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Exploration of Free Convective Heat and Mass Transfer within a Highly Porous Medium, Accounting for Radiation, Chemical Reaction, and Soret Effects.

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Abstract

This study delves into the impact of Soret effects on the unsteady free convection flow of an incompressible viscous fluid through a highly porous medium, confined by an infinitely moving vertical plate. The analysis considers thermal radiation, chemical reaction, and heat source influences. The fluid is characterized as gray, absorptive, and emissive, while not exhibiting scattering. Radiative heat flux is described using the Rosseland approximation within the energy equation. The dimensionless governing equations are solved analytically employing a perturbation technique. Through the investigation, the influence of various governing parameters on velocity, temperature, concentration, skin-friction coefficient, Nusselt number, and Sherwood number is elucidated through figures and tables.

Introduction

The study of convective heat and mass transfer within porous media has garnered significant attention over recent decades. This interest has been spurred by numerous thermal engineering applications across various fields, including geophysics, thermal engineering, insulation engineering, modeling of packed sphere beds, cooling of electronic systems, chemical catalytic reactors, ceramic processes, grain storage devices, fiber and granular insulation, petroleum reservoirs, coal combustors, groundwater pollution, and filtration processes. In their work, Raptis [1] introduced the presence of a magnetic field within a porous medium. Chen and Lin [2] explored natural convection from an isothermal vertical surface embedded in a thermally stratified high-porosity medium. Hayat et al. [3] investigated heat and mass transfer as well as slip flow of a second-grade fluid past a stretching sheet through a porous space. Sreevani [4] analyzed heat and mass transfer in mixed convective flow through a porous medium in channels with dissipative effects. The study by Yamamoto and lwamura [5] delved into flow with convective acceleration through a porous medium.

The implications of this research are anticipated to provide valuable insights into comprehending the impact of heat and mass transfer phenomena coupled with chemical reactions. Such understanding holds significant relevance across various processes [6], commanding substantial attention in recent times. This interest is particularly pronounced in contexts like drying, surface evaporation of water bodies, energy transfer within wet cooling towers [7], and airflow in desert coolers. In the realm of chemical reaction engineering, the simultaneous occurrence of heat and mass transfer plays a pivotal role [8].

Mathematical analysis

In this study, we explore the dynamics of an unsteady, two-dimensional laminar free convective mass transfer flow within a highly porous medium [9]. This flow occurs adjacent to an infinitely moving vertical porous plate, while factors like thermal radiation, heat generation, chemical reaction, and Soret effects are taken into account [10]. The fluid and the porous structure are assumed to be in a

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state of local thermal equilibrium. Additionally, it is considered that radiation solely emanates from the fluid [11].

Continuity equation:

$$\frac{\partial v^*}{\partial y^*} = 0 \tag{1}$$

Momentum equation:

$$\frac{\partial u^*}{\partial t^*} + v^* \frac{\partial u^*}{\partial y^*} = -\frac{1}{\rho}\frac{\partial p^*}{\partial x^*} + \upsilon \frac{\partial^2 u^*}{\partial y^{*2}} + g\beta\left(T^* - T_\infty^*\right) + g\beta^*\left(C^* - C_\infty^*\right) - \frac{\upsilon}{k^*}\varphi u^* \tag{2}$$

Energy equation:

$$\sigma \frac{\partial T^*}{\partial t^*} + \varphi v^* \frac{\partial T^*}{\partial y^*} = \frac{k}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{\varphi}{\rho C_p}\frac{\partial q_r}{\partial y^*} + \frac{Q_0}{\rho C_p}\left(T^* - T_\infty^*\right) \tag{3}$$

Diffusion equation:

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$$\frac{\partial C^*}{\partial t^*} + v^* \frac{\partial C^*}{\partial y^*} = D\frac{\partial^2 C^*}{\partial {y^*}^2} - Kr^*\left(C^* - C_\infty^*\right) + D_1\frac{\partial^2 T^*}{\partial {y^*}^2} \quad (4)$$

