ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
Tome XVIII [2020] | Fascicule 3 [August]

ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
ISSN 1584 - 2665 (printed version); ISSN 2601 - 2332 (online); ISSN-L 1584 - 2665

[1.]Mopuri OBULESU, [2.]Racharla SIVA PRASAD

# HALL CURRENT EFFECTS ON MHD CONVECTIVE FLOW PAST A POROUS PLATE WITH THERMAL RADIATION, CHEMICAL REACTION WITH THERMOPHORESIS

[1-2.]Department Mathematics, Sri Krishnadevaraya University, Anantapur, INDIA

**Abstract:** In this paper an attempt is made to study the chemical reaction and combined buoyancy effects of thermal and mass diffusion on MHD convective flow along an infinite vertical porous plate in the presence of Hall current with variable suction and Soret effect. A uniform magnetic field is applied in a direction normal to the porous plate. The equations governing the fluid flow are solved using the perturbation technique and the expressions for the velocity, the temperature and the concentration distributions have been obtained. Dimensionless velocity, temperature and concentration profiles are displayed graphically for different values of the parameters entering into the problem have been investigated. It has been observed that an increase in the Soret parameter leads to an increase in the primary and secondary velocities, and also a increase in the concentration The primary and secondary velocities decrease with increase in the chemical reaction parameter and magnetic field parameter.

**Keywords:** MHD, Hall effect, Porous medium, Radiation, Chemical reaction, Heat generation/absorption, Soret effect

## 1. INTRODUCTION

The Hall effect is due to the nature of the current in a conductor. Current consists of the movement of many small charge carriers, typically electrons, holes, ions (see electro migration) or all three. When a magnetic field is present, these charges experience a force, called the Lorentz force. When such a magnetic field is absent, the charges follow approximately straight, 'line of sight' paths between collisions with impurities, phonons, etc. However, when a magnetic field with a perpendicular component is applied, their paths between collisions are curved, thus moving charges accumulate on one face of the material. The separation of charge establishes an electronic field that opposes the migration of further charge, so a steady electric potential is established for as long as the charge. Hall effects on unsteady MHD oscillatory free convective flow of second grade fluid through porous medium between two vertical plates was studied by Veera Krishna et al. [1]. Obulsu [2] studied Hall current effects on MHD convective flow past a porous plate with thermal radiation, chemical reaction and heat generation /absorption. Veera Krishna [3] studied Hall effects on unsteady MHD flow of second grade fluid through porous medium with ramped wall temperature and ramped surface concentration.

Thermophoresis (also thermomigration, thermo diffusion, the Soret effect, or the Ludwig–Soret effect) is a phenomenon observed in mixtures of mobile particles where the different particle types exhibit different responses to the force of a temperature gradient. Thethermophoretic force has a number of practical applications. The basis for applications is that, because different particle types move differently under the force of the temperature gradient, the particle types can be separated by that force after they've been mixed together, or prevented from mixing if they're already separated. Venkateswara Raju et al. [4] studied the thermophoresis effect on a radiating inclined permeable moving plate in the presence of chemical reaction and heat absorption. Venkateswara Raju [5] studied thermal diffusion and radiation effects on magneto-casson fluid flow past a vertical porous plate.

Recently researchers [6-8] showed interest in this area. In all the above studies Soret effect is not considered in the presence of Hall currents and chemical reaction as well as heat source /sink. Hence an attempt is made in this paper to address the issues related to Soret effect in the presence of Hall currents and chemical reaction as well as heat source /sink. This paper is an extension work to the paper of Obulesu and Sivaprasad [2] by considering Hall current effects on MHD convective flow past a porous plate with thermal radiation, chemical reaction and heat generation/absorption, along with thermal diffusion. K Raghunath et al. [9] have studied Heat and mass transfer on Unsteady MHD flow of a second grade fluid through porous medium between two vertical plates. Raghunath K et al. [10] Discussed Hall Effects on MHD Convective Rotating Flow of Through a Porous Medium past Infinite Vertical Plate. Raghunath k, et al. [11] have discussed Heat and mass transfer on MHD flow of Non-Newtonian fluid over an infinite vertical porous plate. Raghunath, et al. [12] have discussed Heat and mass transfer on an unsteady MHD flow through porous medium between two porous vertical plates.

