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Hall and Ion-Slip Effects on MHD Free Convection Flow through An Oscillatory Porous Medium With Constant Suction Velocity And Radiation

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Abstract: *Current work focused on perturbation method for the influence of Hall and Ion-slip current on unsteady Magneto Hydrodynamic free convection flow through an oscillatory porous medium with constant suction velocity and chemical reaction in sway of radiation. The numerical outcomes involved in velocity, Skin friction, temperature, Nusselt number, concentration as well as Sherwood number are demonstrated graphically for pertinent parameters entering into the problem. It is revealed that the velocity as well as Skin friction declined with the enhancement of Hall and ion-slip current. Meanwhile temperature diminished with the rise in Prandtl number, but contrast result was eventuated in case of Nusselt number. In addition Concentration and Sherwood number decremented with ascend in chemical reaction as well as Schmidt number.*

Keywords: Prandtl number, Hall, Ion-slip current, Perturbation method.

I. INTRODUCTION

Due to versatile technological as well as manufacturing applications, it is great understand to examine the MHD flow. The foremost objective of MHD principles is to interrupt the flow field in a required direction by fluctuate the formation of the boundary layer. Thus, with the intention of modify the flow kinematics; the idea to execute MHD seems to be more flexible and reliable. In pharmaceutical as well as environmental science, MHD has been playing a essential role in the application of fluid dynamics and medical sciences, owing to its implications in chemical fluids as well as metallurgical fields. Rudraiah [1] analyzed hydro magnetic free convection flow through a porous medium between two parallel plates. In this paper, it was found that velocity as well as temperature diminished with rise in Darcy dissipations and porous parameter. Abdul Hakeem [2] considered analytical solutions for two-dimensional oscillatory flow on free convective radiation through a highly porous medium bounded by an infinite perpendicular plate. Hamza et al. [3] in paper it was observed that the velocity declined with the reduced in magnetic field, porous parameter and Grashof number but reverse effect was shown in case of slip parameter. In this investigation, analytical model (Perturbation method) was utilized for solving the governing equations. M.A. El-Hakiem et al. [4] and Makinde [5] examined constant suction velocity on MHD free convection oscillatory flow on radiation through a porous medium. Raptis [6] analyzed effect of non-constant 2D free convective flow throughout the motion of a viscous incompressible fluid through a very much porous medium. Gholizadeh [7] and Swati [8] analyzed the thermal and mass diffusion effects on MHD oscillatory flow past a vertical porous plate through a porous medium in the presence of heat source**.** In the above all investigation Hall and Ion lip current was not taken into considered. Set et al. [9] have discussed, affect of rotational system on unsteady hydro magnetic flow which is natural convective flow over impulsively affecting erect plate thereby ramped temperature embedded in porous medium by taking thermal diffusion as well as heat absorption.

II. MATHEMATICAL FORMULATION AND SOLUTION OF THE PROBLEM

Contemplate unsteady two-dimensional free convection fluid flow through a highly porous medium which is bounded by a perpendicular infinite plane surface in vicinity of a crosswise magnetic field as well as thermal radiation. The fluid is hypothetical to be a gray, absorbing emitting but non-scattering medium. As stated in axial system of co-ordinates the x^*-axis is purloined along the plane surface by means of a way reversal to the direction tendency of gravity and y^* -axis is normal to it. The physical variables are functions of y^* as well as the time t^* only. The radiate heat flux in the x^*- direction is considered negligible in comparison with that in y^* - direction. Hall, Ion Slip current and heat source has been taken into contemplated. The magnetic Reynolds number of the flow is purloined to be small adequately, thus the induced magnetic field can be omitted. The homogeneous chemical reaction K_r is taken into contemplated. Thence, the equation of the conservation of mass, momentum, energy and concentration are given by

