International Journal of Multidisciplinary Research and Technology
ISSN 2582-7359, Peer Reviewed Journal, Impact Factor 6.325
www.ijmrtjournal.com

ANALYSIS OF MHD HYBRID NANOFLUID FLOW OVER A LINEAR STRETCHED SHEET

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Abstract

In this paper, the magnetohydrodynamic (MHD) hybrid nanofluid flow over a linear stretched sheet is mathematically designed and analysed. The hybrid nanofluid is composed of two nanoparticles suspended in a base fluid, and the effect of a magnetic field is considered for the flow characteristics. The governing equations for mass, momentum, and energy transport are derived, and a similarity transformation is applied to convert these equations into a system of ordinary differential equations. The numerical solution of these equations is obtained using the RKF method, and the results are analysed to study the impact of various parameters, such as the Hartmann number, nanoparticle volume fraction, and Prandtl number, on the flow and heat transfer behaviour. The results indicate that the inclusion of hybrid nanofluids enhances the heat transfer rate and affects the velocity distribution significantly.

1. Introduction

Nanofluids—colloidal suspensions of nanoparticles in base fluids have garnered significant attention due to their enhanced thermal properties, making them ideal candidates for applications in cooling systems, heat exchangers, and energy storage devices. The incorporation of nanoparticles such as metals, oxides, or carbides into base fluids results in improved thermal conductivity and heat transfer rates.

In many engineering applications, the interaction between magnetic fields and electrically conductive fluids is crucial. Magnetohydrodynamics (MHD) studies the behaviour of such fluids under the influence of magnetic fields, leading to the generation of electromagnetic forces that affect flow and heat transfer characteristics. The application of magnetic fields can control and optimize fluid flow, which is particularly beneficial in processes involving high thermal loads.

The concept of hybrid nanofluids—fluids containing two or more different types of nanoparticles—has been introduced to further enhance thermal properties beyond those achievable with single-nanoparticle nanofluids. By combining nanoparticles with complementary properties, hybrid nanofluids offer superior thermal conductivity and heat transfer performance.

The study of MHD hybrid nanofluid flow over a linear stretched sheet is of particular interest due to its relevance in various industrial processes, including extrusion, polymer processing, and metal wire drawing. The stretching of a sheet introduces a velocity gradient, influencing the flow and heat transfer characteristics of the fluid. Understanding the behavior of MHD hybrid nanofluid flow in such scenarios is essential for optimizing these processes.

Recent studies have explored various aspects of MHD hybrid nanofluid flow over stretching sheets. For instance, a study by Yahaya et al. (2022) analysed the MHD flow of hybrid nanofluids past a stretching sheet, considering double stratification and multiple slip effects. Similarly, Sharma and Sood (2022) investigated the impact of radiation and slip conditions on MHD nanofluid flow past an exponentially stretched surface, highlighting the influence of thermal slip and magnetic parameters on heat transfer rates. Additionally, Goyal and Bhargava (2017) employed the Galerkin Finite Element Method to study the thermo-diffusive effects on nanofluid flow over a power-law stretching sheet under the influence of an external magnetic field. These studies underscore the complex interplay between magnetic fields, nanoparticle properties, and flow dynamics in MHD hybrid nanofluid systems. However, a comprehensive understanding of the flow and heat transfer characteristics of MHD hybrid nanofluid flow over a linear stretched sheet remains an area of active research.

This study aims to mathematically model and analyse the MHD hybrid nanofluid flow over a linear stretched sheet, considering the effects of magnetic fields and hybrid nanoparticles on flow behaviour and heat transfer performance. The findings are expected to provide valuable insights for optimizing industrial processes involving MHD hybrid nanofluid flow.

2. Mathematical Formulation

Consider a steady, incompressible, magnetohydrodynamic flow of a hybrid nanofluid over a linear stretched sheet. The base fluid is a water-based nanofluid that contains two types of nanoparticles: copper (Cu) and alumina (Al_2O_3). The magnetic field is applied perpendicular to the flow direction. The schematic diagram is represented in Figure 1.

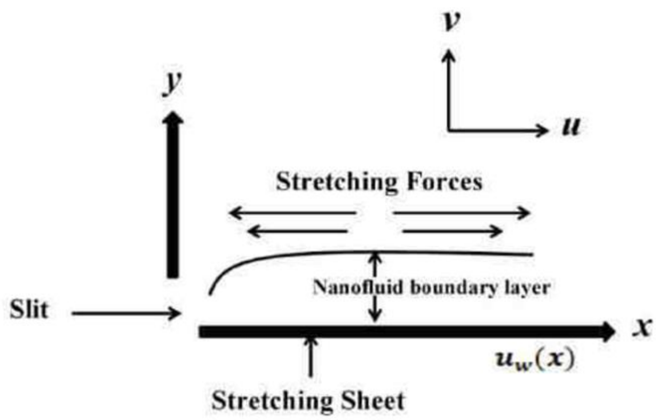

Figure 1. Schematic diagram

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \quad (1)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\frac{\mu_{hnf}}{\rho_{hnf}}\frac{\partial^2 u}{\partial y^2}-\frac{\sigma_{hnf}}{\rho_{hnf}}B^2u \quad (2)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k_{hnf}}{\left(\rho c_p\right)_{hnf}}\frac{\partial^2 T}{\partial y^2} \quad (3)$$

In these equations, the effects of nanoparticles are incorporated by modifying the fluid properties, including the density, dynamic viscosity, thermal conductivity, and specific heat capacity.