## 2. FORMULATION OF THE PROBLEM

The transient MHD free connection flow of an electrically conducting fluid over a porous vertical infinite plate with variable suction and heat generation has been considered. The x- axis is assumed to be along the plate and the *y*- axis is normal to the plate.

We restrict our investigation to the following conditions:

(i) The induced magnetic field can be neglected as the transverse applied magnetic field and the magnetic Reynolds number are very small for metallic liquids and partially ionized fluids; no electric field is present as there is no applied voltage. However Hall Effect is considered due to the intension of the magnitude of applied magnetic field.

(ii) Soret effect is considered as the concentration of diffusing species is not small in comparison with other chemical species.

(iii) Temperature of the fluid governed by energy equation involving radiative heat flux, heat source/sink and species concentration equation involving chemical reaction and Soret effect of first order.

Under the Boussinesq's approximation and the boundary layer theory, the governing equations for the problem under consideration are:

≡ Continuity equation:

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

≡ Momentum equation:

$$\frac{\partial u^*}{\partial t^*}+V^*\frac{\partial u^*}{\partial y^*}=\frac{\partial U^*}{\partial t^*}+\vartheta\frac{\partial^2 u^*}{\partial y^{*2}}+g\beta\,(T^*-T_\infty^*)+gB^*(C^*-C_\infty^*)$$
$$-\frac{\sigma B_0^2}{\rho(1+m^2)}(u^*-U^*+mw^*)-\frac{\vartheta}{K}(u^*-U^*) \tag{2}$$

$$\frac{\partial w^*}{\partial t^*}+V^*\frac{\partial w^*}{\partial y^*}=\vartheta\frac{\partial^2 w^*}{\partial y^{*2}}+\frac{\sigma B_0^2}{\rho(1+m^2)}[m(u^*-U^*)-w^*]-\frac{\vartheta}{K}w^* \tag{3}$$

≡ Energy equation:

$$\frac{\partial T^*}{\partial t^*}+V^*\frac{\partial T^*}{\partial y^*}=\frac{K}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}}-\frac{1}{\rho C_p}\frac{\partial q_r^*}{\partial y^*}-\frac{Q}{\rho C_p}(T^*-T_\infty) \tag{4}$$

≡ Concentration equation:

$$\frac{\partial C^*}{\partial t^*}+V^*\frac{\partial C^*}{\partial y^*}=D\frac{\partial^2 C^*}{\partial y^{*2}}-K_r(C^*-C_\infty)+D_1\frac{\partial^2 T^*}{\partial y^{*2}} \tag{5}$$

The relevant boundary conditions are given as follows

$$\begin{aligned}&u^*=0,\quad w^*=0,\quad T^*=T_\infty+(T_w^*-T_\infty^*),\quad C^*=C_\infty+(C_w^*-C_\infty^*)\quad \text{at}\quad y^*=0\\&u^*\to U^*(t^*),\ w^*\to 0,\quad T^*\to T_\infty^*,\qquad C^*\to C_\infty^*\quad \text{as } y^*\to\infty\end{aligned} \tag{6}$$

The plate is subjected to a variable suction velocity with time so that we can replace $v^*=-v_0(1+\varepsilon e^{i\omega t})(\varepsilon<<1)$, where $v_0$ is the steady suction velocity.

On introducing the following non dimensional quantities

$$u=\frac{u^*}{U_0^*},\quad w=\frac{w^*}{U_0^*}\quad y=\frac{v_0^{*}y^*}{\vartheta},\quad t=\frac{t^*v_0^{*2}}{4\vartheta}\quad T=\frac{T^*-T_\infty}{T_w^*-T_\infty^*},\qquad \lambda=\frac{C^*-C_\infty}{C_w^*-C_\infty^*},$$
$$Pr=\frac{\mu C_p}{K},\quad Sc=\frac{\vartheta}{D},\quad M^2=\frac{\sigma B_0^2\vartheta}{\rho v_0^{*2}},G=\frac{\vartheta g\beta\ (T_W^*-T_\infty^*)}{U_0^*v_0^{*2}},\quad Gc=\frac{\vartheta g\beta^*(C_w^*-C_\infty^*)}{U_0^*v_0^{*2}} \tag{7}$$
$$K_1=\frac{Kv_0^{*2}}{\vartheta^2},\ U=\frac{U^*}{U_0^*},\ \xi=\frac{\vartheta K_r}{v_0^{*2}},\ \eta=\frac{4I_1\vartheta^2}{Kv_0^{*2}},\ \chi=\frac{Q\ v^2}{Kv_0^{*2}},\ S_0=\frac{D_1(T^*_w-T_\infty^*)}{\upsilon(C_w^*-C_\infty^*)},$$