Equation of continuity:

$$\frac{\partial v^*}{\partial y^*} = 0 \qquad (1)$$

$$\Rightarrow v^* = -v_0 \qquad (2)$$

Equation of Momentum:

$$\frac{\partial u^*}{\partial t^*} + v^*\frac{\partial u^*}{\partial y^*} = \frac{-1}{\rho}\frac{\partial p^*}{\partial y^*} + \vartheta\frac{\partial^2 u^*}{\partial y^{*2}} + g\beta(T^* - T^*_\infty) + g\beta^*\left(C^* - C^*_\infty\right) - \frac{\vartheta}{k^*}\left[u^*\right] - \frac{B_0^2\sigma_e\left[\alpha_e u^* + \beta_e w^*\right]}{\rho\left[\alpha_e^2 + \beta_e^2\right]} \qquad (3)$$

$$\frac{\partial w^*}{\partial t^*} + v^*\frac{\partial w^*}{\partial y^*} = \vartheta\left[\frac{\partial^2 w^*}{\partial y^{*2}}\right] - \frac{\vartheta}{k}w^* - \left[\frac{B_0^2\sigma_e}{\rho\left(\alpha_e^2 + \beta_e^2\right)}\right]\left(\beta_e\left(v_1^* - u^*\right) - \alpha_e w^*\right) \qquad (4)$$

$$-\frac{1}{\rho}\frac{\partial p^*}{\partial y^*} = \frac{dv_1^*}{dt^*} + \frac{\vartheta}{k}v_1^* + \frac{\sigma_e}{\rho\left(\alpha_e^2 + \beta_e^2\right)}B_0^2 v_1^* \qquad (5)$$

Equation of Energy:

$$\frac{\partial T^*}{\partial t^*} + v^*\frac{\partial T^*}{\partial y^*} = \alpha\left(\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{1}{k_0}\frac{\partial q_r^*}{\partial y^*}\right) + \frac{Q_0}{\alpha}(T^* - T^*_\infty) \qquad (6)$$

$$\frac{\partial C^*}{\partial t^*} = D\frac{\partial^2 C^*}{\partial y^{*2}} - K_r(C^* - C^*_\infty) \qquad (7)$$

The related boundary conditions are

$$\left.\begin{array}{l} at\ \ y^* = 0: \quad u^* = 0, \quad w^* = 0, \quad T^* = T^*_\infty, \quad C^* = C^*_\infty \\ As\ \ y^* \to \infty: \ u^* \to v_1^* = U_0(1 + e^{i\omega t^*}), w^* \to 0\ T^* = T^*_\infty, C^* = C^*_\infty, \end{array}\right\} \qquad (8)$$

From the equation (3), (4) & (4) then we get

$$\frac{\partial u^*}{\partial t^*} + v^*\frac{\partial u^*}{\partial y^*} = \frac{dv_1^*}{dt^*} + \vartheta\frac{\partial^2 u^*}{\partial y^{*2}} + g\beta\left(T^* - T^*_\infty\right) + \frac{\vartheta}{K^*}\left(v_1^* - u^*\right) - \frac{B_0^2\sigma_e}{\rho\left(\left(1 + \beta_i\beta_e\right)^2 + \beta_e^2\right)}\left(\left(1 + \beta_i\beta_e\right)\left(v_1^* - u^*\right) + \beta_e w^*\right) \qquad (9)$$

$$\frac{\partial w^*}{\partial t^*} + v^*\frac{\partial w^*}{\partial y^*} = \vartheta\left[\frac{\partial^2 w^*}{\partial y^{*2}}\right] - \frac{\vartheta}{k}w^* - \frac{B_0^2\sigma_e}{\rho\left(\left(1 + \beta_i\beta_e\right)^2 + \beta_e^2\right)}\left(\beta_e\left(v_1^* - u^*\right) - \left(1 + \beta_i\beta_e\right)w^*\right) \qquad (10)$$

$$q_r^* = -\frac{4\sigma}{3k_1}\frac{\partial T^{*4}}{\partial y^*} \qquad (11)$$

