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Combined Effects of Radiation, Chemical Reaction and Porosity of the Medium on MHD Flow Past Over Plate with Heat and Mass Transfer in the Presence of Hall Current

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Abstract*: In the present paper, we study the effects of radiation, chemical reaction and porosity of the medium on unsteady flow of a viscous, incompressible and electrically conducting fluid past an impulsively started plate with variable wall temperature and mass diffusion in the presence of transversely applied uniform magnetic field and Hall current. The plate temperature and the concentration level near the plate increase linearly with time. The fluid model under consideration has been solved by Laplace transform technique. The model contains equations of motion, diffusion equation and equation of energy. To analyze the solution of the model, desirable sets of the values of the parameters have been considered. The numerical data obtained is discussed with the help of graphs and tables. The numerical values obtained for skin-friction, Sherwood number and Nusselt number have been tabulated. We found that the values obtained for velocity, concentration and temperature are in concurrence with the actual flow of the fluid.
***Keyword:* MHD flow, Radiation, chemical reaction, variable temperature, mass diffusion, Hall current.**

I. INTRODUCTION

The MHD flow problems play important role in different areas of science and technology. These have many applications in industry, for instance, magnetic material processing, glass manufacturing control processes and purification of crude oil. Afify [1] has worked on effects of radiation and chemical reaction on MHD free convective flow past a vertical isothermal cone. Radiation and chemical reaction effects on isothermal vertical oscillating plate with variable mass diffusion was analyzed by Manivannan et al. [4]. Sahin and Chamkha [7] have considered effects of chemical reaction, radiation, heat and mass transfer on MHD flow along a vertical porous wall in the presence of applied magnetic field. Radiation effect on chemically reacting MHD boundary layer flow of heat and mass transfer through a porous vertical plate was investigated by Ibrahim et al. [3]. Mondal et al. [5] have examined effects of radiation and chemical reaction on MHD free convection flow past a vertical plate in the porous medium. Chemical reaction and radiation effects on unsteady MHD natural convection flow of a rotating fluid past a vertical porous flat plate in the presence of viscous dissipation was presented by Anitha [2]. Swethaa et al. [8] have discussed diffusion-thermo and radiation effects on MHD free convection flow of chemically reacting fluid past an oscillating plate embedded in porous medium. Chemical reaction effect on unsteady MHD flow past an impulsively started oscillating inclined plate with variable temperature and mass diffusion in the presence of Hall current was studied by us [6].

The objective of the present paper is to study the effects of radiation, chemical reaction and porosity of the medium on flow past a moving vertical plate with variable wall temperature and mass diffusion in the presence of transversely applied uniform magnetic field and Hall current. The model has been solved using the Laplace transforms technique. The effects of various parameters on the velocity, temperature and concentration as well as on the skin-friction, Nusselt number and Sherwood number are presented graphically and discussed quantitatively.

II. MATHEMATICAL ANALYSIS

The geometrical model of the problem is shown in figure-1

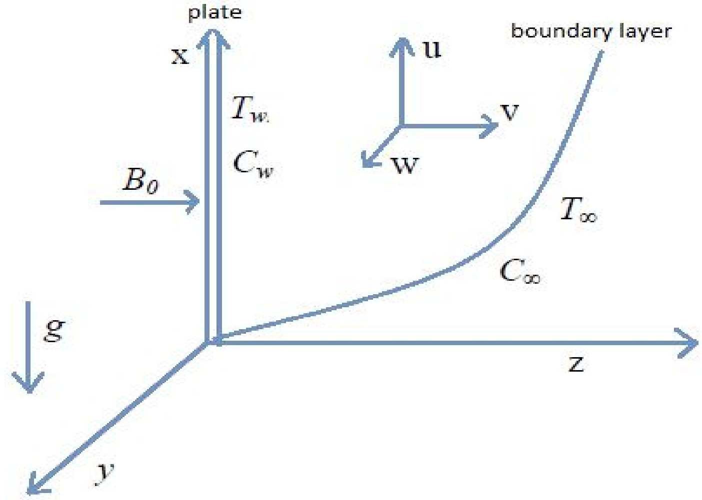

Figure-1. Physical model

The x axis is taken along the vertical plate and z axis is normal to it. Thus the z axis lies in the horizontal plane. The magnetic field B_0 of uniform strength is applied perpendicular to the flow. Initially it has been considered that the plate as well as the fluid is at the same temperature T_∞. The species concentration in the fluid is taken as C_∞. At time t > 0, the plate starts moving with a velocity u_0 in its own plane and temperature of the plate is raised to T_w. The concentration C_w near the plate is raised linearly with respect to time.