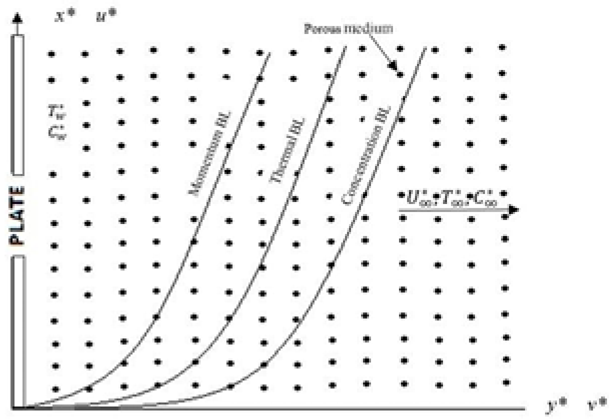

Fig. 1. Flow configuration of the problem

Solution of the problem

Solving these equations and nonlinear partial differential equations analytically in closed form is not feasible [12]. Nevertheless, it is possible to transform these equations into a system of ordinary differential equations, which lends itself to analytical solutions [13]. This transformation involves representing the velocity, temperature, and concentration of the fluid in proximity to the plate as follows:

$$u(y,t) = u_0(y) + \varepsilon e^{nt} u_1(y) + 0(\varepsilon)^2 + \ldots\ldots,$$
$$\theta(y,t) = \theta_0(y) + \varepsilon e^{nt} \theta_1(y) + 0(\varepsilon)^2 + \ldots\ldots,$$
$$C(y,t) = C_0(y) + \varepsilon e^{nt} C_1(y) + 0(\varepsilon)^2 + \ldots\ldots,$$

Results

The relationship depicted in Figure 2 indicates that enhanced surface cooling leads to an augmentation in Gr, subsequently resulting in an increase in velocity as observed in Gc [14]. Gr represents the relative influence of thermal buoyancy force compared to the viscous hydrodynamic force within the boundary layer [15].

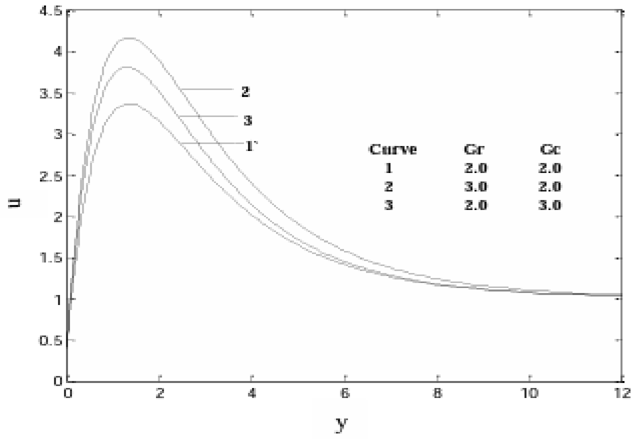

Fig. 2. The graph of u against y for varies values of Gr and Gc.

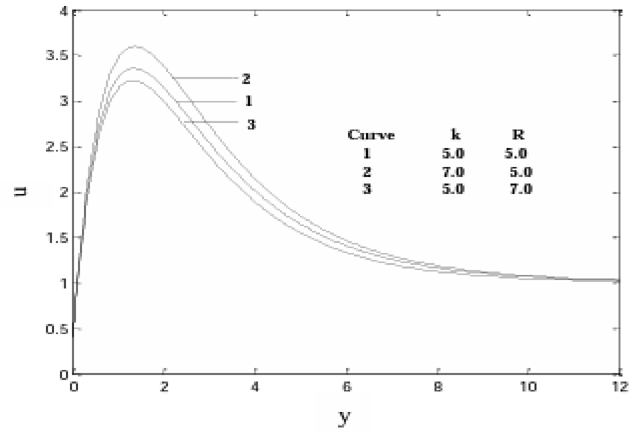

Fig. 3. The graph of u against y for varies values of k and R.

Conclusion

This paper presents a theoretical investigation aimed at comprehending the impacts of chemical reaction and Soret effects on the dynamics of free convective heat and mass transfer within a highly porous medium, while accounting for chemical reaction. The obtained results align with conventional flow expectations. Notably, the analysis reveals that within the boundary layer, velocity experiences augmentation with higher Grashof and modified Grashof numbers (buoyancy parameters). Furthermore, a noteworthy observation is that both velocity and concentration increase as the Schmidt number decreases and the chemical reaction parameter decreases.

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