We obtain the following equations in dimensionless form.

$$\frac{1}{4}\frac{\partial F}{\partial t}-(1+\varepsilon e^{i\omega t})\frac{\partial F}{\partial y}-\frac{\partial^2F}{\partial y^2}+\frac{M^2}{1+m^2}(F-U\ \ )(1-im)=\frac{1}{4}\frac{\partial U}{\partial t}+GT+Gc\lambda-\frac{(F-U)}{K_1} \tag{8}$$

$$\frac{Pr}{4}\frac{\partial T}{\partial t}-Pr(1+\varepsilon e^{i\omega t})\frac{\partial T}{\partial y}=\frac{\partial^2T}{\partial y^2}-\eta_1T \tag{9}$$

$$\frac{Sc}{4}\frac{\partial\lambda}{\partial t}-Sc(1+\varepsilon e^{i\omega t})\frac{\partial\lambda}{\partial y}=\frac{\partial^2\lambda}{\partial y^2}-Sc\xi\lambda\ +ScS_0\frac{\partial^2T}{\partial y^2} \tag{10}$$

where $F = u+iw$, $\eta_1=\eta+\chi$

The corresponding boundary conditions are

$$F=0,\ T=1,\ \lambda=1,\ \text{at } y=0$$
$$F\to v(t),\ T\to0,\ \lambda\to0,\ \text{as } y\to\infty \tag{11}$$

## 3. METHOD OF SOLUTION

To solve the nonlinear equations (8) to (10) with the boundary conditions (11), we assume that

$$F=(1-F_0)+\varepsilon(1-F_1)e^{i\omega t},\ U=1+\varepsilon e^{i\omega t},T=T_0+\varepsilon T_1e^{i\omega t},\lambda=\lambda_0+\varepsilon\lambda_1e^{i\omega t} \tag{12}$$

We now substitute equation (8) to (10) and equating the like terms, neglecting higher order terms in $\varepsilon$, we obtain

Zero order terms:

$$F_0''+F_0'-(\alpha_1+\frac{1}{K_1})F_0=G\,T_0+Gc\,\lambda_0 \tag{13}$$

$$T_0''+Pr\,T_0'-\ \eta_0T_0=0 \tag{14}$$

$$\lambda_0''+Sc\lambda_0'-\ Sc\xi\lambda_0=ScS_0T_0'' \tag{15}$$

First order terms:

$$F_1''+F_1'-(\alpha_1+\frac{i\omega}{4}+\frac{1}{K_1})F_1=-\frac{\partial F_0}{\partial y}+G\,\Gamma_1+Gc\,\lambda_1 \tag{16}$$

$$T_1''+Pr\,T_1'-(\eta_1-\frac{i\omega Pr}{4})T_1=-Pr\frac{\partial T_0}{\partial y} \tag{17}$$

$$\lambda_1''+Sc\lambda_1'-Sc(\xi+\frac{i\omega}{4})\lambda_1=-Sc\frac{\partial\lambda_0}{\partial y}-ScS_0\frac{\partial^2T_1}{\partial y^2} \tag{18}$$

The boundary conditions are

$$F_0=1,\ F_1=1,\ T_0=1,\ T_1=0,\ \lambda_0=1,\ \lambda_1=1,\ \text{at } y=0$$
$$F_0\to0,\ F_1\to0,\ T_0\to0,\ T_1\to0,\ \lambda_0\to0,\ \lambda_1\to0,\ \text{as } y\to\infty \tag{19}$$

