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Numerical study of magnetic field on mixed convection and entropy generation of nanofluid in a trapezoidal enclosure

Alireza Aghaei *, Hossein Khorasanizadeh, Ghanbarali Sheikhzadeh, Mahmoud Abbaszadeh

Department of Mechanical Engineering, University of Kashan, Iran

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ABSTRACT

The flow under influence of magnetic field is experienced in cooling electronic devices and voltage transformers, nuclear reactors, biochemistry and in physical phenomenon like geology. In this study, the effects of magnetic field on the flow field, heat transfer and entropy generation of Cu–water nanofluid mixed convection in a trapezoidal enclosure have been investigated. The top lid is cold and moving toward right or left, the bottom wall is hot and the side walls are insulated and their angle from the horizon are 15°, 30°, 45° and 60°. Simulations have been carried out for constant Grashof number of 10^4, Reynolds numbers of 30, 100, 300 and 1000, Hartmann numbers of 25, 50, 75 and 100 and nanoparticles volume fractions of zero up to 0.04. The finite volume method and SIMPLER algorithm have been utilized to solve the governing equations numerically. The results showed that with imposing the magnetic field and enhancing it, the nanofluid convection and the strength of flow decrease and the flow tends toward natural convection and finally toward pure conduction. For this reason, for all of the considered Reynolds numbers and volume fractions, by increasing the Hartmann number the average Nusselt number decreases. Furthermore, for any case with constant Reynolds and Hartmann numbers by increasing the volume fraction of nanoparticles the maximum stream function decreases. For all of the studied cases, entropy generation due to friction is negligible and the total entropy generation is mainly due to irreversibility associated with heat transfer and variation of the total entropy generation with Hartmann number is similar to that of the average Nusselt number. With change in lid movement direction at Reynolds number of 30 the average Nusselt number and total entropy generation are changed, but at Reynolds number of 1000 it has a negligible effect.

1. Introduction

The growth of industry has made essential to improve the heat transfer parameters for better cooling. Today the industry is able to produce devices such as computer chips in large amount. These devices often require new methods for cooling due to excessive heat generation in small surface. In the recent years, nanofluids which have greater thermal conductivity coefficient than ordinary fluids, has been more considered. Higher thermal conductivity of nanoparticles than base fluid brings about the augmentation thermal conductivity of nanofluids [1]. Because of mixed convection has the combined effect of lid-driven and natural convection, it has many applications in electronics, food, nuclear reactors, industrial lubrication, solar pools, solar collectors, heat exchangers, metal smelting industry, glass and other cases [2].

Entropy generation which represents the amount of irreversibility in a process is the criteria for the performance of engineering machinery [3]. By entropy generation, thermodynamic efficiency reduces. Entropy analysis shows that in which areas of physical model or system energy dissipation is more [4]. Since entropy generation is the criterion for loss of exergy in devices, determining it is necessary to increase the efficiency of devices [5].

Nanofluids affected by the magnetic field have the features of magnetic properties and fluid simultaneously. Fluid flow under influence of magnetic field uses in electronic cooling systems, cooling power converters, reactors, nuclear, biochemical, physical phenomenon such as geology, atmospheric flows and other analogous cases [6]. For example, convection flow in the casting industry causes appearing a heterogeneous structure and coarse piece in casting piece. It is possible to reduce this convection flow with the aid of the magnetic hydrodynamics science. However, in many cases the reduction of convection flows in the magnetic

* Corresponding author.
E-mail addresses: AlirezaAghaei21@gmail.com (A. Aghaei), khorasan@kashanu.ac.ir (H. Khorasanizadeh), Sheikhz@kashanu.ac.ir (G. Sheikhzadeh), abbaszadeh.mahmoud@gmail.com (M. Abbaszadeh).

