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Incorporating Soret and Dufour Effects in Magnetohydrodynamic (MHD) Free Convective Flow over a Vertical Porous Plate with Heat Generation.

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Abstract

We analyze the flow of an MHD fluid along a vertical plate, taking into account the Dufour and Soret effects. The ensuing momentum, energy, and concentration equations are rendered similar through standard similarity transformations. These transformed equations are then solved numerically using the fourth-order Runge-Kutta method along with the shooting technique. The impacts of diverse parameters on dimensionless velocity, temperature, and concentration profiles, as well as local values of skin-friction coefficient, Nusselt number, and Sherwood number, are presented through graphical representation and tabulation.

Introduction

The impact of free convection on the accelerated flow of a viscous, incompressible fluid adjacent to an infinite vertical plate under suction finds significant relevance in astrophysical, geophysical, and engineering contexts. Numerous technological applications stems from this phenomenon, such as room heating through radiators, heat dissipation from hot pipes and ovens, and pivotal roles in manufacturing industries like fin design, steel rolling, nuclear power plants, gas turbines, aircraft propulsion systems, combustion, furnace design, materials processing, energy utilization, and temperature measurements. An extensive array of research explores convective heat transfer mechanisms through porous media, with Nield and Bejan [1] providing a comprehensive review in this realm. Hiremath and Patil [2] examined the influence of free convection currents on oscillatory flow through a porous medium bounded by a vertically oriented plane surface featuring a constant temperature. Fluctuations in heat and mass transfer within a three-dimensional flow through a porous medium characterized by variable permeability were studied by Sharma et al. [3]. To delve deeper, valuable insights and knowledge on this subject can be found in works by Pop and Ingham [4], Ingham and Pop [5], Vafai [6], Vadasz [7], among others.

This paper aims to investigate the impact of Dufour and Soret effects on the magnetohydrodynamic (MHD) free convection flow along a vertical porous plate positioned within a porous medium [8-10]. This analysis is conducted while considering factors such as chemical reaction, thermal radiation, and heat source. The governing equations and boundary conditions are transformed into a set of nonlinear ordinary differential equations through similarity transformations [11]. These equations are then solved using the shooting method in conjunction with a fourth-order Runge-Kutta integration scheme. The study explores the influence of diverse physical parameters on velocity, temperature, and concentration profiles [12]. Furthermore, local skin-friction coefficient, local Nusselt number, and local Sherwood number variations are presented both visually and in tabular format. To validate our findings, a comparison is made with the results of prior research conducted [13]. This comparative analysis underscores a favorable agreement, reinforcing the accuracy of our current numerical outcomes [14].

Mathematical analysis

We investigate a stable two-dimensional motion of an incompressible, electrically conducting viscous fluid adjacent to an infinite vertical porous plate situated within a porous medium. The x-axis is aligned with the infinite plate, running parallel to the vertical free-stream velocity, while the y-axis is oriented perpendicular to the plate [15].

Continuity equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0\,. \tag{2.1}$$

Momentum equation

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}+g\beta\left(T-T_\infty\right)+g\beta^*\left(C-C_\infty\right)-\frac{\sigma B_0^2}{\rho}u-\frac{\upsilon}{K}u-\frac{b}{K}u^2\,. \tag{2.2}$$

Energy equation

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}-\frac{1}{\rho c_p}\frac{\partial q_r}{\partial y}+\frac{D_m}{c_s}\frac{k_T}{c_p}\frac{\partial^2 C}{\partial y^2}+\frac{Q_0}{\rho c_p}\left(T-T_\infty\right). \tag{2.3}$$

Concentration equation

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_m\frac{\partial^2 C}{\partial y^2}+\frac{D_m k_T}{T_m}\frac{\partial^2 T}{\partial y^2} \tag{2.4}$$

The boundary conditions for velocity, temperature and concentration fields are given by

$$\begin{aligned}
&u=U_0\,, \quad v=v_0(x)\,, \quad T=T_w\,, \quad C=C_w \quad \text{at} \quad y=0\,,\\
&u=0\,, \quad v=0\,, \quad T=T_\infty\,, \quad C=C_\infty \quad \text{as} \quad y\to\infty
\end{aligned} \tag{2.5}$$

$$q_r=-\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y} \tag{2.6}$$

Results

Figure 1 illustrates the influence of the Grashof number (Gr) on the velocity field. The Grashof number (Gr) quantifies the relative impact of thermal buoyancy force compared to viscous hydrodynamic force within the boundary layer. As the Grashof number (Gr) rises, the fluid velocity experiences augmentation. In Figure 2, velocity profiles within the boundary layer are depicted for various values of the modified Grashof number (Gc). This modified Grashof number (Gc) characterizes the proportion of species buoyancy force to viscous hydrodynamic force. With an increase in the modified Grashof number (Gc), fluid velocity demonstrates a corresponding escalation.