The flow modal is as under:

Equations of motion

$$\frac{\partial u}{\partial t} = \upsilon \frac{\partial^2 u}{\partial z^2} + g\beta (T - T_\infty) + g\beta^* (C - C_\infty) - \frac{\sigma B_0^2 (u + mv)}{\rho(1+m^2)} - \frac{\upsilon u}{K}$$

$$\frac{\partial v}{\partial t} = \upsilon \frac{\partial^2 v}{\partial z^2} + \frac{\sigma B_0^2 (mu - v)}{\rho(1+m^2)} - \frac{\upsilon v}{K}$$

Diffusion equation

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial z^2} - K_c (C - C_\infty)$$

Equation of energy

$$\rho C_p \frac{\partial T}{\partial t} = k\frac{\partial^2 T}{\partial z^2} - \frac{\partial q_r}{\partial z}$$

The initial and boundary conditions are

$$\left.\begin{array}{l} t \le 0 : u = 0,\ v = 0,\ T = T_\infty,\ C = C_\infty, \ \text{for every } z. \\ t > 0 : u = u_0,\ v = 0,\ T = T + (T_w - T_\infty)A,\ C = C_\infty + (C_w - C_\infty)A, \quad \text{at } z=0. \\ u \to 0,\ v = 0,\ T \to T_\infty,\ C \to C_\infty \ \text{ as } z \to \infty. \end{array}\right\}$$

Here u and v are the primary and secondary velocities along x and z directions respectively, C- species concentration in the fluid, ν- the kinematic viscosity, ρ- the density, C_p- the specific heat at constant pressure, g-the acceleration due to gravity, β -volumetric coefficient of thermal expansion, t-time, m -the Hall current parameter, T-temperature of the fluid, β^* - volumetric coefficient of concentration expansion, k- thermal conductivity of the fluid, D-the mass diffusion coefficient, K- the permeability parameter, T_w - temperature of the plate at $z= 0$, K_c chemical reaction, C_w -species concentration at the plate $z= 0$, B_0- the uniform magnetic field, σ ectrical conductivity.

The local radiant for the case of an optically thin gray gas is expressed by

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$$\frac{\partial q_r}{\partial z} = -4a^{*}\sigma(T_{\infty}^{4} - T^{4})$$

where a^{*} is absorption constant. Considered the temperature difference within the flow sufficiently small, T^{4} can be expressed as the linear function of temperature. This is accomplished by expanding T^{4} in a Taylor series about T_{∞} and neglecting higher-order terms

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

Using above equations, the equation of energy becomes

$$\rho C_p \frac{\partial T}{\partial t} = k\frac{\partial^2 T}{\partial z^2} - 16a^{*}\sigma T_{\infty}^{3}(T - T_{\infty})$$

The following non-dimensional quantities are introduced to transform above equations into dimensionless form:

$$\left.\begin{aligned} &\bar{z} = \frac{zu_0}{\upsilon},\ \bar{u} = \frac{u}{u_0},\ \bar{v} = \frac{v}{u_0},\ \theta = \frac{(T - T_{\infty})}{(T_w - T_{\infty})},\ S_c = \frac{\upsilon}{D},\ K_0 = \frac{\upsilon K_c}{u_0^2}\ P_r = \frac{\mu u_0}{k},R = \frac{16a^{*}\upsilon^2\sigma T_{\infty}^{3}}{ku_0}, \\ &G_r = \frac{g\beta\upsilon(T_w - T_{\infty})}{u_0^{3}},\ M = \frac{\sigma B_0^2\upsilon}{\rho u_0^2},\ G_m = \frac{g\beta^{*}\upsilon(C_w - C_{\infty})}{u_0^{3}},\mu = \rho\upsilon,\overline{C} = \frac{(C - C_{\infty})}{(C_w - C_{\infty})},\ \bar{t} = \frac{tu_0^2}{\upsilon}. \end{aligned}\right\}$$

The symbols in dimensionless form are as under:

$\bar{u}$ - primary velocity, $\bar{v}$ - secondary velocity, P_r - Prandtl number, S_c - Schmidt number, R-Radiation parameter, $\bar{t}$ - time, θ-temperature, $\overline{C}$ - concentration, G_r-thermal Grashof number, G_m- mass Grashof number, μ- coefficient of viscosity, M- magnetic parameter.

