

ALIGNED MHD FLOW OF TERNARY HYBRID NANOFLUIDS OVER A VERTICAL PLATE WITH CONVECTIVE BOUNDARY CONDITION

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Abstract

The present study presents an extensive numerical analysis of the magnetohydrodynamic (MHD) ternary hybrid nanofluid (THNF) flow of Silver (Ag), Copper (Cu), and Alumina (Al_2O_3) nanoparticles suspended in water flowing along a vertical plate under a convective boundary condition. The effects of an inclined external magnetic field, thermal radiation, Brownian motion, and thermophoresis on the temperature and velocity profiles are analyzed. By applying similarity transformations, the boundary layer equations of the problem are solved using MATLAB's `bvp4c` solver. Solutions indicate that the strength of the magnetic field and concentration of nanoparticles increase heat transfer but decrease fluid velocity as a result of the Lorentz force. The surface heat transfer and flow resistance are strongly affected by the Biot number and mixed convection parameters. This study demonstrates the higher thermal conductivity and heat transfer efficiency of THNFs than conventional nanofluids, facilitating their use in future-generation thermal technologies such as electronic cooling and industrial heat exchangers. The theoretical approach formulated provides insight for the optimization of MHD nanofluid systems and lays a platform for experimental validation in the future.

Keywords: *Fuzzy AHP, Payment Methods, Cashless Campus, Digital Payment, Decision-Making*

1. Introduction

This current work aims to investigate the aligned magnetohydrodynamic (MHD) flow of ternary hybrid nanofluids (THNFs) along a vertical plate with a convective boundary condition. The primary purpose is to model the fluid flow and thermal behavior with Silver (Ag), Copper (Cu), and Alumina (Al_2O_3) nanoparticles suspended in water. The focus is the examination of the effects of magnetic field inclination, Biot number, mixed convection, and volume fraction of nanoparticles on heat transfer characteristics, e.g., velocity and temperature profiles, skin friction, and Nusselt number. The analysis is limited to steady, two-dimensional laminar flow with uniform dispersion of nanoparticles under idealized conditions. This study answers the engineering need for efficient thermal management in applications such as heat exchangers, solar collectors, and electronic cooling (Ishak et al., 2024).

2. Methodology

The study starts with the derivation of equations of continuity, momentum, and energy for MHD flow of ternary hybrid nanofluids (THNFs). The equations are generalized to account for the effects of Lorentz force, thermal buoyancy, viscous dissipation, thermal radiation, Brownian motion, and thermophoresis. The physical setup is a vertically positioned plate that is heated on one side due to convection from an exterior fluid and whose boundary condition is modeled by the Biot number. To simplify the governing partial differential equations (PDEs) for solution, similarity transformations are used to reduce them into ordinary differential equations (ODEs). The ODEs are then solved using MATLAB's `bvp4c` solver and augmented with the shooting method to attain high numerical accuracy. Thermophysical properties like density, viscosity, thermal conductivity, and heat capacity are calculated using available composite models for THNFs (Ishak et al., 2023). Parametric studies vary the inclination angle (α), magnetic field (M), volume fractions (ϕ_1, ϕ_2, ϕ_3), Biot number (B_{ix}), and

mixed convection parameter (λ) to study their effects on fluid flow and heat transfer (Makinde & Aziz, Pattnaik et al., 2024).

3. Results / Findings

Simulation results confirm that magnetic field enhancement and nanoparticle volume fraction increase heat transfer performance as evidenced by a rise in the Nusselt number. However, fluid velocity is reduced due to the motion-inhibiting Lorentz force. The Biot number and convective parameter also significantly influence surface heat exchange and flow resistance as shown by actual convective behaviors. The results reflect that ternary hybrid nanofluids outperform mono- and binary nanofluids in terms of thermal conductivity and heat transfer efficiency due to synergistic interactions between Ag, Cu, and Al_2O_3 nanoparticles. Moreover, convective boundary conditions create thicker boundary temperature layers and increased surface temperatures, which are more representative of actual engineering conditions than fixed-wall temperature assumptions. These findings affirm the feasibility of using THNFs as high-performance thermal devices in industrial and energy applications (Raji et al., 2022).

4. Novelty of Research / Product / Project

This study takes into account the behavior of ternary hybrid nanofluids (THNFs) under an inclined magnetic field with convective boundary conditions, which is more practical in the case of solar panels and electronic cooling. The fluid contains three nanoparticles. Silver (Ag), Copper (Cu), and Alumina (Al_2O_3) in water, to achieve better heat transfer than single or double nanoparticle fluids. The governing equations are simplified using similarity transformations and solved using MATLAB 'bvp4c' and the shooting method. The effects of significant parameters like magnetic field direction, Biot number, and nanoparticle volume fractions are investigated on flow, temperature, friction, and heat transfer. This work helps in the design of better thermal systems in the future.

5. Conclusion or Future Work

This study confirms the thermal advantages of ternary hybrid nanofluids in aligned MHD flow under convective boundary conditions. Experimental confirmation and application to turbulent or unsteady flow must be explored by future research to further actualize the model to more practical real-world applications for thermal management technologies (Ishak et al., 2024; Mohd Zukri et al., 2023).

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