# A Study on free convective heat and mass transfer flow through a highly porous medium with radiation, chemical reaction and Soret effects

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**Abstract:** The paper addresses the effects of Soret on unsteady free convection flow of viscous incompressible fluid through a porous medium with high porosity bounded by a vertical infinite moving plate under the influence of thermal radiation, chemical reaction and heat source. The fluid is considered to be gray, absorbing, and emitting but non-scattering medium, and Rosseland approximation is considered to describe the radiative heat flux in the energy equation. The dimensionless governing equations for this investigation are solved analytically using perturbation technique. The effects of various governing parameters on the velocity, temperature, concentration, skin-friction coefficient, Nusselt number and Sherwood number are shown in figures and tables and analyzed in detail. It was noticed that velocity distribution increased with increasing buoyancy parameters, temperature decreased with increasing Prandtl number and concentration decreased with increasing the Schmidt number and chemical reaction parameter.

**Keywords:** Soret; thermal radiation; free convection; chemical reaction; heat source; highly porous.

## 1.Introduction:

Convective heat and mass transfer in porous media has been a subject of great interest for the last few decades. This interest was motivated by numerous thermal engineering applications in various disciplines, such as geophysical, thermal and insulation engineering, modelling of packed sphere beds, the cooling of electronic systems, chemical catalytic reactors, ceramic processes, grain storage devices fibre and granular insulation, petroleum reservoirs, coal combustors, ground water pollution and filtration processes. Raptis [1] proposed the presence of magnetic field through a porous medium. Natural convection from an isothermal vertical surface embedded in a thermally stratified high-porosity medium was investigated by Chen and Lin [2]. Hayat et al. [3] presented the heat and mass transfer and slip flow of a second grade fluid past a stretching sheet through a porous space. Sreevani [4] presented the heat and mass transfer of mixed convective flow through a porous medium in channels with dissipative effects. Flow with convective acceleration through a porous medium was studied by Yamamoto and lwamura [5].

Many processes in new engineering areas occur at high temperature as knowledge of radiative heat and mass transfer become very important for the design of the pertinent equipment. Nuclear power plants, gas turbines and various propulsion devices for aircrafts, missiles, satellites and space vehicles are the examples of such engineering areas. The study of radiation effects on various types of flows is quite complicated. Makinde [6] analyzed heat and mass transfer and thermal radiation of free convective flow of past a moving vertical porous plate. The presence of radiation and heat and mass transfer flow past a plate was derived by Raptis and Massals [7]. Chamkha et al.[8] presented the effects of radiation on free convection flow past a semi-infinite vertical plate with mass transfer. Prasad et al. [9] investigated the effect of radiation, heat and mass transfer on two dimensional past an impulsively started infinite vertical plate. Free convective flow with the effects of radiation from a porous vertical plate was studied by Hossain et al.[10].

The study of heat generation or absorption in moving fluid is important in problems dealing with dissociating fluids. Possible heat generation effect may alter the temperature distribution; consequently, the particle deposition rate in nuclear reactors, electronic chips and semiconductor wafers. Olanrewaju et al.[11] discovered the effect of internal heat generation, thermal boundary layer with a convective surface boundary condition. Rahman et al.[12] prepared thermo-micropolar fluid flow along a vertical permeable plate with uniform surface heat flux in the presence of heat generation. Radiation effects of heat source/sink and work done by deformation on the flow and heat transfer of a viscoelastic fluid over a stretching sheet was noticed by Bataller [13]. Raptis [14] proposed the effects on heat and mass transfer of free convection flow past an infinite moving vertical porous plate with constant suction and heat source. Hussain et al.[15] derived the effects of radiation on mixed convection along a vertical plate in presence of heat generation or absorption .

Chemical reaction can be codified as either heterogeneous or homogeneous process. This depends on whether they occur at an interface or as a single phase volume reaction. Sudheer babu and Satya Narayana [16] derived the chemical reaction and radiation absorption effects on free convection flow through porous medium with variable suction in the presence of uniform magnetic field. Unsteady MHD free convection and chemical reaction flow past an infinite vertical porous plate was studied by Raju et al.[17]. Patil and Kullkarni [18] investigated chemical reaction effect of free convective flow of a polar fluid through a porous medium in the presence of internal heat generation. Muthukumaraswamy and Ganesan [19] examined diffusion and first order chemical reaction on impulsively started infinite vertical plate with variable temperature. The analysis of heat and mass transfer, chemical reaction along a wedge with heat source and concentration in the presence of suction or injection was presented by Kandaswamy et al.[20]. Ibrahim [21] examined the effects of chemical reaction and radiation on free convective flow through a highly porous medium under the influence of heat generation.

Soret is the thermal-diffusion effect, for instance, has been utilized for isotope separation and in mixtures between gases with very light molecular weight ($H_2$, $H_e$) and of medium molecular weight ($N_2$, air). Hari Mohan [22] presented the Soret effect on the rotator thermosolutal convection of the veronis type. Plattern and Charepeyer [23] represented the Soret effect of oscillatory motion in Bernard cell. Soret and chemical reaction effects on magnetohydrodynamic free convective water's memory flow with constant suction and heat sink was derived by Pavan kumar etal.[24]. David Jacqmin [25] derived parallel flows with Soret effect in tilted cylinders.Hurle and Jakeman [26] presented significance of the Soret effect in the Rayleigh-Jeffrey's problem.

Motivated by the above literatures and applications, the present paper explores heat and mass transfer by free convection from a vertical infinite moving plate saturated highly porous medium. The problem is in the presence of thermal radiation, heat source, and chemical reaction and has a Soret number. The governing equations are solved analytical using perturbation method. The results are presented graphically and in tabular form and the different physical aspects of the problem have been discussed.

## 2.Mathematical Analysis

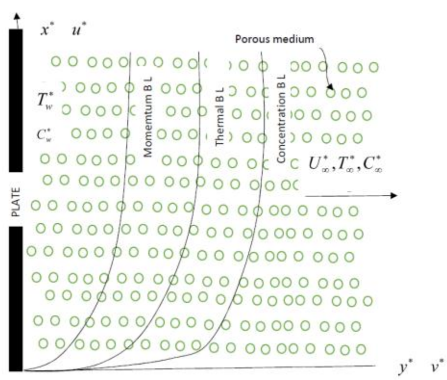


Fig. 1. Flow configuration of the problem

An unsteady two-dimensional laminar free convective mass transfer flow of a viscous incompressible fluid through a highly porous medium past an infinite vertical moving porous plate in the presence of thermal radiation, heat generation, chemical reaction and soret is considered.The fluid and the porous structure are assumed to be in local thermal equilibrium.It is also assumed that there is radiation only from the fluid [21, 28, 29]. The fluid is a gray,emitting,and absorbing,but non-scattering medium, and the Rosseland approximation is used to describe the radiative heat flux in the energy equation. A homogeneous first order chemical reaction between fluid and the species concentration is considered,in which the rate of chemical reaction is directly proportional to the species concentration. All the fluid properties are assumed to be constant except that the influence of the density variation with temperature is considered only in the body force term (Boussinesq's approximation) [21, 28, 29]. The $x^*$-axis is chosen along the plate in the direction opposite to the direction of gravity and the $y^*$-axis is taken normal to it (See Fig. 1). Since the flow field is of extreme size, all the variables are functions of $y^*$ and $t^*$ only. Hence, under the usual Boussinesq's approximation, the equations of mass, linear momentum, energy, and diffusion are

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

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

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

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

Where $x^*, y^*$ and $t^*$ are the dimensional distances along and perpendicular to the plate and dimensional time , respectively; $u^*$, and $v^*$ the components of dimensional velocities along $x^*$ and $y^*$ directions, respectively; $C^*$ and $T^*$ the dimensional concentration and temperature of the fluid, respectively; $\rho$ the fluid density; $\upsilon$ the kinematic viscosity; $C_p$ the specific heat at constant pressure; $\sigma$ the heat capacity ratio; $g$ the acceleration due to gravity; $\beta$ and $\beta^*$ the volumetric coefficient of thermal and concentration expansion; $k^*$ the permeability of the porous medium; $\varphi$ the porosity; $D$ the molecular diffusivity; $Kr^*$ the chemical reaction parameter; and $k$ the fluid thermal conductivity , $D_1$ is the Soret number .The third and fourth terms on the right hand side of the momentum equation (2) denote the thermal and concentration buoyancy effects, respectively and the fifth term represents the bulk matrix linear resistance, that is,Darcy term. Also, the second term on the right hand side of the enegry equation (3) represens thermal radiation. The radiative heat flux term by using the Resseland approximation (Brewster[27]) is given by

$$q_r = \frac{-4\sigma_s}{3k_e}\frac{\partial T^{*4}}{\partial y^*} \tag{5}$$

Where $\sigma_s$ is the Stefan-Boltzman constant and $K_e$ is the men absorption coefficient. It should be noted that by using the Rosseland approximation, the present analysis is limited to optically We assume that the temperature difference within the flow are sufficiently small such that $T^4$ may be expressed as a linear function of the temperature. This is accomplished by expanding in a Taylor series about $T_\infty$ and neglecting higher-order terms, thus