The flow model in dimensionless form is

$$\frac{\partial \bar{u}}{\partial \bar{t}} = \frac{\partial^2 \bar{u}}{\partial \bar{z}^2} + G_r\,\theta + G_m\,\overline{C} - \frac{M(\bar{u} + m\bar{v})}{(1 + m^2)} - \frac{\bar{u}}{\overline{K}}$$

$$\frac{\partial \bar{v}}{\partial \bar{t}} = \frac{\partial^2 \bar{u}}{\partial \bar{z}^2} + \frac{M(m\bar{u} - \bar{v})}{(1 + m^2)} - \frac{\bar{v}}{\overline{K}}$$

$$\frac{\partial \overline{C}}{\partial \bar{t}} = \frac{1}{S_c}\frac{\partial^2 \overline{C}}{\partial \bar{z}^2} - K_0\overline{C}$$

$$\frac{\partial \theta}{\partial \bar{t}} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial \bar{z}^2} - \frac{R\theta}{P_r}$$

The corresponding boundary conditions become:

$$\left.\begin{aligned} &\bar{t} \le 0 : \bar{u} = 0,\ \bar{v} = 0,\ \theta = 0,\ \overline{C} = 0, && \text{for every } \bar{z}. \\ &\bar{t} > 0 : \bar{u} = 1,\ \bar{v} = 0,\ \theta = \bar{t},\ \overline{C} = \bar{t}, && \text{at } \bar{z} = 0. \\ &\bar{u} \to 0,\ \bar{v} \to 0,\ \theta \to 0,\ \overline{C} \to 0, && \text{as } \bar{z} \to \infty. \end{aligned}\right\}$$

Dropping bars in the above equations, we get

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial z^2} + G_r\,\theta + G_m\,C - \frac{M(u + mv)}{(1 + m^2)} - \frac{u}{K}$$

$$\frac{\partial v}{\partial t} = \frac{\partial^2 v}{\partial z^2} + \frac{M(mu - v)}{(1 + m^2)} - \frac{v}{K}$$

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$$\frac{\partial C}{\partial t}=\frac{1}{S_c}\frac{\partial^2 C}{\partial z^2}-K_0 C$$

$$\frac{\partial \theta}{\partial t}=\frac{1}{P_r}\frac{\partial^2 \theta}{\partial z^2}-\frac{R\theta}{P_r}$$

The boundary conditions become

$$\left.\begin{array}{ll} t\le 0: u=0, v=0, \theta=0, C=0, & \text{for every z.}\\ t>0: u=1, v=0,\ \theta=t,\ C=t, & \text{at z=0.}\\ u\to 0,\ v\to 0,\ \theta\to 0,\ C\to 0, & \text{as } z\to\infty. \end{array}\right\}$$

Writing the above equations in combined form (using $q= u + i\,v$)

$$\frac{\partial q}{\partial t}=\frac{\partial^2 q}{\partial z^2}+G_r\,\theta+G_m\,C-qa$$

$$\frac{\partial C}{\partial t}=\frac{1}{S_c}\frac{\partial^2 C}{\partial z^2}-K_0 C$$

$$\frac{\partial \theta}{\partial t}=\frac{1}{P_r}\frac{\partial^2 \theta}{\partial z^2}-\frac{R\theta}{P_r}$$

Finally, the boundary conditions become:

$$\left.\begin{array}{ll} t\le 0: q=0, \theta=0, C=0, & \text{for every z.}\\ t>0: q=1, \theta=t, C=t, & \text{at z=0.}\\ q\to 0,\ \theta\to 0,\ C\to 0, & \text{as } z\to\infty. \end{array}\right\}$$

The above dimensionless governing equations, subject to the corresponding boundary conditions, are solved by the usual Laplace transform technique. The solution obtained is as under:

$$C=\frac{e^{-z\sqrt{S_cK_0}}}{4\sqrt{K_0}}\left\{erfc[\frac{z\sqrt{S_c}-2t\sqrt{K_0}}{2\sqrt{t}}](-z\sqrt{S_c}+2t\sqrt{K_0})+e^{2z\sqrt{S_cK_0}}erfc[\frac{z\sqrt{S_c}+2t\sqrt{K_0}}{2\sqrt{t}}](z\sqrt{S_c}+2t\sqrt{K_0})\right\}$$

$$\theta=\frac{e^{-\sqrt{R}z}}{4\sqrt{R}}\{erfc[\frac{-2\sqrt{Rt}+zP_r}{\sqrt{P_r t}}](2\sqrt{Rt}-zR)+e^{2\sqrt{R}z}erfc[\frac{2\sqrt{Rt}+zP_r}{\sqrt{P_r t}}](2\sqrt{Rt}+zR)\},$$

