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Natural Convection and Entropy Generation in a Nanofluid-Filled Semi-Circular Enclosure with Heat Flux Source

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Abstract

The effect of presence of nanoparticles on natural convection and entropy generation in a semi-circular enclosure with present heat flux is investigated numerically in the present work. The enclosure is filled with nanofluids (Cu-water). The heat flux 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 ($-45°\leq\gamma\leq+45°$) is assumed at constant cold temperature and the other parts of the circular arc are adiabatic. Finite element method based on the variational formulation is employed to solve momentum and energy as well as post-processing streamfunctions. The results are based on visualization of isotherms, streamfunction and entropy generation. Comparison with previously published work is performed and the results are found to be in a good agreement. The influence of pertinent parameters such as Rayleigh number ($10^4 \leq Ra\leq 10^7$) and solid volume fraction of nanoparticles ($0\leq\Phi\leq 0.15$ step 0.05) on the flow, temperature, and entropy generation are examined in the present paper. The results show that the heat transfer rate increases with an increase of the Rayleigh number and the nanoparticles volume fraction. The system irreversibility increases as nanoparticles fraction increase.

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Keywords: Nanofluid; Natural Convection; Entropy Generation.

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. Different cavities shape were studied: rectangular [2], triangular [3], trapezoidal [4], sinusoidal [5], octagonal [6], prismatic [7] and annulus area [8]. Different boundary conditions had been employed for the convection heat transfer inside cavity, like: constant wall temperature and constant heat flux. The present of heat flux inside enclosure which is filled with nanofluid had been studied in different works. Aminossadati and Ghasemi,

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[9], numerically analyzed natural convection inside a cavity embedded with heat source on the bottom wall and filled with nanofluids. Their results indicated that the adding of nanoparticles into pure water improves its cooling performance especially at low Rayleigh numbers. Mahmoudi et al [10], studied the entropy generation and heat transfer in natural convection flow inside enclosure which is filled by nanofluid (Cu-water). Their analysis has been done for a two dimensional trapezoidal enclosure with the left vertical wall and inclined walls kept in a constant cold temperature and a heat flux source embedded on the bottom wall. The results show that at Ra=10^4 and 10^5 the enhancement of the Nusselt number increases due to presence of nanoparticles.

The present study may be encountered in a number of electronic cooling devices equipped with nanofluids. Hence, the main purpose of present analysis is to investigate numerically the effects of a presence of nanoparticles on the natural convection and entropy generation inside semi-circular cavity. The study is performed for various values of Rayleigh number ($10^4 \leq Ra \leq 10^7$) and volume fraction of the nanoparticles ($0 \leq \Phi \leq 0.15$ step 0.05).

Nomenclature

q"	heat flux (W/m^2)
Pr	Prandtl number
T	temperature (K)
Be	Bejan number
Ra	Rayleigh number
Nu	Nusselt number on the heat source surface
U	dimensionless velocity component in x-direction
V	dimensionless velocity component in y-direction
X	dimensionless coordinate in horizontal direction
Y	dimensionless coordinate in vertical direction
α	thermal diffusivity (m^2/s)
ε	length of heat source at base wall (m)
ψ	dimensionless stream function
μ	dynamic viscosity (kg.s/m)
Φ	nanoparticle volume fraction
ζ	dimensionless length of base heat source (ε/Lc)

2. Problem description and assumptions

The physical model of the present study shows in Fig.1. It consists of a two dimensional semi-circular cavity of radius(r). A heat source with length (2ε) is embedded on the enclosure base wall. The remaining boundary parts of the base wall are thermally insulated. The center of the circular arc ($-45° \leq \gamma \leq +45°$) kept at constant cold temperature (T_c) and the other parts of the boundary circular arc are adiabatic. The fluid in the enclosure is a nanofluid (Cu-water).

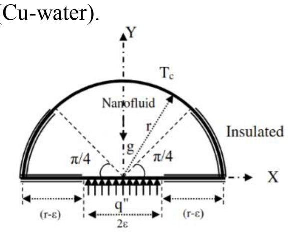

Fig. 1. Schematic of the case study.

The assumptions that used here as follows [1]: the nanofluid are assumed to be Newtonian and incompressible. The flow is assumed to be laminar. The base fluid and the nanoparticles are assumed to be in thermal equilibrium and no slip occurs between them. Thermophysical properties of the nanofluid are assumed to be constant except the density variations causing a body force term in the vertical component of momentum equation.

3. Mathematical formulation and simulation

The final governing equations (mass, momentum and energy) for steady state two-dimensional natural convection in the semi-circular cavity can be written with following dimensionless variables or numbers [9]: