid. By increasing Richardson and Hartmann numbers, the transfer momentum of cap in the bottom layers of fluid penetrates lesser and the amount of heat transfer reduces. The enhancement of volume fraction of nanoparticles and the reduction of Richardson and Hartmann numbers, significantly enhance the heat transfer of enclosure with cold fluid. Also, the changes of volume fraction of nanoparticles have less influence on the variations of velocity domain and the changes of magnetic field intensity greatly affect the velocity domain.

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1. Introduction

The use of novel technologies in today's industries has solved many industrial challenges. The environmental prolusions, the increase of energy expenses and losing the nonrenewable energies, have made the researchers to use and investigate the optimized methods of heat transfer. The nanofluid technology can indulge the needs of miniature industrial equipment and systems by providing the possibilities for designing smaller and lighter heat exchangers. Today, the heat transfer in the enclosures, channels, microchannel, tubes and other geometrics, according to their numerous functions in the engineering equipment such as cooling the electronic equipment, fined heat exchangers, enclosures receiving solar energy, have attracted the researchers of heat transfer field [1–12]. Using nanofluid in order to increase the thermal efficiency, can greatly reduce the influence of decreasing factors of heat transfer, like the existence of magnetic and electricity domains. According to the efficiency of industrial equipment such as solar cells, fuel storage tanks, electronic transmissions and double-glazed windows, many researchers have studied the behavior of heat transfer in these equipment, especially in the enclosures. Talebi et al. [13] studied the nat-

ural and forced convective heat transfer of Water/Cu nanofluid in a lid-driven square enclosure. By considering Reynolds number as constant, he investigated the effects of volume fraction of nanofluid on the heat transfer behavior and flow hydrodynamics in high Rayleigh numbers and observed that, by increasing Rayleigh number, the effect of volume fraction of nanoparticles reduces. Ghasemi and Aminossadati [14] studied the forced and natural convective heat transfer in a triangular enclosure with Water/ Al_2O_3 nanofluid as the cooling fluid. In their numerical study, the effects of Richardson number, volume fraction and the direction of vertical wall movement have been investigated. Their results demonstrated that, by increasing volume fraction for different Richardson numbers, the amount of heat transfer on the direction of vertical wall movement, increases. Also, when the vertical wall moves to the bottom side, a stronger rotational flow has been created and the amount of heat transfer enhances. Kadri et al. [15] studied the convective heat transfer with magnetic field in a square cavity containing Water/ Al_2O_3 nanofluid as the cooling fluid. His results indicated that, the heat transfer of nanofluid is under the influence of Hartmann number and the direction of applied magnetic field and by increasing the intensity of magnetic field, the conductive heat transfer becomes dominant. Hasanuzzaman et al. [16] investigated the effect of magnetic field on the natural convection in a trapezoidal enclosure. He studied the effects of different parameters such as Rayleigh number, Hartmann

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Nomenclature

Gr	Grashov number
Ha	Hartman number
Ri	Richardson number
C_p	Heat capacity ($\text{J kg}^{-1}\text{K}^{-1}$)
B_0	magnetic field strength
k	Thermal conductivity coefficient ($\text{Wm}^{-1}\text{K}^{-1}$)
L	Down layer microchannel length(m)
L_1	Top layer microchannel length(m)
Nu	Nusselt number
P	Fluid pressure(Pa)
G	gravitational acceleration (m.s^{-2})
Pr	Prandtl number
L_2	lid length(m)
L	Hot area length (m)
L	Insulation area length (m)
Re	Reynolds number
T	Temperature(K)
$(U_0, V_0) = (u/ U_{\text{lid}}, v/ U_{\text{lid}})$	Dimensionless velocity components in x, y directions
$(X, Y) = (x/h, y/h)$	Cartesian dimensionless coordinates
u, v	Velocity components in x, y directions (ms^{-1})
H	local heat transfer coefficient ($\text{W m}^{-2}\text{K}^{-1}$) and enclosure height (m)
Greek symbols	
β	Thermal expansion coefficient (K^{-1})
φ	Nanoparticles volume fraction
σ	Electrical conductivity ($\Omega^{-1}\cdot\text{m}^{-1}$)
μ	Dynamic viscosity (Pa s^{-1})
θ	Dimensionless temperature
ρ	Density (kgm^{-3})
α	fluid thermal diffusivity ($\text{m}^2\cdot\text{s}^{-1}$)
ν	Kinematics viscosity (m^2s^{-1})
Super- and Sub-scripts	
c	Cold
eff	Effective
f	Base fluid (pure Water)
h	Hot
in	Inlet
nf	Nanofluid
p	Solid nanoparticles

