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Review

Effect of magnetic field on natural convection in a nanofluid-filled semi-circular enclosure with heat flux source

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ABSTRACT

In the present paper, the effect of constant magnetic field on natural convection in a semi-circular enclosure that is filled with nanofluids (copper (nanoparticles) with pure water (base fluid)) with present heat flux is investigated numerically. The heat flux (q'') is supplied partly in the center of the base wall, and the other parts of base wall of the enclosure are assumed adiabatic. The center of the circular arc ($-45° \leqslant \gamma \leqslant +45°$) is assumed at constant cold temperature (T_c) and the other parts of the circular arc are adiabatic. The gravity (g) acts normal to the y-direction and the uniform external magnetic field (B_o) is applied parallel to gravity. Finite element method based on the variational formulation is employed to solve momentum and energy balance as well as post-processing streamfunctions and heatfunctions. The results are based on visualization of heat flow via temperature lines and heatfunctions, and fluid flow via streamfunctions. Comparisons with previously published work are performed and the results are found to be in good agreement. This paper examines the influence of pertinent parameters such as Rayleigh number ($10^4 \leqslant Ra \leqslant 10^7$), Hartmann number ($0 \leqslant Ha \leqslant 80$ step 20), and solid volume fraction of nanoparticles ($0 \leqslant \phi \leqslant 0.15$ step 0.05) on the flow, temperature fields and the heat transfer performance of the enclosure.

The results show that the heat transfer rate increases with an increase of the Rayleigh number and the nanoparticles volume fraction but it decreases with an increase of the Hartmann number. The effect of the magnetic field on heat transfer increases with the increase of Rayleigh number and it decreases with the increase of the nanoparticles fraction effect.

Contents

1. Introduction 72
2. Problem description 73
3. Mathematical formulation and simulation 73
   3.1. Assumptions 73
   3.2. Velocity and temperature distributions 73
   3.3. Streamfunction and heatfunction 75
   3.4. Boundary conditions 76
4. Numerical method and validation 77
5. Results and discussion 78
   5.1. Streamfunction 78
   5.2. Isotherms 80
   5.3. Heatfunction 82
   5.4. Local and average Nusselt number 83
6. Conclusion 84
   References 84

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Nomenclature

q''	heat flux (W/m^2)
C_p	specific heat at constant pressure (kJ/kg K)
g	gravitational acceleration (m/s^2)
r	radius of the circular enclosure (m)
k	thermal conductivity (W/m K)
L_c	characteristic length = r (m)
P	dimensionless pressure
p	pressure (Pa)
Pr	Prandtl number
T	temperature (K)
T_c	temperature of the cold surface (K)
Ha	Hartmann number
Greek symbols	
α	thermal diffusivity (m^2/s)
θ	dimensionless temperature
ε	length of heat source at base wall (m)
Ψ	dimensional stream function (m^2/s)
ψ	dimensionless stream function
μ	dynamic viscosity (kg s/m)
ν	kinematic viscosity (m^2/s)
Subscripts	
c	cold
f	pure fluid
p	nanoparticles
min	minimum
Ra	Rayleigh number
Nu	local Nusselt number on the heat source surface
$\overline{\text{Nu}}$	average Nusselt number along the heat source
U	dimensionless velocity component in x-direction
u	velocity component in x-direction (m/s)
V	dimensionless velocity component in y-direction
v	velocity component in y-direction (m/s)
X	dimensionless coordinate in horizontal direction
x	cartesian coordinate in horizontal direction (m)
Y	dimensionless coordinate in vertical direction
y	cartesian coordinate in vertical direction (m)
B_o	strength of the magnetic field
ϕ	nanoparticle volume fraction
σ	electrical conductivity
ζ	dimensionless length of base heat source (ε/L_c)
ΔT	ref. temperature difference (°C)
β	volumetric coefficient of thermal expansion (K^{-1})
ρ	density (kg/m^3)
Π	heatfunction
nf	nanofluid
s	heat source surface
max	maximum

1. Introduction

The problem of natural convection in enclosures has many engineering applications such as the cooling systems of electronic components, the building and thermal insulation systems, the built-in-storage solar collectors, the nuclear reactor systems, the food storage industry and the geophysical fluid mechanics [1].

Various techniques have been proposed to enhance the convection heat transfer performance of fluids inside the enclosure. Convective heat transfer can be enhanced by changing flow geometry, boundary conditions and by enhancing thermal conductivity of the fluid.

The effect of flow geometry on the natural convection was investigated in many researches [2]. Different cavities shape were studied: rectangular [3], triangular [4], trapezoidal [5], sinusoidal [6], octagonal [7], prismatic [8] and annulus area [9–12].

Different boundary conditions had been employed for the convection heat transfer inside cavity, like: constant wall temperature, constant heat flux, presence heat generation and presence magnetic field.

The influence of a magnetic field on convective flow and heat transfer inside enclosure had received considerable attention because of their a wide variety of its application in engineering areas, such as chemical industry, power and cooling industry for drying, chemical vapour deposition on surfaces, cooling of nuclear reactors, crystal growth in liquids, cooling of nuclear reactors, electronic packages, petroleum industries, and microelectronic devices [13].

Recently, the number of studies which have been performed on combined of the above techniques to enhance the convection heat transfer [14].

The effect of the magnetic field on free convection were solved for different cavity shape: trapezoidal [15], rectangular [16], square [17] and sinusoidal corrugated [6]. Pirmohammadi and Ghassemi [18] investigated the effect of a magnetic field on laminar natural-convection flow in a tilted enclosure heated from below, cooled from top and its filled with liquid gallium. They found that at Ra = 10^4, value of Nusselt number depends strongly upon the inclination angle for relatively small values of Hartmann number. Lo [19] simulated the effect of a transverse magnetic field on buoyancy-driven magnetohydrodynamic flow in a rectangular enclosure. He showed at a constant value of Gr, the heat transfer rate is maximum for higher Prandtl number and in the absence of magnetic field effects. Saha [6] investigated numerically the steady magneto-convection in a sinusoidal corrugated enclosure. Two vertical sinusoidal corrugated walls are maintained at a constant low temperature whereas a constant heat flux source is discretely embedded at the bottom wall. His results indicated that the heat source surface area increases the average Nusselt number decreases and the heat source size has significant effect on the heat transfer rate. Subbarayalu and Velappan [17] studied numerically the magnetoconvection in a tilted square cavity with differentially thermally active vertical walls. The two vertical sidewalls of enclosure are hot and cold surface while the horizontal top and bottom walls are adiabatic. Their results confirmed that the average Nusselt number increases with increase in Grashof number but decreases with increase in Hartmann number and behaves in a non-linear fashion with angles of inclination. Bakhshan and Ashoori [20] analyzed a 2-D computational of steady state free convection in a rectangular enclosure filled with an electrically conducting fluid under effect of magnetic field. They observed that Nusselt number and heat flux will increase with increasing Grashof and Prandtl numbers and decreasing the slope of the orientation of magnetic field.

From the literatures, the effect of the magnetic field on the natural convection inside the enclosure is decreased the convection effect and then reduced the heat transfer. Therefore, the addition of nanoparticles to the fluid can improve and increase its thermal performance (since the thermal conductivity of solid is typically higher than that of liquids) and enhance the heat transfer mechanism in the enclosure [21,22].