$$T^{*4} \cong 4T_\infty^{*3}T^* - 3T_\infty^{*4} \tag{6}$$

It is assumed that the permeable plate moves with constant velocity in the direction of fluid flow. It is also assumed that the plate temperature and concentration are exponentially varying with time. Under these assumptions, the appropriate boundary conditions for the velocity, temperature, and concentration fields are

$$u^* = U_p^*,\ T^* = T_w^* + \varepsilon(T_w^* - T_\infty^*)e^{n^*t^*},$$

$$C^* = C_w^* + \varepsilon(T_w^* - T_\infty^*)e^{n^*t^*} \text{ at } y^* = 0, \tag{7}$$

$$u^* \to U_\infty^*, T^* \to T_\infty^*, C^* \to C_\infty^*, \text{ as } y^* \to \infty$$

Where $U_p^*$ is the wall dimensional velocity; $C_w^*$ and $T_w'$ are the wall dimensional concentration, and temperature, respectively; $U_\infty^*$, $C_\infty^*$ and $T_\infty^*$ are the free stream dimensional velocity, concentration and temperature, respectively; and $n^*$ is the constant.

It is clear from (1) that the suction velocity normal to the plate is either a constant or a function of time. Hence the suction velocity normal to the plate is taken as

$$v^* = -v_0 \tag{8}$$

Where $v_0$ is a scale of suction velocity which is a nonzero positive constant. The negative sign indicates that the suction is towards the plate.

Outside the boundary layer, (2) gives

$$\frac{1}{\rho}\frac{dp^*}{dx^*} = -\frac{\varphi\upsilon}{K^*}U_\infty^* \tag{9}$$

To render dimensionless solutions and facilitate analytical analysis, we define the following dimensionless variables:

$$u = \frac{u^*}{U_\infty^*}, y = \frac{y^* v_0}{\upsilon}, U_p = \frac{U_p'}{U_\infty'}, n = \frac{n^*\upsilon}{v_0^2},$$

$$t = \frac{t^* v_0^2}{\upsilon}, \lambda = \frac{\sigma}{\varphi}, \theta = \frac{T^* - T_\infty^*}{T_w^* - T_\infty^*}, \tag{10}$$

$$C = \frac{C^* - C_\infty^*}{C_w^* - C_\infty^*}.$$

In view of (5)-(10),(2)-(4) reduce to the following non-dimensional form:

$$\frac{\partial u}{\partial t} - \frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + Gr\theta + GcC + \frac{1}{k}(1-u) \tag{11}$$

$$\lambda\frac{\partial \theta}{\partial t} - \frac{\partial \theta}{\partial y} = \frac{1}{\Gamma}\frac{\partial^2 \theta}{\partial y^2} + Q\theta \tag{12}$$

$$\frac{\partial C}{\partial t} - \frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - KrC + So\frac{\partial^2 \theta}{\partial y^2} \tag{13}$$

The corresponding dimensionless boundary conditions are

$$u = U_p,\ \theta = 1 + \varepsilon e^{nt},\ C = 1 + \varepsilon e^{nt} \text{ at } y = 0,$$

$$u \to 1, \theta \to 0, C \to 0 \text{ as } y \to \infty.$$

Where $\Gamma = \frac{3R\Pr}{3R+4}$, $Gr = \frac{g\beta\upsilon\left(T_w^* - T_\infty^*\right)}{U_\infty^* v_0^2}$ is thermal Grashof number, $Gc = \frac{g\beta^*\upsilon\left(C_w^* - C_\infty^*\right)}{U_\infty^* v_0^2}$ is solutal Grashof number, $k = \frac{k^* {v_0}^2}{\varphi\upsilon^2}$ permeability of porous parameter, $\Pr = \frac{\rho C_p \varphi\upsilon}{k}$ is Prandtl number, $R = \frac{K_e k}{4\varphi\sigma_s {T_\infty}^3}$ is thermal radiation parameter, $Q = \frac{Q_0 v}{\varphi\rho C_p {v_0}^2}$ is heat source parameter, $Sc = \frac{\upsilon}{D}$ is Schmidt number, $Kr = \frac{Kr^*\upsilon}{v_0^2}$ is the chemical reaction parameter and $So = \frac{D_1\left({T_w}^* - {T_\infty}^*\right)}{\upsilon\left({C_w}^* - {C_\infty}^*\right)}$

### 3. Solution of the problem

Equations (11)-(13) are coupled, nonlinear partial differential equations and these cannot be solved in closed form. However, these equations can be reduced to a set of ordinary differential equations, which can be solved analytically. This can be done by representing the velocity, temperature, and concentration of the fluid in the neighborhood of the plate as

$$u(y,t) = u_0(y) + \varepsilon e^{nt} u_1(y) + 0(\varepsilon)^2 + \ldots\ldots,$$

$$\theta(y,t) = \theta_0(y) + \varepsilon e^{nt} \theta_1(y) + 0(\varepsilon)^2 + \ldots\ldots, \quad (14)$$

$$C(y,t) = C_0(y) + \varepsilon e^{nt} C_1(y) + 0(\varepsilon)^2 + \ldots\ldots,$$

Substituting (14) in equations (11) – (13), equating the harmonic and non-harmonic the higher order terms of $O\left(\varepsilon^2\right)$, we obtain

$$u_0'' + u_0' - \frac{1}{k}u_0 = -\frac{1}{k} - Gr\theta_0 - GcC_0$$

$$u_1'' + u_1' - M_1 u_1 = -Gr\theta_1 - GcC_1$$

$$\theta_0'' + \Gamma\theta_0' + \Gamma Q\theta_0 = 0$$

$$\theta_1'' + \Gamma\theta_1' + \Gamma \mathrm{M}_2\theta_1 = 0 \quad (15)$$

$$C_0'' + ScC_0' - ScKrC_0 = -ScS_0\theta_0''$$

$$C_1'' + ScC_1' - M_3 ScC_1 = -ScS_0\theta_1''$$

Where $M_1 = \frac{1}{k} + n$, $M_2 = Q - n\lambda$, $M_3 = Kr + n$

The prime denotes ordinary differentiation with respect to *y*.

The corresponding boundary conditions can be written as

$$u_0 = U_p,\ u_1 = 0,\ \theta_0 = 1,\ \theta_1 = 1,\ C_0 = 1,\ C_1 = 1$$

at *y=0*

$$\theta_1 \to 0,\ C_0 \to 0,\ C_1 \to 0 \ as\ y \to \infty \quad (16)$$

Solving (15) subject to boundary conditions (16), we obtained the velocity, temperature, and concentration distributions in the boundary layer as

$$u(y,t) = \left(A_7 e^{-m_5 y} + 1 - A_5 e^{-m_5 y} + A_6 e^{-m_1 y}\right) + \varepsilon e^{nt}\left(A_{10} e^{-m_6 y} - A_8 e^{-m_4 y} + A_9 e^{-m_2 y}\right) \quad (17)$$

$$\theta(y,t) = \left(e^{-m_1 y}\right) + \varepsilon e^{nt}\left(e^{-m_2 y}\right) \quad (18)$$

$$C(y,t) = \left(A_2 e^{-m_3 y} - A_1 e^{-m_1 y}\right) + \varepsilon e^{nt}\left(A_4 e^{-m_4 y} + A_3 e^{-m_2 y}\right) \quad (19)$$

Where the expressions for the constants are given in the appendix.

The skin-friction, Nusselt number, and Sherwood number are important physical parameters for this type of boundary layer flow. These parameters can be defined and determined as follows.

Knowing the velocity field, skin-friction at the plate can be obtained, which in non-dimensional form is given by

$$Cf = \frac{\tau'}{\rho U_0 v_0} = \left(\frac{\partial u}{\partial y}\right)_{y=0} = \left(\frac{\partial u_0}{\partial y} + \varepsilon e^{nt}\frac{\partial u_1}{\partial y}\right)_{y=0}$$

$$= \begin{matrix}\left(-m_5 A_7 + m_3 A_5 - m_1 A_6\right) + \\ \varepsilon e^{nt}\left(-m_6 A_{10} + A_8 m_4 - A_9 m_2\right)\end{matrix}$$

Knowing the temperature field, the rate of heat transfer coefficient can be obtained ,which in the non-dimensional form, in term of the number, is given by

$$\mathrm{Nu} = -x\frac{\left(\frac{\partial T}{\partial y'}\right)_{y'=0}}{\left(T'_w - T'_\infty\right)} \Rightarrow Nu\,\mathrm{Re}_x^{-1}$$

$$= -\left(\frac{\partial \theta}{\partial y}\right)_{y=0}$$

$$= -\left(\frac{\partial \theta_0}{\partial y} + \varepsilon e^{nt}\frac{\partial \theta_1}{\partial y}\right)_{y=0}$$

$$= m_1 + \varepsilon e^{nt} m_2$$

Knowing the concentration field, rate of mass transfer coefficient can be obtained, which in the non-dimensional form, in terms of the Sherwood number, is given by

$$\mathrm{Sh} = -x\frac{\left(\frac{\partial C}{\partial y'}\right)_{y'=0}}{\left(C'_w - C'_\infty\right)} \Rightarrow Sh\,\mathrm{Re}_x^{-1}$$

$$= -\left(\frac{\partial C}{\partial y}\right)_{y=0}$$

$$= -\left(\frac{\partial C_0}{\partial y} + \varepsilon e^{nt}\frac{\partial C_1}{\partial y}\right)_{y=0}$$

$$= \left(m_3 A_2 - m_1 A_1\right) + \varepsilon e^{nt}\left(m_4 A_4 - m_2 A_3\right)$$

Where $\mathrm{Re}_x = v_0 x / v$ is the local Reynolds number.

**4.Results and Discussion:**

The system of ordinary differential equations (15) with boundary conditions (16) is solved analytically by employing the Perturbation technique. The solutions are obtained for the steady and unsteady velocity, temperature and concentration fields from the given by (17)-(19).The expressions obtained in previous section are studied with the help of graphs from Figs. 2-10 and Tables 1-3. The effects of various physical parameters viz., the thermal Grashof number *Gr*, the solutal Grashof number *Gc*, Prandtl number *Pr*, Schmidt number *Sc*, the radiation parameter *R*, the permeability of the porous medium *k*, the heat generation parameter *Q*, the chemical reaction parameter *Kr* and the Soret number *So*. In the present study the following default parametric values are adopted: *Gr=2.0, Gc=2.0, k=5.0,* $\lambda$ *=1.4, Sc=0.2, R=5.0, Kr=2.0, Q=0.1, Pr=0.71, So=0.5, Up=0.4, A=0.5, t=1.0, n=0.1,* and $\varepsilon$ *=0.01.*

It is evident from Fig. 2 that greater cooling of surface, an increase in thermal Grashof number *Gr*, and in solutal Grashof number *Gc* result in an increase in the velocity. The thermal Grashof number *Gr* signifies the relative effect of the thermal buoyancy force to the viscous hydrodynamic force in the boundary layer. The solutal Grashof number *Gc* is the ratio of the species buoyancy force to the viscous hydrodynamic force. It is due to the fact that the increase in the values of thermal Grashof number *Gr*, and an increase in solutal Grashof number *Gc* has the tendency to increase the thermal and mass buoyancy effect.

The effect of the permeability of the porous medium *k*, and the radiation parameter *R* on the velocity field are shown in Fig. 3. The radiation parameter *R* defines the relative contribution of conduction heat transfer to thermal radiation transfer. It is seen from this figure that the velocity increases with the increase of permeability of the porous medium *k*, while it decreases with the increase of radiation parameter *R*.

The variation of Prandtl number *Pr* and heat generation *Q* on the velocity and temperature fields are shown in the Figs. 4 and 7. From these figures it is observed that velocity and temperature decreases when Prandt number *Pr* increases, where as they increases when heat generation *Q* increases. The reason is that conductivity of the fluid and therefore heat is able to diffuse away from the heated surface more rapidly for higher values of Prandtl number. Hence in the case of smaller Prandtl numbers the thermal boundary layer is thicker and the rate of heat transfer is reduced.

Figs. 5 and 9 show the variation of velocity and concentration profiles for various values of Schmidt number *Sc* and Soret number *So*. The Schmidt number embodies the ratio of the momentum to the mass diffusivity. The Schmidt number therefore quantifies the relative effectiveness of the momentum and mass transport by diffusion in the hydrodynamic (velocity) and concentration (species) boundary layers. It is observed from these figures that increasing in the values of *Sc*, decrease velocity and concentration distribution, and also this figures shows that increasing in the values of *So*, increases velocity and concentration distribution.

Figs. 6 and 10 display the dimensionless velocity and concentration profiles for different values of chemical reaction *Kr*. It can be seen that both velocity and the concentration profiles decreases with the increase of chemical reaction *Kr*. Fig. 8 depicts the temperature profiles for different values of radiation parameter *R* and it is observed that an increasing the radiation parameter *R* the temperature decreases.

The variation in local skin-friction coefficient, local couple stress, local Nusselt number and local Sherwood number for various parameters are investigated through tables 1 - 3. The behavior of theses physical parameters is self evident from tables 3 and 4 and hence they are not discussed any further to keep brevity.

For the validity of our work we have compared our results with the existing results of Ibrahim[ 21] in the absence of Soret number. Our result appears to be in good agreement with the existing results (see Table 4).

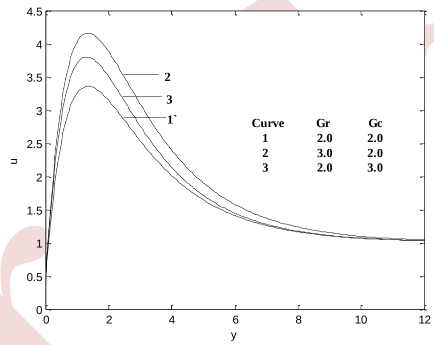


Fig-2.The graph of *u* against *y* for varies values of *Gr* and *Gc*.

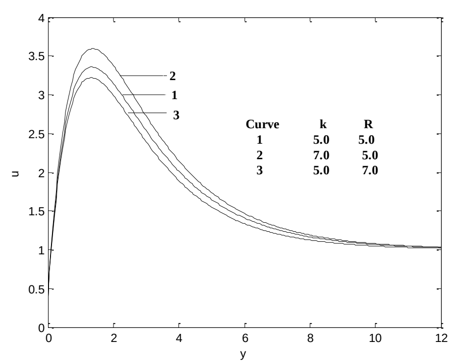


Fig-3.The graph of *u* against *y* for varies values of *k* and *R*.

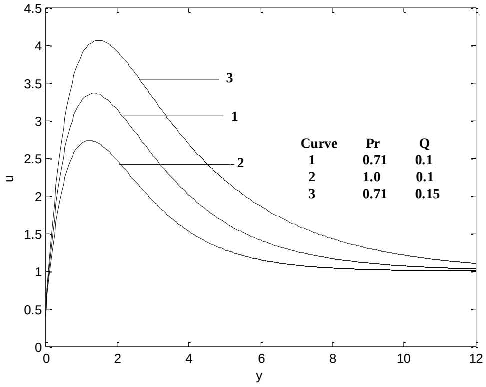


Fig-4.The graph of $u$ against $y$ for varies values of $Pr$ and $Q$.

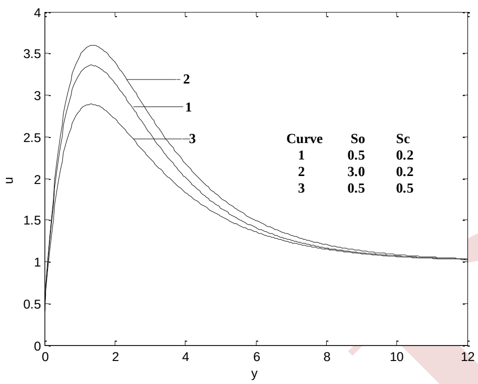


Fig-5.The graph of $u$ against $y$ for varies values of $So$ and $Sc$.

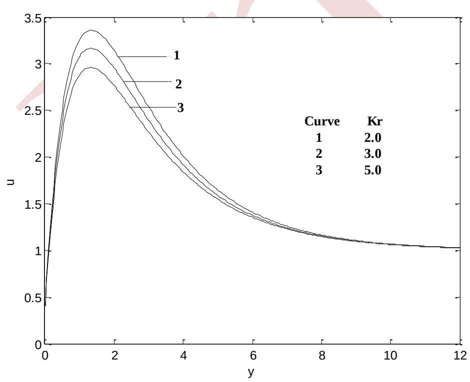


Fig-6.The graph of $u$ against $y$ for varies values of $Kr$.

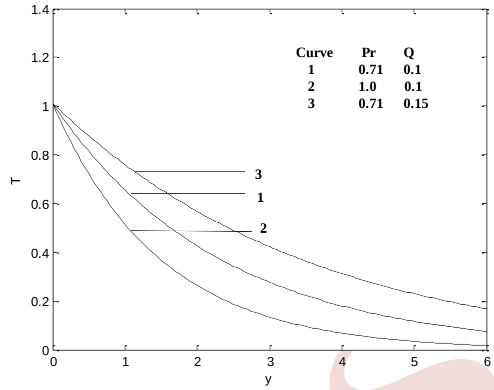


Fig-7.The graph of $T$ against $y$ for varies values of $Pr$ and $Q$.