Now Non-dimensional quantities are defined as

$$\left.\begin{array}{l} f=\frac{u^*}{U_0}, g=\frac{w^*}{U_0}\, y=\frac{V_0 y^*}{\vartheta}, v_1=\frac{v_1^*}{U_0}, t=\frac{V_0^2 t^*}{\vartheta}, U=\frac{U^*}{U_0} \\ K=\frac{K^*\vartheta^2}{V_0^2}, T^*=T_\infty^*+\theta\left(T_w^*-T_\infty^*\right), C^*=C_\infty^*+C\left(C_w^*-C_\infty^*\right) \end{array}\right\} \tag{12}$$

After substituting the boundary conditions and non-dimensional variables in the governing equations (3), (4), (6) & (7) then we get,

$$\frac{\partial f}{\partial t}-\frac{\partial f}{\partial y}=\frac{dv_1}{dt}+\frac{\partial^2 f}{\partial y^2}-\frac{B_0^2\sigma_e\vartheta}{V_0^2\rho\left(\left(1+\beta_i\beta_e\right)^2+\beta_e^2\right)}\left(\left(1+\beta_i\beta_e\right)\left(v_1-f\right)+\beta_e g\right)+G_r\theta+G_m C+\frac{1}{k}\left(v_1-f\right) \tag{13}$$

$$\frac{\partial g}{\partial t}-\frac{\partial g}{\partial y}=\frac{\partial^2 g}{\partial y^2}-\frac{1}{k}g-\frac{B_0^2\sigma_e\vartheta}{V_0^2\rho\left(\left(1+\beta_i\beta_e\right)^2+\beta_e^2\right)}\left(\beta_e\left(v_1-f\right)-\left(1+\beta_i\beta_e\right)g\right) \tag{14}$$

$$\frac{\partial\theta}{\partial t}-\frac{\partial\theta}{\partial y}=(\Pr)^{-1}\left(\left(1+\frac{4R}{3}(\theta+\phi)^3\right)\frac{\partial^2\theta}{\partial y^2}+4R(\theta+\phi)^2\left(\frac{\partial\theta}{\partial y}\right)^2\right)+\eta\theta \tag{15}$$

$$\frac{\partial C}{\partial t}=(Sc)^{-1}\frac{\partial^2 C}{\partial y^2}-K_r C \tag{16}$$

The boundary conditions are

$$\left.\begin{array}{ll} At\ y=0 & f=0,\ g=0,\ \theta=1, C=1 \\ As\ y\to\infty & f=\left(1+\varepsilon e^{i\omega t}\right), g\to 0, \theta\to 0, C\to 0 \end{array}\right\}$$ (El-Hakiem et al [4]) (17)

Take $F=f+i\,g$ (18)

$$\frac{\partial F}{\partial t}-\frac{\partial F}{\partial y}=\frac{dv_1}{dt}+\frac{\partial^2 F}{\partial y^2}+G_r\theta+N\left(v_1-F\right) \tag{19}$$

$$\left.\begin{array}{l} G_r=\frac{\vartheta\beta g\left(T_w^*-T_\infty^*\right)}{V_0^2 U_0}, M=\frac{\sigma B_0^2}{\rho V_0^2}, \eta=\frac{\vartheta Q_0}{V_0^2\alpha}, K_r=\frac{k_1\vartheta}{V_0^2}, \Pr=\frac{\vartheta}{\alpha}, R=\frac{4\sigma\left(T_w^*-T_\infty^*\right)^3}{k_0 k_1}, \\ \phi=\frac{T_\infty^*}{\left(T_w^*-T_\infty^*\right)}\, N=\left[\frac{1}{k}+\frac{M}{\left(\left(1+\beta_i\beta_e\right)^2+\beta_e^2\right)}\left(\left(1+\beta_i\beta_e\right)+i\beta_e\right)\right], Sc=\frac{\vartheta}{D} \end{array}\right\} \tag{20}$$

So as to solve the deferential equation (15), (16) & (19) it was suppose that

$$F=F_0(y)+\varepsilon e^{i\omega t}F_1(y)......\theta=\theta_0(y)+\varepsilon e^{i\omega t}\theta_1(y).........C=C_0(y)+\varepsilon e^{i\omega t}C_1(y)\Big\} \tag{21}$$