Boundary Conditions are

$$\left.\begin{array}{ll} u=u_w=ax,\ v=0,\ T=T_w & \text{at} \quad y=0 \\ u\to 0,\ T\to T_\infty, & \text{as} \quad y\to\infty \end{array}\right\} \quad (4)$$

Similarity Variables

$$\eta=\sqrt{\frac{a}{\nu}}y\ ,\ \theta=\frac{T-T_\infty}{T_w-T_\infty},\ u=axf'(\eta),\ v=-\sqrt{a}f(\eta)$$

Reduced ordinary differential equations are

$$\frac{\mu_{hnf}}{\mu_f}f''' + \frac{\rho_{hnf}}{\rho_f}\left(ff''-f'^2\right)-\frac{\sigma_{hnf}}{\sigma_f}Mf'=0 \quad (5)$$

$$\frac{k_{hnf}}{k_f}\theta''+Prf\theta'=0 \quad (6)$$

Corresponding Boundary Conditions

$$\left.\begin{array}{l} f(0)=0, f^{'}(0)=1, \theta(0)=1 \\ f^{'}(\infty)=0, \theta(\infty)=0 \end{array}\right\} \quad (7)$$

The physical quantities of our interest are skin friction coefficient and Nusselt number, which are represented as

$$C_f=\frac{\tau_w}{\rho\, {u_w}^2} \quad \text{and} \quad Nu=\frac{xq_w}{k(T_w-T_\infty)}$$

3. Results and Discussion

The dimensionless ordinary differential equations (5)-(6) along with boundary conditions (7) are solved using RKF-45 method. The study of MHD hybrid nanofluid flow over a linear stretched sheet presents several important findings:

Figures 2 and 3 show how the hybrid nanofluid's velocity and temperature profiles are affected by the presence of a magnetic field, respectively. The Lorentz force, which opposes the fluid flow, is directly proportional to the magnitude of M. As a result, a stronger Lorentz force means a higher resistivity to the fluid flow, which means the momentum is decreasing as M increases. Since nanoparticles can conduct more heat, a higher temperature is observed because of this decrease in the flow's velocity.

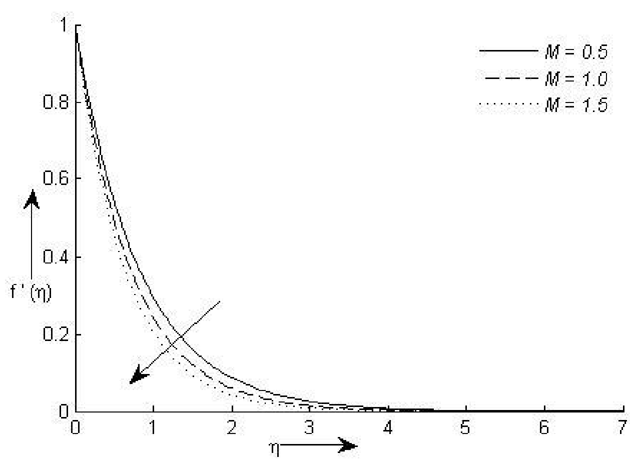

Figure 2. Velocity profiles for M

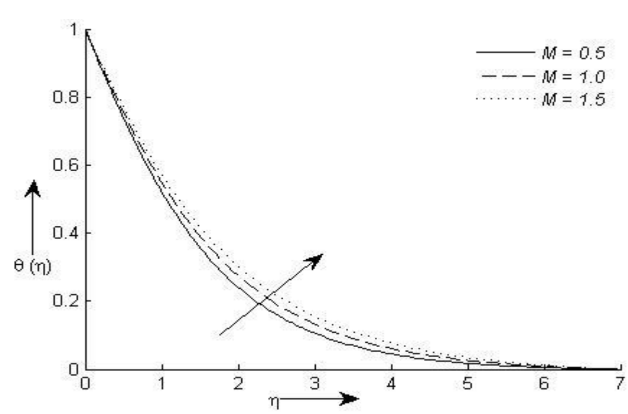

Figure 3. Temperature profiles for M

The hybrid nanofluid expressions improved heat transfer characteristics compared to conventional fluids. This is because the two types of nanoparticles provide enhanced thermal conductivity, leading to better heat dissipation from the surface. The temperature gradient is higher for hybrid nanofluids, indicating faster heat transfer from the surface to the surrounding fluid.

4. Conclusion

The mathematical modelling and numerical study of MHD hybrid nanofluid flow over a linear stretched sheet reveal that both the magnetic field and the presence of hybrid nanoparticles significantly influence the flow and heat transfer characteristics. By incorporating two types of nanoparticles, the hybrid nanofluid offers enhanced thermal conductivity and improved heat dissipation. The results suggest that MHD hybrid nanofluid flow is a promising approach for thermal management applications in engineering systems.

Further studies show that the increase in the magnetic field resists the flow of hybrid nanofluid. The heat generated due to strong Lorentz force caused the hybrid nanofluid to conduct more heat.

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