In Equations (13) to (18), the primes denote the derivatives with respect to y. solving equations (13) to (18) subject to the boundary conditions (19), we obtain the Velocity, Temperature and Concentration field

$$\begin{aligned}F\ &=[1-(B_7e^{-A_1y}+B_8e^{-A_3y}+B_9e^{-A_5y})]\\&+\varepsilon[1-(B_{10}e^{-A_1y}+B_{11}e^{-A_2y}+B_{12}e^{-A_3y}+B_{13}e^{-A_4y}+B_{14}e^{-A_5y}+B_{15}e^{-A_6y})]e^{i\omega t}\end{aligned} \tag{20}$$

$$T=e^{-A_1y}+\varepsilon B_1(e^{-A_1y}-e^{-A_2y})e^{i\omega t} \tag{21}$$

$$\lambda\ =(1+B_2)e^{-A_3y}-B_2e^{-A_1y}+\varepsilon(B_3e^{-A_1y}+B_4e^{-A_2y}+B_5e^{-A_3y}+B_6e^{-A_4y})e^{i\omega t} \tag{22}$$

### — SKINFRICTION

The skin-friction coefficient ($\tau$) at the plate is:

$$\tau = \left(\frac{\partial F}{\partial y}\right)_{y=0}$$

$$\tau = (A_1B_7 + A_3B_8 + A_5B_9) + \varepsilon(A_1B_{10} + A_2B_{11} + A_3B_{12} + A_4B_{13} + A_5B_{14} + A_6B_{15})e^{i\omega t} \tag{23}$$

**— NUSSELT NUMBER**

The rate of heat transfer in terms of the Nusselt number is given by

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

$$Nu = A_1 + \varepsilon B_1(A_1 - A_2)l_3)e^{i\omega t} \tag{24}$$

**— SHERWOOD NUMBER**

The rate of mass transfer on the wall in terms of Sherwood number is given by

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

$$Sh = (A_3(1+B_2) - A_1B_2) + \varepsilon(A_1B_3 + A_2B_4 + A_3B_5 + A_4B_6)e^{i\omega t} \tag{25}$$

## 4. RESULTS AND DISCUSSION

In order to get a physical insight into the problem numerical calculations are carried out for the transient primary velocity u, the secondary velocity $w$, the temperature $T$ and concentration λ, in terms of the parameters Magnetic field parameter (M), Permeability parameter ($K_1$), Grash of number(G), Modified Grash of number(Gc), Schmidt number (*Sc*), Prandtl number (*Pr*),Heat absorption parameter (χ), Chemical reaction parameter (ξ), Hall parameter (*m*), Soret parameter($S_0$) and Radiation parameter (η) respectively. Throughout the computations we employ the Prandtl number Pr= 0.71, Grashoff number $G$ = 5, Modified Grashoff number Gc= 2, Schmidt number Sc= 0.22, Magnetic field parameter M=3, Radition parameter η=0.5, Heat absorption parameter χ=1, Chemical reaction parameter ξ=0.1, Hall parameter m=1 Permeability Parameter $K_1$= 0.5, Soret parameter $S_0$=1, ω = 5, ε = 0.01, and $\omega t=\pi/6$.

**— VELOCITY PROFILES**

Figures 1 to 8 display the effects of a magnetic field parameter (M), permeability parameter ($K_1$), Grash of number(G),modified Grash of number(Gc), Schmidt number (Sc), Prandtl number (*Pr*),heat absorption parameter (χ), chemical reaction parameter (ξ), Hall parameter (*m*), Soret parameter($S_0$) on primary and secondary velocity distributions respectively. From Figures 1 and 2, it is observed that an increase of magnetic field parameter leads to decrease in primary and secondary velocity fields. It is because that the application of transverse magnetic field will result a resistive type force (Lorentz force) similar to drag force which tends to resist the fluid flow and thus reducing its velocity. In Figures 3 and 4, we represent the velocity profiles for different values of permeability parameter ($K_1$). The flow field suffers a increase in the primary velocity and secondary velocity at all points in the presence of permeability parameter ($K_1$).