$$\begin{aligned} q=&\frac{1}{2}\exp(-\sqrt{a}z)A_{33}+\frac{G_r}{4(a-R)^2}((\exp(-\sqrt{a}z)(2RtA_1-2atA_1+z\sqrt{a}A_2+2A_1(P_r+1))-\frac{A_2 z}{\sqrt{a}})\\ &-\frac{2A_5P_rz}{\sqrt{A_{32}}A_{11}}(at-Rt+P_r-1)+\frac{2A_{28}A_6P_rz}{A_{11}}(P_r-1)-2A_{26}A_3(P_r-1)-\frac{P_rz\sqrt{A_{32}P_r}}{A_{10}\pi\sqrt{R}}(\frac{1}{a}-\frac{1}{R}))\\ &+\frac{G_m}{4(a-K_0S_c)^2}((\exp(-\sqrt{a}z)(z\sqrt{a}A_2-2atA_1-2A_1(S_c-1)+2tA_1K_0S_c)-\frac{z\exp(-\sqrt{a}z)A_2K_0S_c}{\sqrt{a}}\\ &-2A_{27}A_4(S_c-1))+\exp(-z\sqrt{S_cK_0})(-\frac{aA_8z\sqrt{S_c}}{\sqrt{K_0}}-2atA_7-2A_7-2A_7(S_c-1)+2tA_7K_0S_c\\ &+zA_8S_c\sqrt{S_cK_0})+2A_{27}A_9(S_c-1)) \end{aligned}$$

The expressions for the symbols involved in the above solutions are given in the appendix.

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III.SKIN FRICTION

The dimensionless skin friction at the plate is

$$\left(\frac{dq}{dz}\right)_{z=0} = \tau_x + i\tau_y .$$

The numerical values of τ_x and τ_y, for different parameters are given in table-1.

IV.NUSSELT NUMBER

The dimensionless Nusselt number at the plate is given by

$$Nu = \left(\frac{\partial\theta}{\partial z}\right)_{z=0} = erfc[\frac{\sqrt{Rt}}{\sqrt{tP_r}}](\sqrt{Rt}-\frac{\sqrt{R}}{2}t+\frac{P_r}{4\sqrt{R}}) - erfc[-\frac{\sqrt{Rt}}{\sqrt{tP_r}}](\frac{\sqrt{R}}{2}t+\frac{P_r}{4\sqrt{R}}) - \frac{e^{-\frac{Rt}{P_r}}\sqrt{tP_r}}{\sqrt{\pi}}$$

The numerical values of Nu for different parameters are given in table-2.

V. SHERWOOD NUMBER

The dimensionless Sherwood number at the plate is given by

$$S_h = \left(\frac{\partial C}{\partial z}\right)_{z=0} = erfc[-\sqrt{tK_0}](-\frac{1}{4\sqrt{K_0}}\sqrt{S_c} - \frac{t\sqrt{S_cK_0}}{2}) + \sqrt{S_c}\,erfc[\sqrt{tK_0}](\frac{1}{4\sqrt{K_0}}+t\sqrt{K_0}) - \frac{e^{-tK_0}\sqrt{tS_cK_0}}{\sqrt{\pi K_0}}$$

The numerical values of S_h for different parameters are given in table-3.

VI. RESULTS AND DISCUSSION

The present study is carried out to examine the effects of radiation, chemical reaction and permeability of porous medium on the flow. The behaviour of other parameters like magnetic field, Hall current and thermal buoyancy is almost similar the earlier model studied by us [6]. The analytical results are shown graphically in figures 2 to 8. The numerical values of skin-friction, Sherwood number and Nusselt number are presented in Table-1, 2 and 3 respectively. From figures 4 and 5, it is observed that primary and secondary velocities increase with permeability parameter *(K)*. This result is due to the fact that increases in the value of *(K)* results in reducing the drag force, and hence increasing the fluid velocity. Chemical reaction effect on fluid flow behaviour is shown by figures 2 and 3. It is seen here that when chemical reaction parameter (K_0) increases, primary and secondary velocities decreases throughout the boundary layer region. Figures 6 and 7, indicates that effect of radiation (R) in the boundary layer region near the plate tends to accelerate primary and secondary velocities. Further, it is observed that the temperature and concentration of the fluid near the plate decreases when radiation and chemical reaction parameters increased (figures 8 and 9).

Skin friction is given in table1. The values of τ_x and τ_y increase with the increases in radiation parameter and permeability parameter. It is decrease with chemical reaction parameter. Sherwood number is given in table2. The value of S_h decreases with the increase in the chemical reaction parameter, Schmidt number and time. Nusselt number is given in table2. The value of Nu decreases with increase in Prandtl number, radiation parameter and time.