number and the angle of enclosure wall and concluded that, for different Rayleigh numbers, by increasing volume fraction of nanoparticles and Hartmann number, the amount of heat transfer decreases. Kefayati et al. [17] numerically investigated the applying vertical magnetic field on nanofluid in a lid-driven cavity. He concluded that, by increasing Richardson and Hartmann numbers, heat transfer reduces. Kasaeipoor et al. [18] presented a numerical study about the forced and convective heat transfer in a T-shaped cavity. By solving the governing equations using SIMPLE algorithm, he demonstrated that, in low Reynolds numbers, the mean Nusselt number, same as Hartmann number, increases, while in high Reynolds numbers, the mean Nusselt number enhancement with Hartmann number, becomes more significant. Deng et al. [19] studied the natural convection of laminar fluid in a rectangular enclosure with separated heat sources on the enclosure wall. He indicated that, in general, the effect of constant heat sources is more than the constant heat flux sources. Da Silva et al. [20] investigated the nat-

ural convection in a trapezoidal enclosure with two internal obstacles on the bottom wall. He indicated that, in constant Rayleigh number, by increasing the height of obstacles, the amount of heat transfer reduces and for a specific height of obstacle, by enhancing Rayleigh number, the heat transfer increases. Rudraiah et al. [21] numerically investigated the effect of applying constant magnetic field in the same direction with gravity acceleration on the natural convection of flow crossing inside a square enclosure with constant temperature of lateral walls and insulated horizontal walls. He indicated that, by increasing the intensity of magnetic field, the destroyed convective flow and the rate of heat transfer reduce. Sheikholeslami et al. [22] numerically investigated the fluid flow and heat transfer in an angled L-shaped enclosure with the applying magnetic field. He concluded that, the angle of enclosure has an important effect on heat transfer and behavior of fluid flow. Davoudian and Arab Solgher [23] numerically analyzed the natural convection in an enclosure with the existence of vertical thin obstacle and indicated that, by decreasing flow velocity, the mean Nusselt number of the heated wall reduces and Hartmann number has a great effect on flow and temperature domain. Malekpour and B. Ghasemi [24] numerically studied the effect of homogeneous magnetic field on the natural convective heat transfer of nanofluid in a triangular enclosure and showed that, the augment of Hartmann number causes the reduction of nanofluid movement and heat transfer. In another research, Pishkar and Ghasemi [25] revealed that, using nanofluid in the natural and forced heat transfer causes better distribution of temperature and the enhancement of mean temperature.

In his numerous researches, Kefayati et al. [26–35], studied the flow and convective heat transfer of fluids and nanofluids in a closed enclosure. His numerical investigations have been done in order to estimate the heat transfer, entropy generation, magnetic field influence on the mixed convection behavior for Newtonian and non-Newtonian fluids with various nanofluids. In most studies, the augment of heat transfer, by increasing volume fraction of solid nanoparticles, has been reported.

In present study, the natural convection of Water/ Al_2O_3 nanofluid flow with different volume fractions of nanoparticles in an enclosure with specific geometrics has been numerically studied. The purpose of this research is investigating the hydrodynamic parameters of flow and heat transfer, such as the velocity and temperature domain and the changes of Nusselt number. The results of this research have been analyzed and interpreted in the comparing figures for these parameters and contours explaining the behavior of streamlines and temperature domain in different volume fractions, Hartmann and Rayleigh numbers.

2. Problem statement

In present research, the laminar flow and the natural and convective heat transfer inside a T-shaped close enclosure have been numerically simulated. In this research, Water/ Al_2O_3 nanofluid in different volume fractions (φ) of 0, 2, 4 and 6% of nanoparticles has been used as the cooling fluid. The applying of magnetic domain with constant intensity of (B_0) at the range of Hartmann numbers of 0, 30 and 60 and different gravity fields (Richardson numbers) of 0.1, 1 and 10 have been considered. Grashof number has been considered as constant and $\text{Gr} = 50,000$. The lid at the top side of enclosure moves to the positive direction of X axis with constant velocity of U_0 . The bottom wall of enclosure with the length of L is under the influence of hot temperature of $T_h = 308^\circ\text{K}$ and the top wall with the length of $L_2 = (L + 2L_1)/3$, is under the influence of cold temperature of $T_c = 298^\circ\text{K}$. The height of enclosure is $h = (L + 2L_1)/6$ and $L_1 = L/2$. Fig. 1 indicates the schematic of studied geometrics in this research.

Other walls of enclosure are insulated and according to this figure, the constant magnetic field is applied from the left to the right side of the enclosure. The study of flow behavior and heat transfer of Water/ Al_2O_3 nanofluid in different volume fractions, applying homogeneous magnetic field to the two-dimensional enclosure with specific geometrics and the analysis of results for different range of Richardson

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