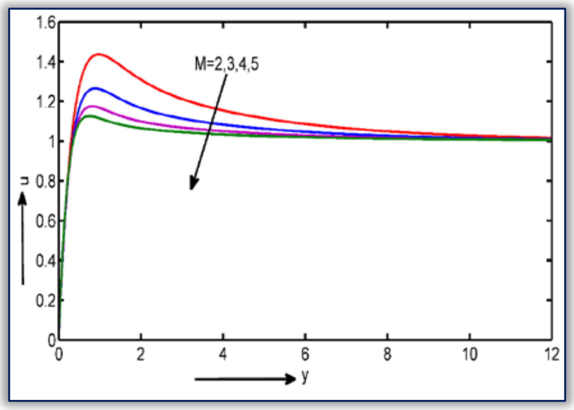


Figure 1: Effect of Magnetic Parameter on Primary Velocity

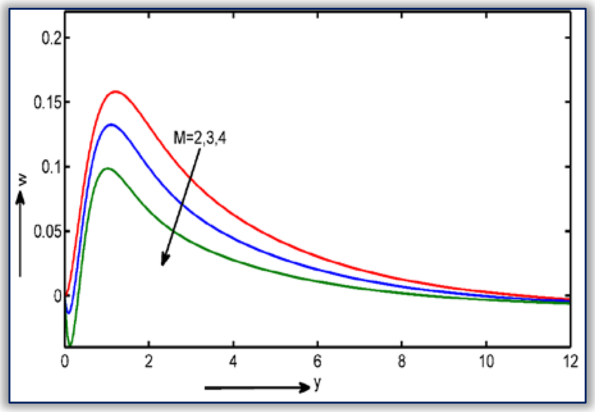


Figure 2: Effect of Magnetic Parameter on Secondary Velocity

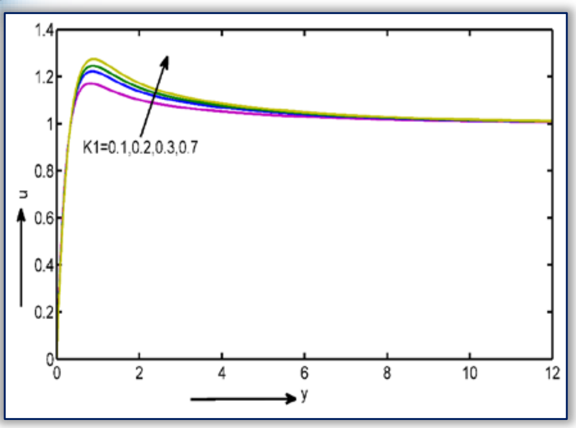


Figure 3: Effect of Permeability Parameter on Primary Velocity

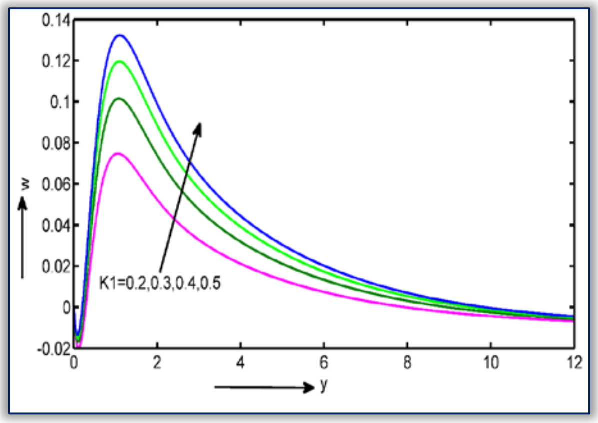


Figure 4: Effect of Permeability Parameter on Secondary Velocity

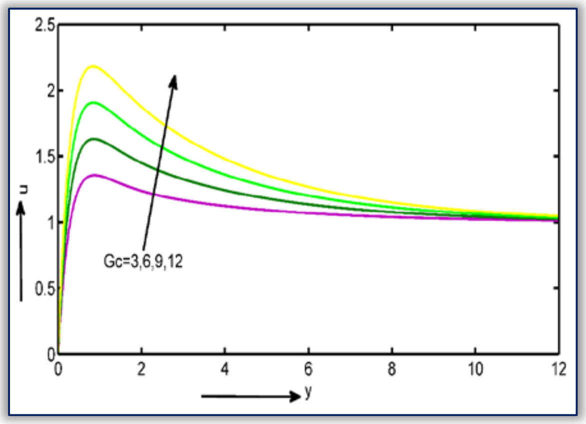


Figure 5: Effect of Modified Grashof Number on Primary Velocity

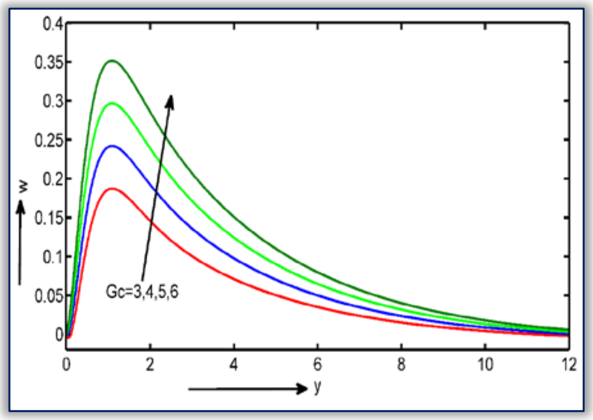


Figure 6: Effect of Modified Grashoff Number on Secondary Velocity

In Figures 5 and 6, we represent the velocity profiles for different values of Modified Grashof number (Gc). From this figures it is noticed that, velocity increases with increases in Modified Grashof number (Gc). It is seen from Figures 7 and 8 that Hall parameter (m) accelerates the both primary and secondary velocity field.

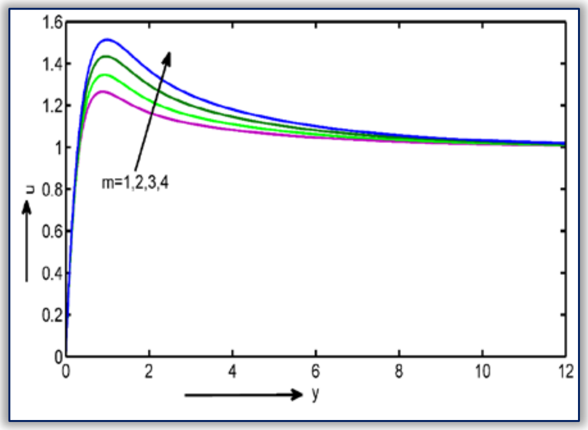


Figure 7: Effect of Hall Parameter on Primary Velocity

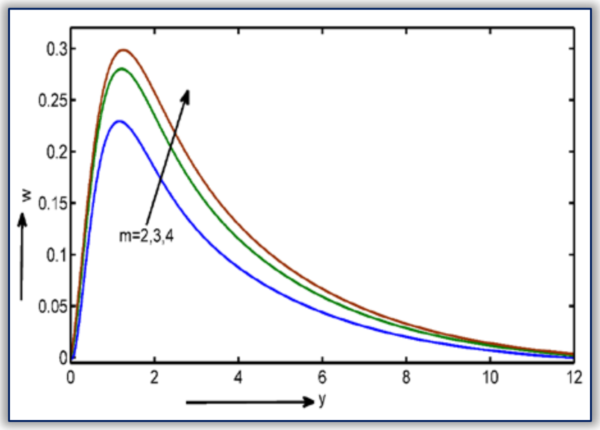


Figure 8: Effect of Hall Parameter on Secondary Velocity

## — TEMPERATURE PROFILES

Figures 9 to 11 show the effects of material parameters such as Pr, $\eta$ and $\chi$ on temperature distribution. The effect of Prandtl number is very important in temperature profiles. There is a decrease in temperatures due to increasing values of the Prandtl number (Pr) as shown in Figure 9. From Figure10, it is clear that temperature decreases with the increase in radiation parameter ($\eta$). In Figure11, the effect of heat absorption parameter ($\chi$) is shown on temperature profile. From this figure it is observed that temperature decreases with an increase in $\chi$.