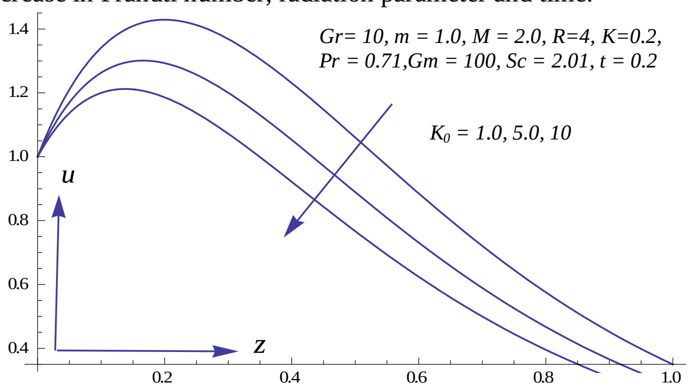

Figure 2: velocity u for different values of K_0

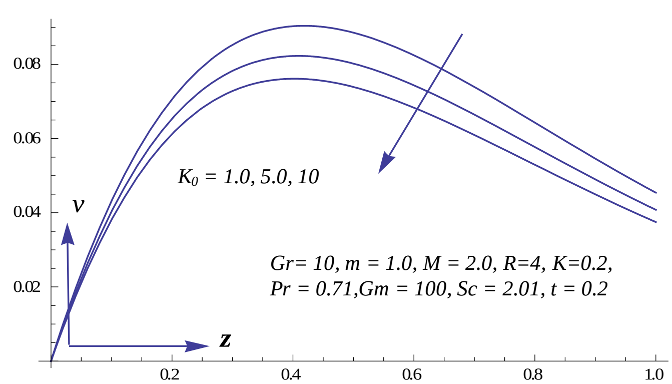

Figure 3: velocity v for different values of K_0

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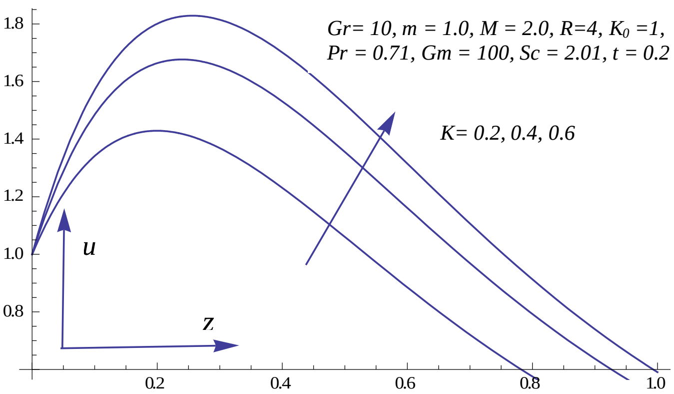

