

Soret-Dufour Effect on Free Convective Flow through Porous Medium Bounded by Vertical Plane

Govindarajan.A,¹ Ramesh.M,² Rajeswari.M,³ Jothinagamani,⁴ Renuka Devi.R,⁵ Ezhil.T⁶

^{1,2,3,4} Department of Mathematics (SH), PERI Institute of Technology, Mannivakkam, Chennai-600048.

^{5,6} Department of Mathematics, PERI College of Arts and Science, Mannivakkam, Chennai-600048.

Abstract:

In this article, we studied the Soret and chemical reaction effect of a free convection flow through a porous medium bounded by a vertical infinite surface. Using regular perturbation technique to solve the governing equations and finding the velocity, temperature and concentration of the fluids. The respective profiles have been obtained for different values of parameters like the Grashof number, Prandtl number, and the chemical reaction parameter. The graphs depicted shown the various reactions of the different fluid parameters.

INTRODUCTION

The increasing necessity for Soret and chemical effects in chemical and hydrometallurgical industries leads the study of heat and mass transfer with chemical reaction. More transport situations are governed by the combined action of buoyancy forces due to both Soret effect and mass diffusion in the presence of chemical reaction effect. These are observed in so many sectors like nuclear reactor safety and combustion systems, solar collectors also in metallurgical and chemical engineering. Some more applications like solidification of binary alloys and crystal growth dispersion of dissolved materials or particulate water in flows, dehydration and drying process in chemical and food processing plants and combustion of atomized liquid fuels. The amount of foreign mass in water or air leads few chemical reactions. This foreign mass may be occurs either by itself or as mixed with air or water. In many chemical engineering processes, a chemical reaction occurs between foreign mass and the fluid where the plate is in moving state. All these take place in countless industrial applications, like manufacturing sectors of polymer and ceramics or glassware, also in food production process.

“Gebhart and Pera” discussed the effect of foreign mass on free convection flow past a semi-infinite vertical plate (1). When a foreign material is present in water or air, it causes a variety of chemical reactions. Furthermore, heat is produced during chemical recombination between two species. (2). A chemical reaction is classified as either heterogeneous or homogeneous. It also depends on whether the reaction occurs in a single phase or at the interface. If the rate of a reaction is directly proportional to the concentration, it is said to be first order. (3). Chemical reaction has been studied to see how it affects heat and mass transmission in a laminar boundary layer flow. Several authors looked into it under various circumstances (4–10). “Ganesan and Rani” [11] studied the diffusion of chemically reactive species in a convective flow down a vertical cylinder. R.Muthucumaraswamy investigated the effect of a chemical reaction on a moving isothermal vertical surface with suction.[12]. Kandasamy et al. [13], continuing their research on chemical reactions, looked at the chemical reaction and temperature stratification effects over a vertically expanding surface. Raptis et al. [14] investigated a viscous flow over a nonlinearly extending sheet in the presence of a chemical process and a magnetic field. The influence of chemical reaction, heat, and mass transfer on a boundary-layer flow across a porous wedge was studied by Kandasamy et al. [15].

They found that diminishing the flow temperature was beneficial. To determine how efficient a surface's heat insulation is, a flow through a porous medium must be studied, as well as the influence of chemical reaction on heat and mass transfer. As a result, the purpose of this paper is to study such phenomena. Simultaneously, the goal of this research is to investigate the heat and mass transfer effects of a steady flow of viscous fluid through a porous medium bounded by a porous surface exposed to suction with constant velocity in the presence of a homogeneous first-order chemical reaction. Examining a flow model like this demonstrates the impact of chemical reactions during the Soret effect. The flow field is significantly influenced by the chemical reaction parameter, according to the study of the results obtained. It is intended that these findings will not only provide important knowledge for application, but will also supplement prior research.

MATHEMATICAL ANALYSIS

We consider a continuous flow of incompressible viscous fluid through a porous material in a semi-infinite region of space surrounded by a vertical infinite surface. The x-axis runs vertically along the surface, whereas the y-axis is perpendicular to it. Except for the density in the body force, the fluid parameters are assumed to be constant. The vertical surface emits a chemically reactive species.

$$\partial v / \partial y = 0 \quad (1)$$

$$V (\partial u / \partial y) = V (\partial^2 u / \partial y^2) + g\beta (T - T_\infty) + g\beta (C - C_\infty) - \sigma (B_2 / \rho) u - (vu / KP) \quad (2)$$

$$V (\partial T / \partial y) = (\alpha / \rho C_p) (\partial^2 T / \partial y^2) + N_2 T - ST \quad (3)$$

$$V (\partial C / \partial y) = D (\partial^2 C / \partial y^2) - K_c C + (D_m K_t / TM) (\partial T / \partial y) \quad (4)$$

We have concluded that the level of species concentration is extremely low; hence, the created as a result of chemical reactions is very low. We've assumed that the concentration of species is extremely low, thus the heat created by the chemical reaction can be ignored. Equation (1) results

$$v = \text{const} = -v_0 \quad (5)$$

Take $v_0 > 0$ where v is the surface's steady normal suction velocity. these are the relevant boundary conditions.

$$u=0, \quad \theta = \theta_w, \quad \varphi = \varphi_w \quad \text{at } y=0$$

$$u \rightarrow 0, \quad \theta \rightarrow \theta_\infty, \quad \varphi \rightarrow \varphi_\infty \quad \text{as } y \rightarrow \infty \quad (6)$$

Let's have a look at some nondimensional parameters:

$$\begin{aligned} u &= u / v_0, \quad y = (v_0 y) / v, \quad \theta = (T - T_\infty) / (T_w - T_\infty), \quad C = (C - C_\infty) / (C_w - C_\infty), \\ Pr &= \rho v c_p / \alpha, \quad Sc = v / D, \quad Gr = v g \beta_1 (T_w - T_\infty) / v_0^3, \\ Gc &= v g \beta_2 (C_w - C_\infty) / c, \quad E = v_0^2 / c_p (T_w - T_\infty), \\ k &= (v_0^2 / v^2) k_p, \quad k_0 = (v / v_0^2) k_c \end{aligned} \quad (7)$$

By Using (7), the governing system of equations (1)–(4) is simplified to the nondimensional form:

$$u'' + u' = -Gr\theta - Gc\varphi + k - 1 + M_2 u \quad (8)$$

$$\theta'' + Pr\theta' = N_2\theta - S\theta - PrEu'^2 \quad (9)$$

$$\varphi'' + Sc\varphi' = k_0 Sc\varphi - ScSr\theta'' \quad (10)$$

The associated boundary conditions are as follows:

$$u=0, \quad \theta=1, \quad \varphi=1 \quad \text{at } y \text{ equals } 0$$

$$u \rightarrow 0, \quad \theta \rightarrow \infty, \quad \varphi \rightarrow \infty \quad \text{as } y \text{ tends to } \infty \quad (11)$$

We expand θ , φ and u in powers of Eckert number E (E is very small) to get the solutions of the coupled nonlinear system of equations (8-10) with boundary conditions in (11)

$$\begin{aligned} u &= u_0 + E u_1 + O(E^2), \\ \theta &= \theta_0 + E \theta_1 + O(E^2), \\ \varphi &= \varphi_0 + E \varphi_1 + O(E^2). \end{aligned} \quad (12)$$

Substitute equation (12) in equation (8-10), and by comparing We extract the following equations from the coefficients at terms with the same powers of e , ignoring terms of order E^2 and higher orders:

ZERO ORDER

$$u_0'' + u_0' = -Gr\theta_0 - Gc\varphi_0 + (k-1+M_2)u_0 \quad (13)$$

$$\theta_0'' + Pr\theta_0' - (N_2 - S)\theta_0 = 0 \quad (14)$$

$$\varphi_0'' + Sc\varphi_0' = k_0 Sc\varphi_0 - Sr\theta_0'' \quad (15)$$

FIRST ORDER

$$U_1'' + u_1' = -Gr\theta_1 - Gc\varphi_1 + (k-1+M_2)u_1 \quad (16)$$

$$\theta_1'' + \text{Pr} \theta_1' - (N_2 - S) \theta_1 = -\text{Pr} u \theta_1' \quad (17)$$

$$\phi_1'' + \text{Sc} \phi_1' = k_0 \text{Sc} \phi_1 - \text{Sc} \text{Sr} \theta_1'' \quad (18)$$

The boundary conditions are:

$$\begin{aligned} u_0 = 0, u_1 = 0, \theta_0 = 1, \theta_1 = 0, \phi_0 = 1, \phi_1 = 0 \text{ at } y = 0; \\ u_0 \rightarrow 0, u_1 \rightarrow 0, \theta_0 \rightarrow 0, \theta_1 \rightarrow 0, \phi_0 \rightarrow 0, \phi_1 \rightarrow 0 \text{ at } y \text{ tends to } \infty \end{aligned} \quad (19)$$

We can represent the answers for u , θ and ϕ , and as follows by solving equations (13 to 18) under the boundary conditions in (19) and substituting the obtained solutions in equation (12):

$$u = M e^{r_6 y} + (L_2 - L_1) e^{r_2 y} - L_2 e^{r_4 y} + E \{ a e^{r_{12} y} - K_2 e^{r_{10} y} + (K_3 - A_1) e^{r_8 y} + (A_2 - K_1) e^{2r_6 y} + (A_3 - K_5) e^{2r_2 y} \\ + (A_4 - K_6) e^{2r_4 y} + (A_5 - K_7) e^{(r_2 + r_6) y} + (K_8 - A_6) e^{(r_2 + r_4) y} + (K_9 - A_7) e^{(r_6 + r_4) y} \} \quad (20)$$

$$\theta = e^{r_2 y} + E \{ B e^{r_8 y} - M_1 e^{2r_6 y} - M_2 e^{2r_2 y} - M_3 e^{2r_4 y} - M_4 e^{(r_2 + r_6) y} + M_5 e^{(r_2 + r_4) y} + M_6 e^{(r_6 + r_4) y} \} \quad (21)$$

$$\phi = (1 + K_1) e^{r_4 y} - K_2 e^{r_2 y} + E \{ A e^{r_{10} y} - B_1 e^{r_8 y} + B_2 e^{2r_6 y} + B_3 e^{2r_2 y} + B_4 e^{2r_4 y} + B_5 e^{(r_2 + r_6) y} \\ - B_6 e^{(r_2 + r_4) y} - B_7 e^{(r_6 + r_4) y} \} \quad (22)$$

The nondimensional skin friction at the surface is given by

$$\tau = (\partial u / \partial y)_{y=0} = r_6 M + r_2 (L_3 - L_1) - r_4 L_2 + E \{ r_{12} a - r_{10} K_2 + (K_3 - A_1) r_8 + (A_2 - K_4) 2r_6 \\ + (A_3 - K_5) 2r_2 + (A_4 - K_6) 2r_4 + (r_6 + r_2) (A_5 - K_7) + (r_4 + r_2) (K_8 - A_6) + (K_9 - A_7) (r_6 + r_4) \} \quad (23)$$

In the Appendix, you'll find the expressions for the constants used in Eqs. (20)–(22). Under the following conditions, equation (22) for fluid concentration can be used: $k_0 > 0$ for a destructive reaction; $k_0 = 0$ in the absence of reaction; $k_0 < 0$ for a generative reaction.

In terms of the Nusselt number, the rate of heat transmission is given by

$$N = -(\partial \theta / \partial y)_{y=0} = -r_2 + E \{ -B r_8 + 2r_6 M_1 + 2r_2 M_2 + 2r_4 M_3 + (r_6 + r_2) M_4 - (r_4 + r_2) M_5 - (r_6 + r_4) M_6 \} \quad (24)$$

Rate of mass transfer

$$(\partial \phi / \partial y)_{y=0} = r_4 (1 + k_1) - k_2 r_2 + E \{ r_{10} A - r_8 B_1 + 2r_6 B_2 + 2r_2 B_3 + 2r_4 B_6 + (r_2 + r_6) B_5 - B_6 (r_4 + r_2) - B_7 (r_6 + r_4) \} \quad (25)$$

DISCUSSION AND RESULTS

Velocity Profile:

Numerical results are given in figures to provide a clear understanding of the physical situation. By using perturbation technique for different values of non-dimensional parameters as defined in the transformed governing equation.. The effect of various parameters like Grashof number (Gr), magnetic number (M), radiation parameter (N), Schmidt number (Sc), chemical reaction parameter (Kc), suction parameter (S) on velocity profile (u), concentration distribution (Φ), temperature distribution (θ) are analysed

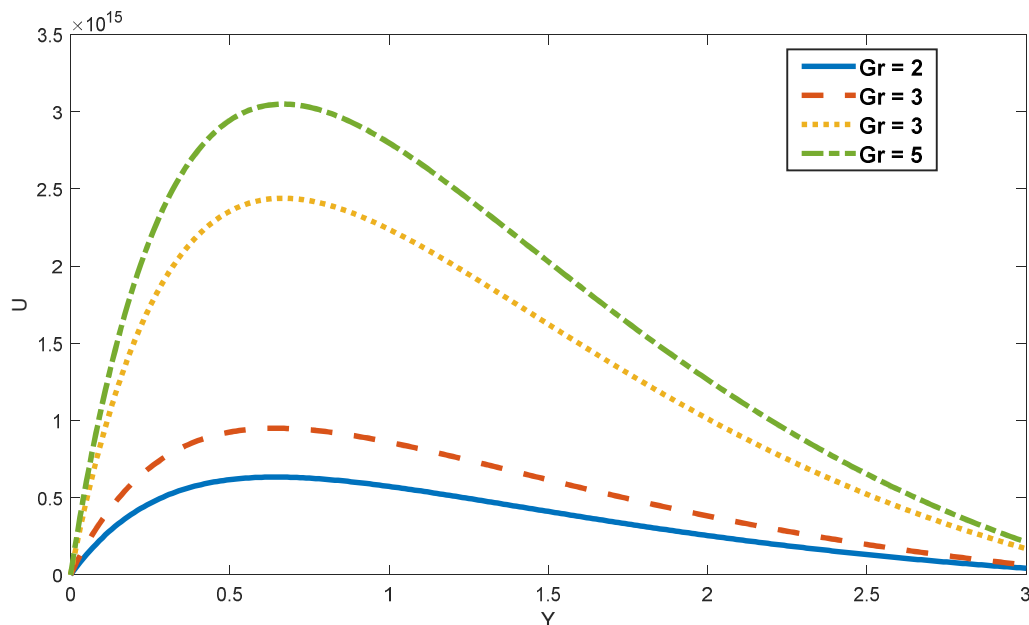


FIGURE 1. Vaariation of velocity profile for different values of Gr

Concentration profile:

There is a reduction in concentration when the Sc values are increases.

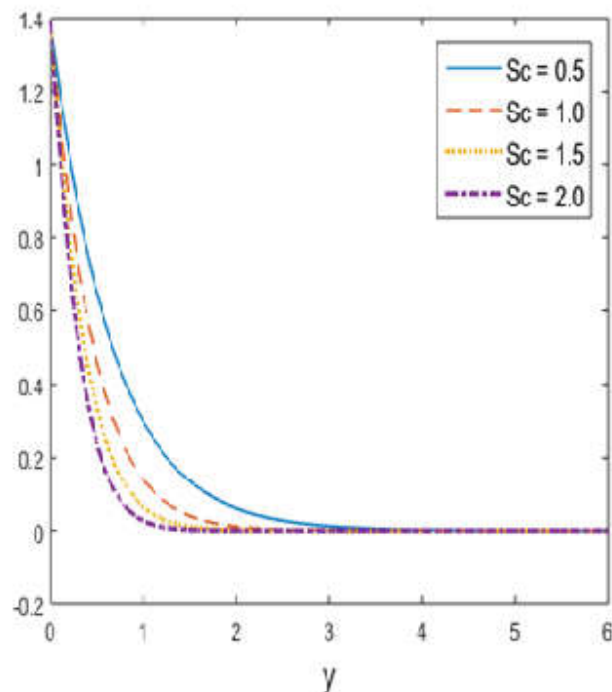


FIGURE 2. Effect of Sc on concentration profile

Temperature profile:

Fig 3, is drawn to see the impact of Radiation parameter N . It is noted that an expansion is N results in an increase in temperature.

