Magnetohydrodynamic Natural Convection of Micropolar Fluid Flow in a Quadrant shaped enclosure

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1. INTRODUCTION & OBJECTIVE

Extensive research has been conducted on natural convection flows within various enclosure geometries, which has been largely motivated by the ample applications in architectural systems, materials processing and fuel cells. A seminal review was provided by leading researcher, Ostrach [1] which covers many fundamentals of free convective transport in enclosures and also emphasizes the importance of corroborating numerical simulations with laboratory experiments, albeit for Newtonian fluids only. Subsequently many investigations have been communicated considering both viscous and non-Newtonian thermal convection in a variety of geometries with a spectrum of multi-physics effects including mass transfer, thermal/solutal stratification, porous media etc. Bhargava et al. [2] utilized a variational FEM to simulate the thermal mass transport of Eringen micropolar fluid in an enclosure filled. Kimura et al. [3] deliberate the natural convection of thermal flow in a differentially heated semicircular enclosure containing water with a heated base wall and isothermally cooled radial boundary. Liquid crystal and thermocouple methods were employed to measure temperatures, revealing that increased heat transfer rates occur when plume-like flow develops along both the hot and cold walls in the scenario of an upward-facing hot wall. They corroborated their findings with theoretical and numerical calculations. Temperature distribution within the fluid is also significantly influenced by the imposed magnetic field. Rudraiah et al. [4] performed a modified implicit ADI and SLOR methods to compute numerically the vorticity-stream version of the conservation equations in natural convection of magnetized incompressible gas (Prandtl number of 0.733) in a rectangular enclosure subjected to a horizontal magnetic field. They considered the case with two vertical isothermal walls sustained at different thermal conditions and top and bottom horizontal adiabatic walls. They observed that with weak thermal buoyancy (small Grashof number) and low magnetic field (small Hartmann number), a circulating flow is mobilized in the cavity. In addition, they noted that at higher magnetic field intensity (larger Hartmann number), internal convection is damped and Nusselt number at the hot vertical wall is suppressed. Bég et al. [5] used a Harlow-Welch marker and cell (MAC) algorithm to simulate computationally the magneto-convection of a Newtonian gas (helium) with strong thermal buoyancy in a square domain equipped with a saturated non-Darcian porous medium and with heat generation. Their results showed that, at vertical walls, Nusselt numbers are increased at the highest permeability number and higher Grashof number (higher thermal buoyancy). Venkatadri et al. [6] used a strong finite difference approach to model the heat transfer through natural convection in a solar collector with a triangular porous medium. The model also took into account radiative heat transfer and variations in porosity

The objective of this study is to comprehensively analyze the thermo-fluidic heat transfer dynamics in a right-angled enclosure with a curved diagonal cold wall filled with micropolar fluid, focusing on the effects of a magnetic field and thermal radiation. By employing a vorticity-stream finite difference approach in Cartesian coordinates, the study investigates the incompressible laminar natural convection, examining the interplay between convection, conduction, and magnetic phenomena. Key parameters such as the Hartmann number (Ha), Prandtl number (Pr), micropolar parameter (K), and Rayleigh number (Ra) are evaluated to understand their influence on vortices, temperature distribution, internal circulation, and micro-rotation. The study presents graphical depictions of streamline, isotherm, and iso-microrotation contours, as well as the local Nusselt number at the hot wall, to provide insights into how magnetic fields and micropolar characteristics modify heat transfer and fluid behavior.

2. RESULTS & HIGHLIGHTS OF IMPORTANT POINTS

The vorticity-stream function approach is a specialized novel technique within computational fluid dynamics (CFD) that provides an alternative formulation for solving fluid flow problems. This approach is particularly useful for simulating incompressible, two-dimensional flows. The vorticity and stream function are two auxiliary functions used to describe fluid motion. The effects of fluid and thermal parameters were demonstrated through flow patterns, thermal distribution, and iso-concentrations. The following range of the three key parameters has been considered in the computations: Hartmann *number, Ha =0, 10, 20 and 30, and 0.0001, Rayleigh number* $Ra = 10^3, 10^4, 10^5$ *and* 10^6 *and vortex viscosity parameter K = 0, 1, 3, 5 and 7*.

The numerical computation of MHD laminar thermos gravitational micropolar fluid flow in a quadrant shaped enclosure containing an electrically conducting aqueous liquid (Prandtl number of 6.2) has been presented. The quadrant enclosure top wall has been assumed to be adiabatic, the right wall has been prescribed as hot and isothermal, and the circular boundary simulated as a cold wall. The modelling governing equations are employed with a vorticity-stream finite difference numerical approach. Comprehensive study have been conducted to assess how varying parameters such as the Hartmann magnetic number, and Rayleigh (natural convection) number and microrotation parameter influence the distribution of streamlines and isotherms, as well as heat transfer rate along the hot vertical boundary. The major findings of this study can be outlined as follows:

- With an increase in the Hartmann number, the isotherms change from a strongly sigmoidal distribution to one that has a more parallel distribution relative to the hot vertical wall.
- With increasing Rayleigh number, the single vortex cell observed in the enclosure is progressively distorted from an elliptic topology to a distorted structure in the lateral direction and becomes orientated towards the centre of the quadrant.
- Optimum heat transfer to the vertical isothermal wall i. e. maximum Nusselt numbers are associated with high Rayleigh number ($Ra = 10^6$) and can be achieved in the fuel cell enclosure with $Ha = 2.0$ (weak magnetic field).
- Minimal Nusselt numbers are associated with very low Rayleigh number i.e weak thermal buoyancy force ($Ra = 10^3$), non-magnetic flow ($Ha = 0.0$).
- The heat transfer reduction is observed significantly in the micropolar fluid with the influence of magnetic fluid.

- The thermal Rayleigh number boosted the convective thermal flow of Newtonian fluid when compare with micropolar fluid.

Some interesting insights have been gained from the present computations in to thermofluidic characteristics in hybrid magnetic fuel cells. Future research may consider more complex boundary configurations e. g. wavy walls and also nanofluids which hold excellent promise for thermal enhancement in fuel cell systems

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