Figure 4: velocity u for different values of K

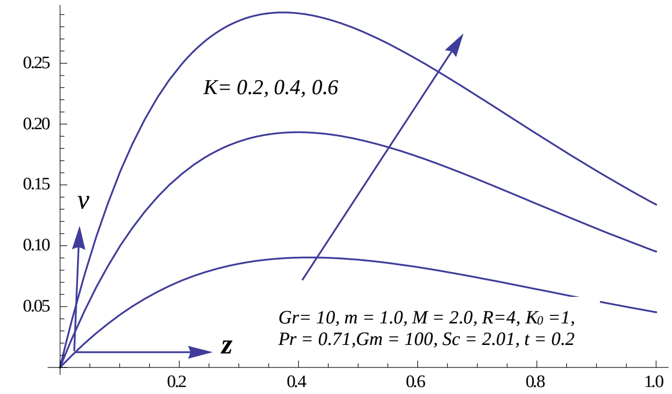

Figure 5: velocity v for different values of K

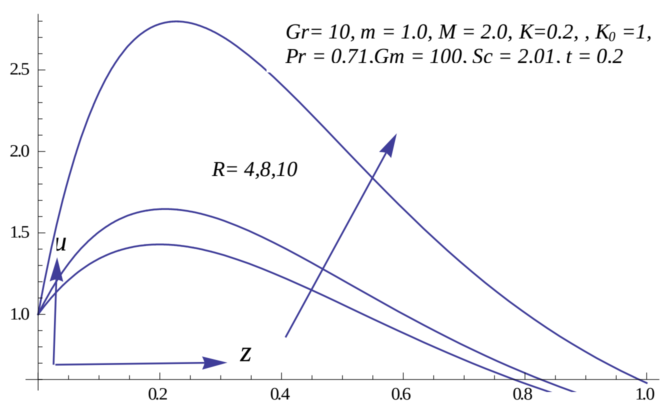

Figure 6: velocity u for different values of R

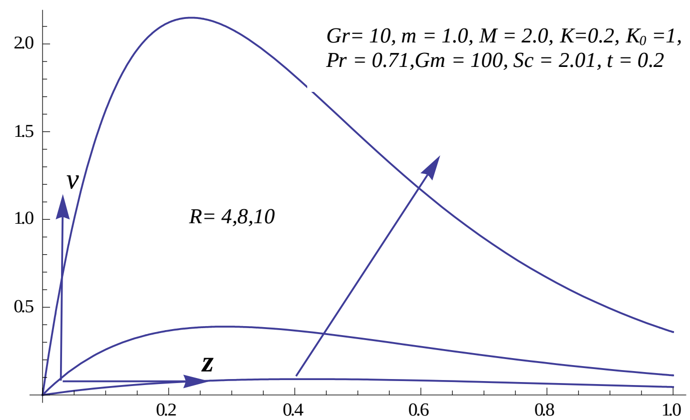

Figure 7: velocity v for different values of R

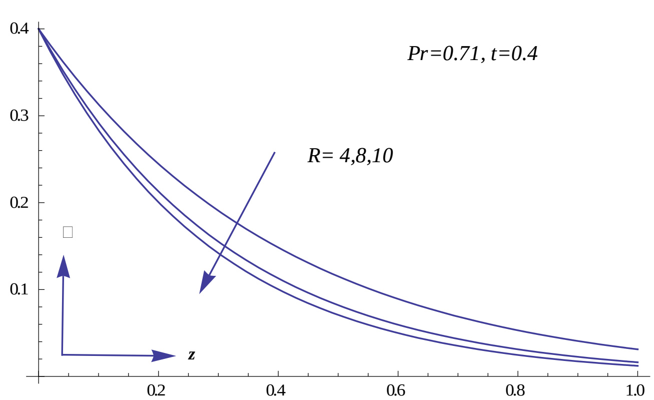

Figure 8: Temperature θ for different values of R

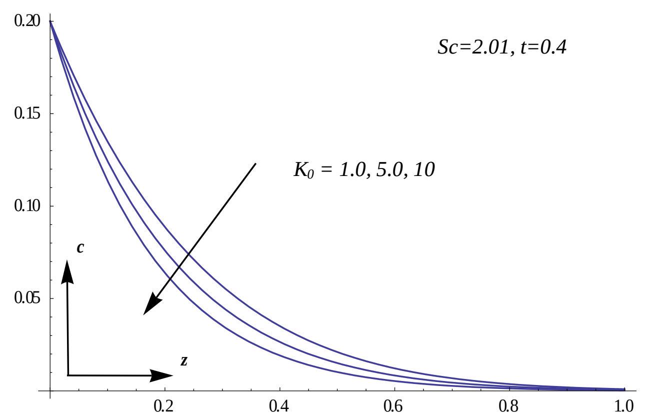

Figure 9: Concentration c for different values of K_0

Table 1: Skin friction for different parameter

M	m	Pr	Sc	Gm	Gr	K	R	K_0	t	τ_x	τ_y
2	1	0.71	2.01	100	10	0.2	04	01	0.4	0127.4586	0036.8154
2	1	0.71	2.01	100	10	0.4	04	01	0.4	0295.9028	0163.9768
2	1	0.71	2.01	100	10	0.6	04	01	0.4	0440.0617	0306.6097
2	1	0.71	2.01	100	10	0.2	08	01	0.4	0635.6466	0529.2414
2	1	0.71	2.01	100	10	0.2	10	01	0.4	2584.1086	3350.1372

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2	1	0.71	2.01	100	10	0.2	04	05	0.4	0126.6326	0036.7864
2	1	0.71	2.01	100	10	0.2	04	10	0.4	0125.9559	0036.7635

Table 2: Sherwood number for different Parameters.