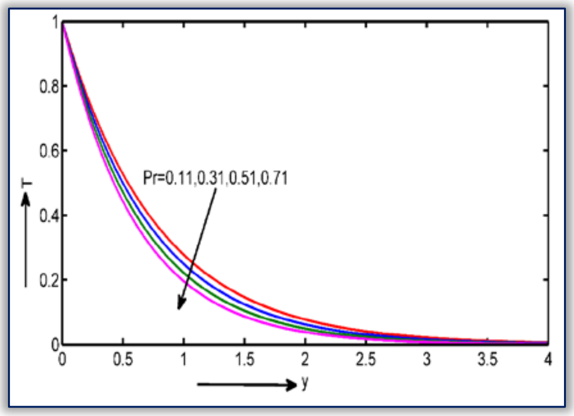


Figure 9: Effect of Prandtl Number on Temperature

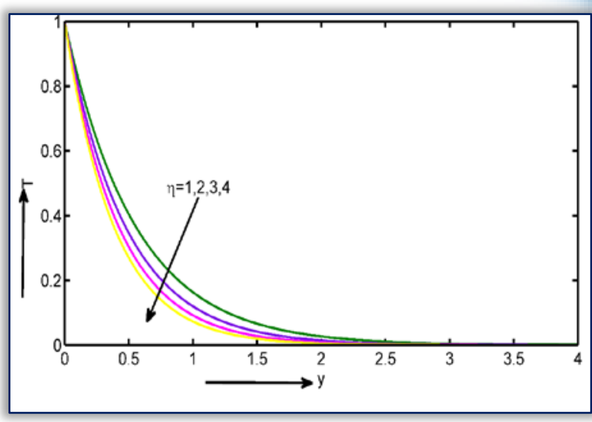


Figure 10: Effect of Radiation Parameter on Temperature

## — CONCENTRATION PROFILES

Figure12 depicts the variations in concentration profile for different values of Soret parameter ($S_0$). From this figure it is noticed that, concentration increases when So increases. Figures (13) and (14) show the effect of Schmidt number (Sc) and chemical reaction parameter (ξ) on concentration profile.

From Figures13-14, it is clear that concentration decreases with the increase in Schmidt number and chemical reaction parameter.

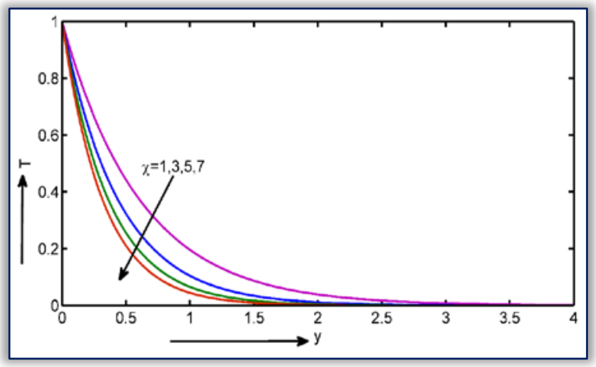


Figure 11: Effect of Heat absorption Parameter on Temperature

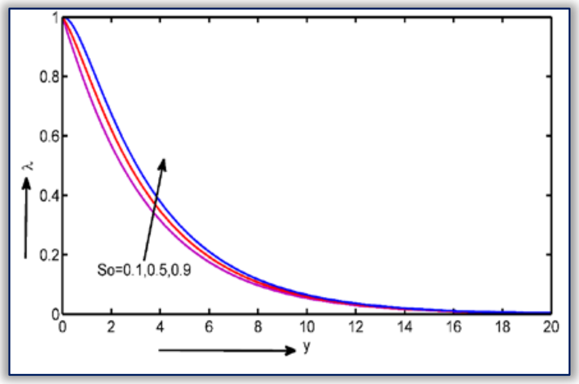


Figure 12: Effect of Soret Parameter on Concentration

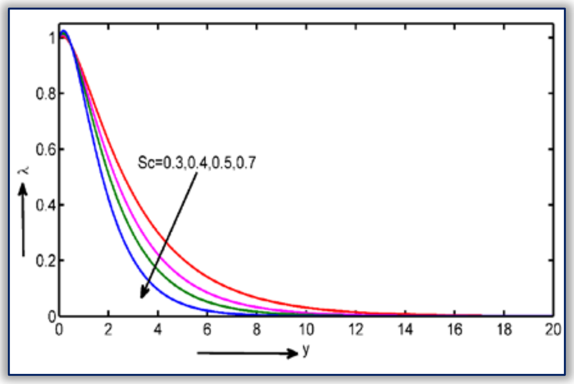


Figure 13: Effect of Schmidt Number on Concentration

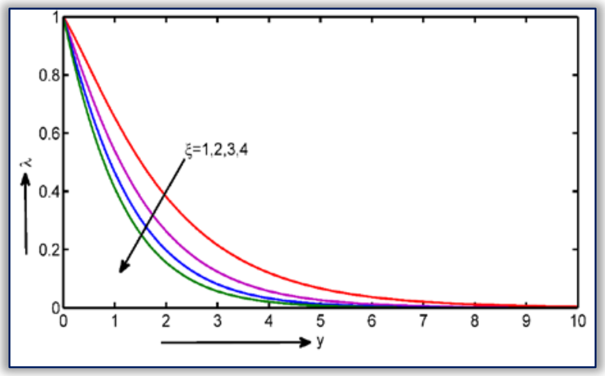


Figure 14: Effect of Chemical reaction Parameter on Concentration

Table – 1 shows numerical values of skin-friction for several of Prandtal number (Pr), heat absorption parameter (χ), chemical reaction parameter (ξ), Schmidt number (Sc) and magnetic parameter (M). From table 1, we observe that the skin-friction decreases with an increase heat absorption parameter (χ), chemical reaction parameter (ξ), Schmidt number (Sc), Prandtl number (Pr) and magnetic parameter (M).