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Nomenclature

A	Area
B_0	The applied magnetic field
C	Constant of relation (21)
c_P	Specific heat at constant pressure (J kg^{-1} K^{-1})
d_f	Diameter of the water molecule (nm)
d_p	Diameter of the nanoparticles (nm)
F	Lorentz force (N, Newton)
g	Gravitational acceleration (m s^{-2})
Gr	Grashof number
h	Convection heat transfer coefficient
H	Enclosure height (m)
Ha	Hartmann number
J	Circuit density
k	Coefficient of thermal conductivity (W m^{-1} K^{-1})
k_B	Boltzmann constant
l	Size of the enclosure bottom side (m)
L	Dimensionless length
M, N	M and N is the number of grid points in the x and y
Nu	Nusselt number
p	Pressure (Pa)
P	Dimensionless pressure
Pe	Peclet number
Pr	Prandtl number
q	Heat flux
Re	Reynolds number
Ri	Richardson number
s_{gen}	Total entropy generation (W m^{-3} K^{-1})
S_{gen}	Dimensionless total entropy generation
T	Temperature (K)
u	velocity component in the direction of X
v	velocity component in the direction of Y
U	Dimensionless velocity component in the direction of X
U_0	Speed of upper enclosure wall
V	Dimensionless velocity component in the direction of Y
x, y	Cartesian coordinates (m)
X, Y	Dimensionless Cartesian coordinates

Greek symbols

α	Thermal diffusivity (m^2 s^{-1})
β	Coefficient of thermal expansion(K^{-1})
μ	Viscosity (kg m^{-2} s^{-1})
υ	Kinematic viscosity (m^2 s^{-1})
θ	Dimensionless temperature
θ_s	Angle of the side walls of enclosure to horizontal direction
ρ	Density (kg m^{-3})
χ	Irreversibility coefficient
ϕ	Angle of the magnetic field relative to the x axis
σ	Fluid electrical conductivity coefficient
φ	Volume fraction of nanoparticles
ϕ	Angle of the magnetic field to horizontal direction (positive counterclockwise direction)
ψ	Stream function(m^2 s^{-1})
Ψ	Dimensionless stream function
γ	Number of iterations

Subscripts

Avg	Average
c	Cold
f	Fluid
h	Hot
gen	Generation
nf	Nanofluid
p	Nanoparticle

field, reduces the heat transfer which is not desirable. There is an instance of this phenomenon in an electronic device that affected by the magnetic field and is cooled with fluid. In recent years the study of fluid flow which is impressed by magnetic field and its effect on the entropy generation has been more considered due to its importance in the industry [7].

In recent studies, square and rectangular enclosures have been more considered for different reasons such as the simplicity of calculation. The trapezoidal enclosures are used in micro-channels, casting industry and unwanted spaces, such as an electronic device that is placed in a trapezoidal space [8]. Nevertheless, so far the flow field, heat transfer and entropy generation have not been studied in mixed convection of the nanofluids that is impressed by magnetic field in a trapezoidal enclosure. Thus, in investigation of previous studies the mixed convection of nanofluids in enclosures, then the entropy generation caused by natural convection in the enclosures, after that the effect of magnetic field in convection and at the end of the study the temperature and flow of nanofluids in trapezoidal enclosures will be discussed. Mansour et al. [1] did a numerical study on nanofluid mixed convection in an enclosure which was applied constant heat flux. According to their results by increasing nanoparticles volume fraction, the fluid flow slow down, but the average Nusselt number increases. Ghasemi and Aminossadati [9] investigated on mixed convection of the water–Al_2O_3 nanofluids in the orthorhombic triangle enclosure. Based on their results, for all Richardson numbers range, heat transfer increases by increasing volume fraction of nanoparticles. Pishkar and Ghasemi [10] examined heat transfer and flow of nanofluids on mixed convection in a horizontal channel with blades. Based on their results increasing volume fraction and Reynolds number, increases heat transfer. Chamkhaa and Abunada [11] investigated heat transfer and fluid flow on mixed convection in a square enclosure. According to their results, by increasing volume fraction and decreasing Richardson number, the average Nusselt number increases. In recent studies, it has been considered to minimize entropy generation to find out the optimum conditions for design of devices. Famouri and Hooman [12] investigated numerically entropy generation on natural convection of fluid in a rectangular enclosure. According to their results, by increasing Rayleigh number, the entropy generation increases. Mukhopadhyay [13] investigated numerically entropy generation on natural convection of the fluid flow in a square cavity. Based on his results, the entropy generation caused by heat transfer is much more than entropy generation caused by the viscosity of the fluid. Shahi et al. [14] evaluated entropy generation on natural convection of the nanofluid in a square cavity with constant heat flux on its walls. According to their results when the warm obstacle is placed on the bottom wall and its dimensionless distance from the left wall is 0.8, entropy generation is minimum. Khorasanizadeh et al. [15] investigated entropy generation in natural convection of nanofluid in a square cavity where blade is placed on its bottom wall. Based on their results by increasing Rayleigh number the