Figure 4 presents the impact of the Reynolds number (Re) on the velocity distributions. It is noteworthy that the Reynolds number (Re) exhibits minimal influence on the velocity profiles.

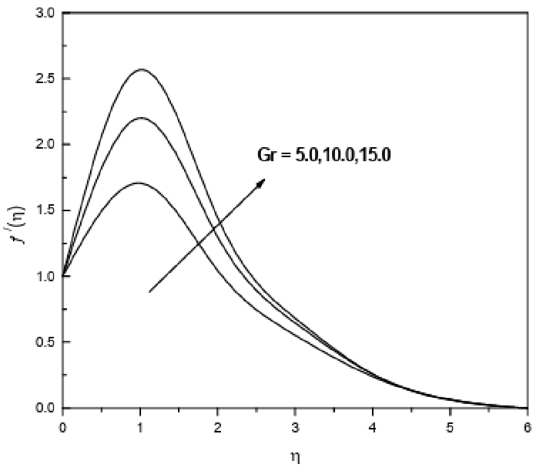

Fig.1. Velocity profiles for different values of Gr.

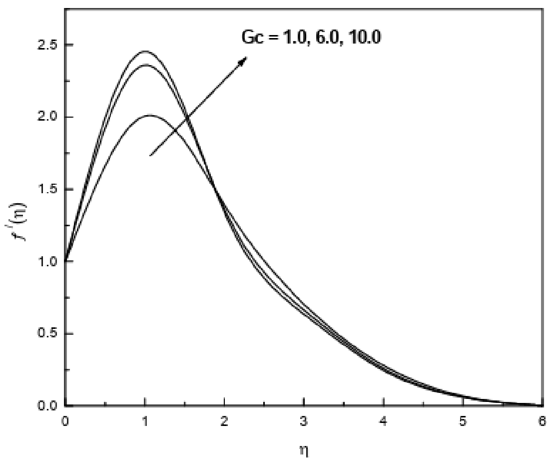

Fig.2. Velocity profiles for different values of Gc.

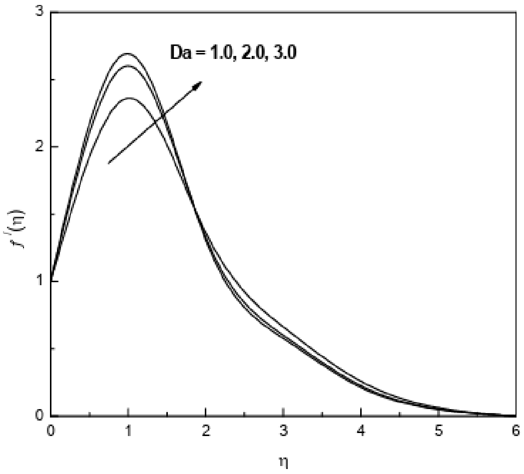

Fig.3. Velocity profiles for different values of Da.

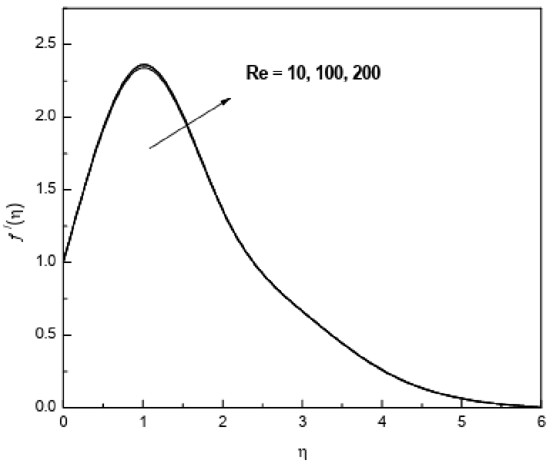

Fig.4. Velocity profiles for different values of Re.

Conclusion

The study's findings can be summarized as follows:

- An elevation in the Grashof number and modified Grashof number leads to an increase in velocity.

- The velocity diminishes as the magnetic field parameter and permeability parameter increase.

- An upsurge in the radiation parameter corresponds to heightened fluid temperature and velocity.

- Similarly, an increase in the heat source parameter results in elevated fluid temperature and velocity.

- The radiation parameter exhibits an inverse relationship with skin-friction coefficient and Nusselt number.

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