Table-1: Variations in skin friction

| Pr | χ | ξ | Sc | M | $\tau$ |
|---|---|---|---|---|---|
| 0.3 | | | | | 5.3187 |
| 0.5 | | | | | 5.2844 |
| 0.71 | | | | | 5.2481 |
| | 1.5 | | | | 5.2007 |
| | 2 | | | | 5.1617 |
| | 2.5 | | | | 5.1285 |
| | | 0.2 | | | 5.2337 |
| | | 0.4 | | | 5.2128 |
| | | 0.6 | | | 5.1969 |
| | | 0.8 | | | 5.1838 |
| | | | 0.2 | | 5.2483 |
| | | | 0.3 | | 5.2475 |
| | | | 0.6 | | 5.2469 |
| | | | | 0.5 | 5.6120 |
| | | | | 1 | 5.4818 |
| | | | | 1.5 | 5.3269 |
| | | | | 2 | 5.2203 |

Table – 2 demonstrates the numerical values of Nusselt number (Nu) for different values of Prandtl number (Pr), heat absorption parameter (χ) and radiation parameter (η). From table 2, we noticed that the Nusselt number increases with an increase in Prandtl number (Pr), heat absorption parameter (χ) and radiation parameter (η).

Table 3 shows numerical values of Sherwood number (Sh) for the distinction values of Schmidt number (Sc), chemical reaction parameter (ξ) Soret parameter ($S_0$). It can be noticed from Table 3 that the Sherwood number enhances with rising values of Schmidt number, chemical reaction parameter and decreases with the increase in Soret parameter.

Table-2: Variations in Nusselt number

| Pr | χ | $\eta$ | Nu |
|---|---|---|---|
| 0.1 | | | 1.2759 |
| 0.5 | | | 1.5006 |
| 0.71 | | | 1.6309 |
| 7 | | | 7.2173 |
| | 2 | | 1.9764 |
| | 3 | | 2.2602 |
| | 4 | | 2.5068 |
| | 5 | | 2.7279 |
| | | 0.5 | 1.6309 |
| | | 0.6 | 1.6695 |
| | | 0.7 | 1.7071 |
| | | 0.8 | 1.7436 |

Table-3: Variations in Sherwood number

| Sc | ξ | So | Sh |
|---|---|---|---|
| 0.2 | | | 0.0347 |
| 0.3 | | | 0.0823 |
| 0.4 | | | 0.1321 |
| | 0.1 | | 0.0440 |
| | 0.4 | | 0.1123 |
| | 0.6 | | 0.1861 |
| | | 1 | -0.0440 |
| | | 2 | -0.3871 |
| | | 3 | -0.7302 |

## 5. CONCLUSIONS

In this problem, we have studied Hall current effects on MHD convective flow past a porous plate with thermal radiation, chemical reaction with Soret effect. In the analysis of the flow the following conclusions are made:

- The primary and secondary velocities increase with an increase in permeability parameter, Grashof number, modified Grashof number, Hall parameter and Soret parameter.
- The primary and secondary velocities decrease with an increase in magnetic parameter, Schmidt number, Prandtl number, heat absorption parameter and chemical reaction parameter.
- Temperature decreases with an increase in Prandtl number, radiation parameter, heat absorption parameter and increases with an increase in radiation absorption parameter (R).
- Concentration decreases with an increase in Schmidt number, chemical reaction parameter and increases with an increase.
- As significant decreases in seen in skin friction for increase heat absorption parameter, chemical reaction parameter, Schmidt number, Prandtl number, magnetic parameter.
- The rate of heat transfer increases with an increase Prandtl number, heat absorption parameter, radiation parameter.
- The rate of mass transfer increases with an increase Schmidt number, chemical reaction parameter and decreases with an Soret parameter.

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**ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering**
**ISSN 1584 - 2665 (printed version); ISSN 2601 - 2332 (online); ISSN-L 1584 - 2665**