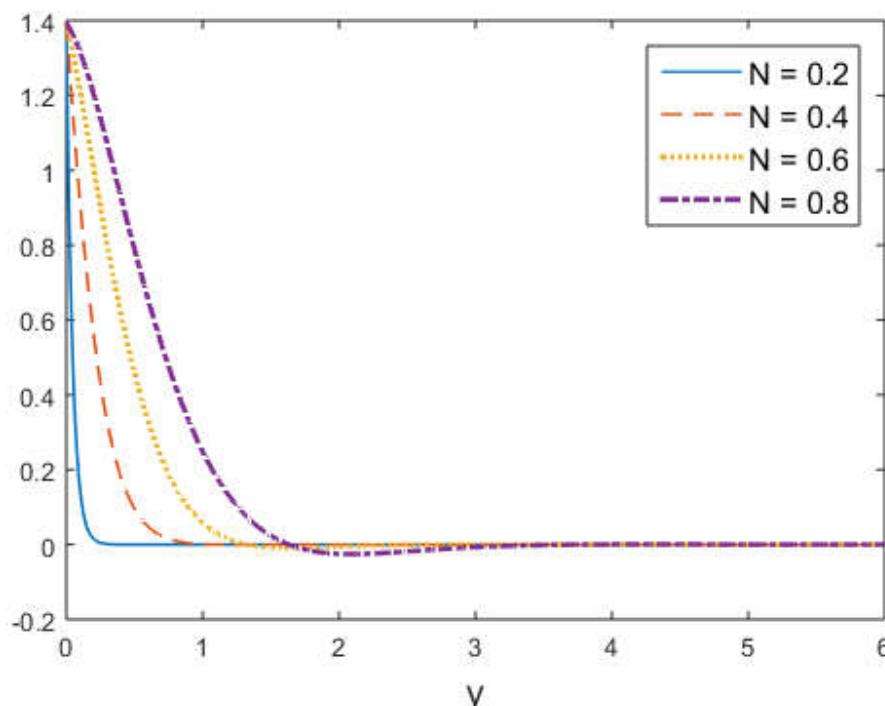


FIGURE 3. Effect of N on temperature profile

CONCLUSION

1. When the fluid flow velocity raises with Eckert number, With an increase in the chemical reaction parameter, Pr and the Grashof number decrease.
2. In some circumstances, the velocity reaches a maximum near the surface and then decreases
3. If temperature profiles for +ve values of E , K , and Gr change, the curves for large +ve values of the above parameter show hills, and the curves for large +ve values of the above parameter show hills.
4. 4. Because the chemical reaction parameter values have increased, the concentration has decreased. In the presence of a generative reaction, the concentration rises.
5. A destructive chemical reaction lowers the temperature of the fluid, whereas a generative reaction raises it.
6. In the porous media, the surplus heat produced during the generative first order homogenous chemical reaction is decreased.

The current study of the mechanics of fluid flow over a vertical surface can be used as a foundation for a variety of scientific and practical applications, as well as for tackling increasingly complex vertical surface problems.

NOTATIONS

C, concentration, mol/m³; C, fluid concentration far away from the wall, mol/m³; c_p, specific heat at a constant pressure, J/(kgdeg); c_p, specific heat at a constant pressure, J/(kgdeg); c_p, specific heat at a constant pressure, J/(kgdeg); c_p, specific heat at a constant pressure m²/sec, mass diffusivity; D, mass diffusivity; G_c, mass; E, Eckert number k, nondimensional permeability coefficient of a porous medium; k₀, nondimensional rate of a chemical reaction; k_c, rate of chemical reaction, sec⁻¹; k_p, permeability of a porous medium, m²; g, gravitational acceleration, m/sec²; g, gravitational acceleration, m/sec²; g, gravitational acceleration, m/sec²; g, gravitational acceleration, m/sec N is the Nusselt number, Pr is the Prandtl number, and Sc is the Schmidt number. u, v velocity components, m/sec; u, nondimensional velocity; v₀, suc; T, fluid temperature,

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