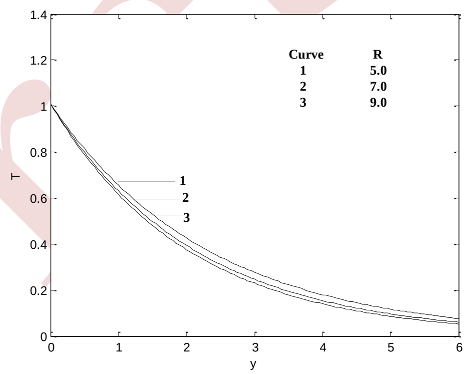


Fig-8.The graph of $T$ against $y$ for varies values of $R$.

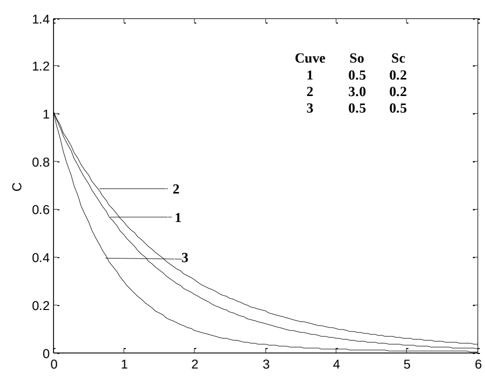


Fig-9.The graph of $C$ against $y$ for varies values of $So$ and $Sc$.

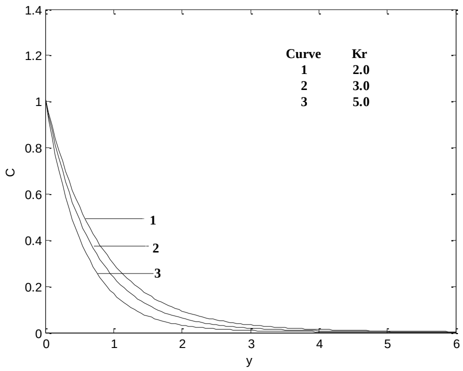


Fig-10.The graph of *C* against *y* for varies values of *Kr*.

Table 1: Effect of various physical parameter on Skin friction for $k=5.0$, $Q=0.1$, $\lambda=1.4, Pr=0.71, R=5.0, Sc=0.2, Kr=2.0, So=0.5, Up=0.4$ values.

| *Gr* | *Gc* | *K* | *Cf* | *Nu* | *Sh* |
|---|---|---|---|---|---|
| 2.0 | 2.0 | 5.0 | 6.3439 | 0.4369 | 0.7292 |
| 3.0 | 2.0 | 5.0 | 8.0208 | 0.4369 | 0.7292 |
| 4.0 | 2.0 | 5.0 | 9.6977 | 0.4369 | 0.7292 |
| 2.0 | 3.0 | 5.0 | 7.4878 | 0.4369 | 0.7292 |
| 2.0 | 4.0 | 5.0 | 8.6316 | 0.4369 | 0.7292 |
| 2.0 | 2.0 | 6.0 | 6.5443 | 0.4369 | 0.7292 |
| 2.0 | 2.0 | 7.0 | 6.7037 | 0.4369 | 0.7292 |

Table 2: Effect of various physical parameter on Skin friction for $Gr=2.0, Gc=2.0, k=5.0$, $\lambda=1.4, Sc=0.2, Kr=2.0, So=0.5, Up=0.4$ values.

| *Pr* | *R* | *Q* | *Cf* | *Nu* | *Sh* |
|---|---|---|---|---|---|
| 0.71 | 5.0 | 0.1 | 6.3439 | 0.4369 | 0.7292 |
| 1.0 | 5.0 | 0.1 | 5.4114 | 0.6811 | 0.7109 |
| 1.5 | 5.0 | 0.1 | 4.6688 | 1.0875 | 0.6763 |
| 0.71 | 6.0 | 0.1 | 6.2273 | 0.4594 | 0.7277 |
| 0.71 | 7.0 | 0.1 | 6.1449 | 0.4763 | 0.7265 |
| 0.71 | 5.0 | 0.01 | 5.8027 | 0.5577 | 0.7205 |

| | | | | | |
|---|---|---|---|---|---|
| 0.71 | 5.0 | 0.015 | 5.8225 | 0.5525 | 0.7209 |

Table 3: Effect of various physical parameter on Skin friction for *Gr=2.0,Gc=2.0,k=5.0,Q=0.1,* $\lambda$ *=1.4,Pr=0.71,R=5.0,Up=0.4* values.

| *Sc* | *Kr* | *S0* | *Cf* | *Nu* | *Sh* |
|---|---|---|---|---|---|
| 0.2 | 2.0 | 0.5 | 6.3439 | 0.4369 | 0.7292 |
| 0.3 | 2.0 | 0.5 | 5.9556 | 0.4369 | 0.9231 |
| 0.4 | 2.0 | 0.5 | 5.7103 | 0.4369 | 1.0962 |
| 0.2 | 3.0 | 0.5 | 6.0305 | 0.4369 | 0.8739 |
| 0.2 | 4.0 | 0.5 | 5.8254 | 0.4369 | 0.9958 |
| 0.2 | 2.0 | 0.6 | 6.3580 | 0.4369 | 0.7254 |
| 0.2 | 2.0 | 0.7 | 6.3721 | 0.4369 | 0.7215 |

Table 4. Computations showing comparison with Ibrahim [21] results for $Gc = 2.0$, $K= 5.0$, $\lambda =1.4$, $Pr = 0.71$, $R = 5.0$, $Kr = 2.0$, $Q = 0.1$, $U_p = 0.4$, $A = 0.5$, $t = 1.0$, $n = 0.1$, $\varepsilon = 0.01$ and $S0 = 0.0$.

| | | | Ibrahim [21] | | | Present result | | |
|---|---|---|---|---|---|---|---|---|
| Gr | Pr | Sc | *Cf* | *Nu* | *Sh* | *Cf* | *Nu* | *Sh* |
| 2.0 | 0.71 | 0.2 | 6.2735 | 0.4369 | 0.7487 | 6.2735 | 0.4369 | 0.7487 |
| 3.0 | 0.71 | 0.2 | 7.9503 | 0.4369 | 0.7487 | 7.9503 | 0.4369 | 0.7487 |
| 2.0 | 1.0 | 0.2 | 5.3134 | 0.6811 | 0.7487 | 5.3134 | 0.6811 | 0.7487 |
| 2.0 | 0.71 | 0.6 | 5.3141 | 0.6811 | 1.4519 | 5.3141 | 0.6811 | 1.4519 |

**Conclusion**

In this paper a theoretical analysis has been done to study the effects of chemical reaction and Soret effects on free convective heat and mass transfer flow through a highly porous medium in presence of chemical reaction. The results obtained are in agreement with the usual flow. It has been noticed that the velocity in boundary layer increases with buoyancy parameters. It is also observed the velocity and concentration increases with decreasing Schmidt number and chemical reaction parameter. It is found that the effect of increasing values of *Gr, Gc, k, Q* and *So* is to increase skin-friction factor. Nusselt number increase in the values of *Pr* and *R*. In addition, the value of Sherwood number increases as *Sc* and *Kr.*

This work can further be extended by considering some more relevant fluid parameters like magnetic field parameter, Dufour number and Eckert number.

**Applications of the study:** This study is expected to be useful in understanding the influence of heat and mass transfer problems with chemical reaction are of importance in many processes and have, therefore received a considerable amount of attention in recent years. In processes such as drying, evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler, in chemical reaction engineering heat and mass transfer occur simultaneously.

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**Appendix**

$$m_1 = \frac{\Gamma + \sqrt{\Gamma^2 - 4Q\Gamma}}{2},$$

$$m_2 = \frac{\Gamma + \sqrt{\Gamma^2 - 4\Gamma M_2}}{2},$$

$$m_3 = \frac{Sc + \sqrt{Sc^2 + 4ScKr}}{2},$$

$$m_4 = \frac{Sc + \sqrt{Sc^2 + 4ScM_3}}{2},$$

$$m_5 = \frac{1+\sqrt{1+\left(\frac{4}{k}\right)}}{2},$$

$$m_6 = \frac{1+\sqrt{1+4M_1}}{2},$$

$$A_1 = \frac{m_1^{\,2} SoSc}{m_1^{\,2} - Scm_1 - ScKr},$$

$$A_2 = 1 + A_1,$$

$$A3 = \frac{m_2^{\,2} SoSc}{m_2^{\,2} - Scm_2 - ScM_3},$$

$$A_4 = 1 + A_3,$$

$$A_5 = \frac{GcA_2}{m_3^{\,2} - m_3 - (1/k)},$$

$$A_6 = \frac{GcA_1 - Gr}{m_1^{\,2} - m_1 - (1/k)},$$

$$A_7 = U_p - 1 + A_5 - A_6,$$

$$A_8 = \frac{GcA_4}{m_4^{\,2} - m_4 - M_1},$$

$$A_9 = \frac{GcA_3 - Gr}{m_2^{\,2} - m_2 - M_1},$$

$$A_{10} = A_8 - A_9,$$