K_0	Sc	t	S_h
01	2.01	0.2	-0.762200
05	2.01	0.2	-0.933049
10	2.01	0.2	-1.118240
01	3.00	0.2	-0.931175
01	4.00	0.2	-1.075230
01	2.01	0.3	-0.961323
01	2.01	0.4	-1.141570

Table 3: Nusselt number for different parameter

Pr	*R*	*t*	*Nu*
0.71	2	0.4	-0.805273
7.00	2	0.4	-1.959260
0.71	3	0.4	-0.894014
0.71	4	0.4	-0.976083
0.71	2	0.5	-0.950956
0.71	2	0.6	-1.094940

VII. CONCLUSION

In this paper a theoretical analysis has been done to study the unsteady MHD flow through porous medium past a moving vertical plate with variable wall temperature and mass diffusion in the presence of Hall current, radiation and chemical reaction. The results obtained are in agreement with the usual flow. It has been found that the velocity in the boundary layer increases with the values of permeability parameter and radiation parameter but trend is reversed with chemical reaction parameter. That is the velocity decreases when chemical reaction parameter is increased. It is also observed that the permeability parameter and radiation parameter increases the drag at the plate surface, and decreases with chemical reaction parameter. Sherwood number and Nusselt number decreases with increase in radiation parameter and chemical reaction parameter.

Appendix

$$A=\frac{u_0^2 t}{\upsilon},\ a=\frac{M(1-im)}{1+m^2}+\frac{1}{K},\ A_1=(1+A_{12}+e^{2\sqrt{az}}(1-A_{13})),\ A_2=(1+A_{12}-e^{2\sqrt{az}}(1-A_{13})),$$

$$A_3=(A_{14}-1+A_{29}(A_{15}-1)),\ A_4=(A_{16}-1+A_{30}(A_{17}-1)),\ A_5=(A_{18}-1+A_{33}(A_{19}-1)),$$

$$A_6=(A_{20}-1+A_{31}(A_{21}-1)),\ A_7=(e^{2z\sqrt{K_0S_c}}(A_{23}-1)-A_{22}-1)),\ A_8=(e^{2z\sqrt{K_0S_c}}(A_{23}-1)+A_{22}+1)),$$

$$A_9=(A_{30}(A_{25}-1)-A_{24}-1),\ A_{10}=(1-A_{18}+A_{32}(A_{19}-1)),\ A_{11}=Abs[z]Abs[P_r],\ A_{12}=erf[\frac{1}{2\sqrt{t}}(2\sqrt{a}t-z)],$$

$$A_{13}=erf[\frac{1}{2\sqrt{t}}(2\sqrt{a}t+z)],\ A_{14}=erf[\frac{1}{2\sqrt{t}}(z-2t\sqrt{\frac{aP_r-R}{P_r-1}})],\ A_{15}=erf[\frac{1}{2\sqrt{t}}(z+2t\sqrt{\frac{aP_r-R}{P_r-1}})],$$

$$A_{16}=erf[\frac{1}{2\sqrt{t}}(z-2t\sqrt{\frac{(a-K_0)S_c}{S_c-1}})],\ A_{17}=erf[\frac{1}{2\sqrt{t}}(z+2t\sqrt{\frac{(a-K_0)S_c}{S_c-1}})],\ A_{18}=erf[\frac{A_{11}}{2\sqrt{t}}-\sqrt{\frac{tR}{P_r}}],$$

$$A_{19}=erf[\frac{A_{11}}{2\sqrt{t}}+\sqrt{\frac{tR}{P_r}}],\ A_{20}=erf[\frac{A_{11}}{2\sqrt{t}}-\sqrt{\frac{(R-aP_r)t}{P_r-P_r^2}})],\ A_{21}=erf[\frac{A_{11}}{2\sqrt{t}}+\sqrt{\frac{(R-aP_r)t}{P_r-P_r^2}})],$$

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$$A_{22} = erf[\frac{1}{2\sqrt{t}}(2t\sqrt{K_0} - z\sqrt{S_c})],\ A_{23} = erf[\frac{1}{2\sqrt{t}}(2t\sqrt{K_0} + z\sqrt{S_c})],\ A_{24} = erf\,[\frac{1}{2\sqrt{t}}(2t\sqrt{\frac{(a-K_0)S_c}{S_c - 1}} - z\sqrt{S_c})],$$

$$A_{25} = erf\,[\frac{1}{2\sqrt{t}}(2t\sqrt{\frac{(a-K_0)S_c}{S_c - 1}} + z\sqrt{S_c})],\ A_{26} = \exp(\frac{at}{P_r - 1} - \frac{Rt}{P_r - 1} - z\sqrt{\frac{aP_r - R}{P_r - 1}}),$$

$$A_{27} = \exp(\frac{at}{S_c - 1} - \frac{tS_c K_0}{S_c - 1} - z\sqrt{\frac{(a-K_0)S_c}{S_c - 1}}),\ A_{28} = \frac{1}{A_{31}}\exp(\frac{at}{P_r - 1} - \frac{Rt}{P_r - 1}),\ A_{29} = \exp(2z\sqrt{\frac{-R + aP_r}{P_r - 1}}),$$

$$A_{30} = \exp(2z\sqrt{\frac{(a-K_0)S_c}{S_c - 1}}),\ A_{31} = \exp(2Abs[z]\sqrt{\frac{P_r(aP_r - R)}{P_r - 1}}),\ A_{32} = \exp(2Abs[z]\sqrt{P_r R}),$$

$$A_{33} = 1 + A_{34} + \exp(2\sqrt{az})A_{35},\ A_{34} = erf[\frac{1}{2\sqrt{t}}(2\sqrt{at} - z)],\ A_{35} = erfc[\frac{1}{2\sqrt{t}}(2\sqrt{at} + z)].$$

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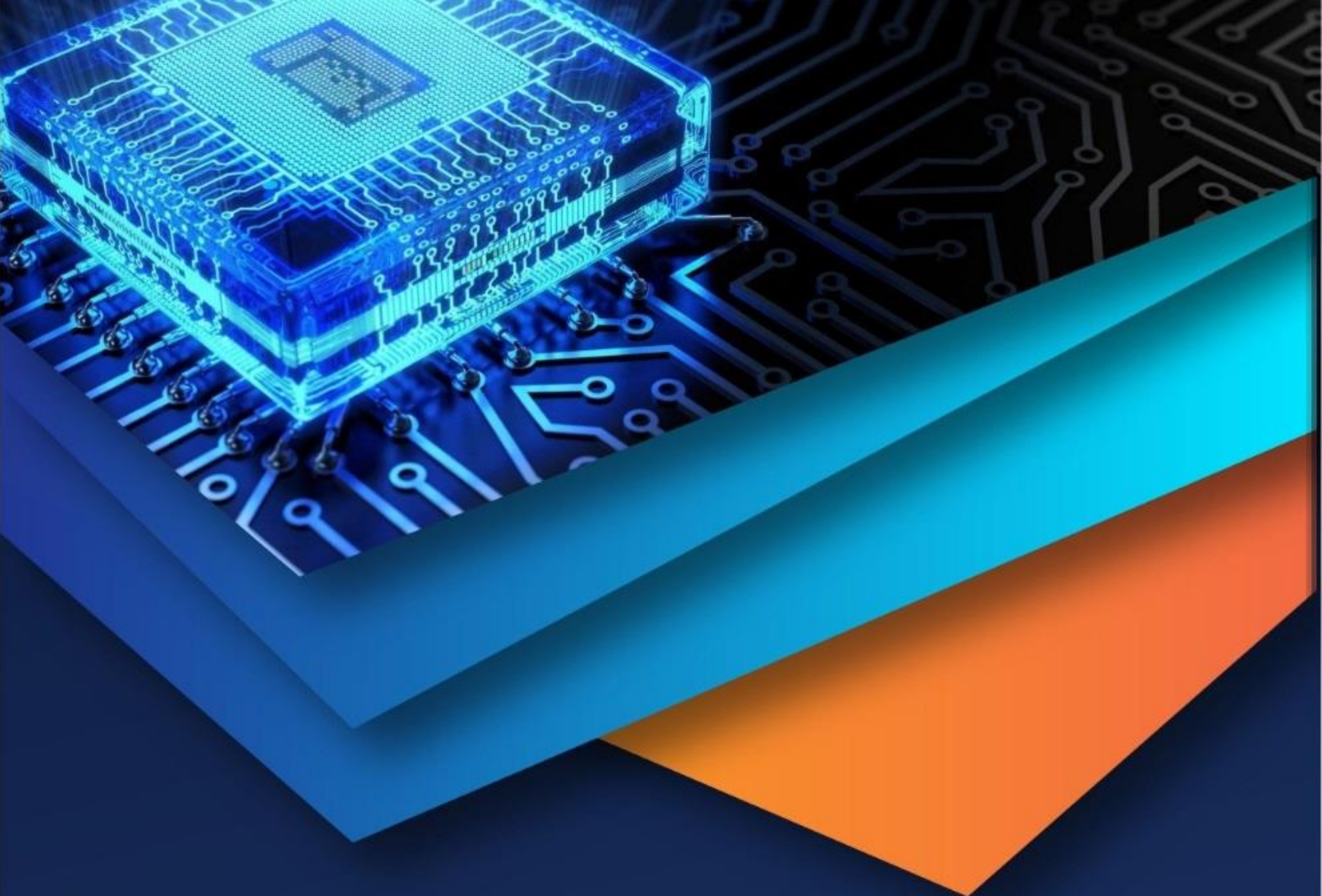

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