From equation (15), (16), (19) & (21) then we get;

$$F_0''+F_0'-NF_0=-G_r\theta_0-G_m C_0-N \tag{22}$$

$$F_1''+F_1'-(N+i\,\omega)F_1=-(N+i\,\omega)-G_r\theta_1-G_m C_1 \tag{23}$$

$$\left[1+\frac{4}{3}R(\theta_0+\phi)^3\right]\theta_0''+4R(\theta_0+\phi)^2(\theta_0')^2+\Pr\theta_0'+\Pr\eta\,\theta_0=0 \tag{24}$$

$$\left.\begin{array}{r} \left[1+\frac{4}{3}R(\theta_0+\phi)^3\right]\theta_1''+8R(\theta_0+\phi)^2(\theta_0')^2\theta_1+8R(\theta_0+\phi)^2\theta_0'\theta_1'+\Pr\theta_1' \\ +4R(\theta_0+\phi)^2\theta_0''\theta_1-i\omega\Pr\theta_1+\Pr\eta\theta_1=0 \end{array}\right\} \tag{25}$$

$$C_0''-S_C K_r C_0=0 \tag{26}$$

$$C_1'' - Sc(K_r + n)C_1 = 0 \tag{27}$$

The corresponding boundary conditions are

$$\left.\begin{array}{l} F_0 = 0, F_1 = 0, \theta_0 = 1, \theta_1 = 0, C_0 = 1, C_1 = 0, \quad at\ y = 0 \\ F_0 = 1, F_1 = 1, \theta_0 \to 0, \theta_1 \to 0, C_0 \to 0, C_1 \to 0\ as\ y \to \infty \end{array}\right\} \tag{28}$$

Initially solve equation (25) &equation (26) then we obtain,

$$C_0 = e^{-\left(\sqrt{ScKr}\right)y} \quad \& \quad C_1 = 0 \tag{29}$$

If we suppose that the radiation parameter R to be small, we expand (23)-(25) as

$$\left.\begin{array}{l} F_0 = F_{01}(y) + R\ F_{02}(y) .... F_1 = F_{11}(y) + R\ F_{12}(y) \\ \theta_0 = \theta_{01}(y) + R\ \theta_{02}(y) .... \theta_1 = \theta_{11}(y) + R\ \theta_{12}(y) \end{array}\right\} \tag{30}$$

From the equation (22)-(25) & equation (30) then we obtain:

$$F_{01}'' + F_{01}' - NF_{01} = -Gr\theta_{01} - G_m C_0 - N \tag{31}$$

$$F_{02}'' + F_{02}' - NF_{02} = -Gr\theta_{02} \tag{32}$$

$$F_{11}'' + F_{11}' - (N + i\omega)F_{11} = -(N + i\omega) - Gr\theta_{11} - G_m C_1 \tag{33}$$

$$F_{12}'' + F_{12}' - (N + i\omega)F_{12} = -Gr\theta_{12} \tag{34}$$

$$\theta_{11}'' + \Pr\theta_{11}' + (\eta - i\omega)\Pr\theta_{11} = 0 \tag{35}$$

$$\theta_{01}'' + \Pr\theta_{01}' + \Pr\eta\theta_{01} = 0 \tag{36}$$

$$\theta_{02}'' + \frac{4}{3}(\theta_{01} + \phi)^3\theta_{01}'' + 4(\theta_{01} + \phi)^2(\theta_{01}')^2 + \Pr\theta_{02}^1 + \Pr\eta\ \theta_{02} = 0 \tag{37}$$

$$\left.\begin{array}{l} \theta_{12}'' + \frac{4}{3}(\theta_{01} + \phi)^3\theta_{11}'' + 8(\theta_{01} + \phi)^2(\theta_{01}')^2\theta_{11} + 8(\theta_{01} + \phi)^2\theta_0^1\theta_{11}^1 + \Pr\theta_{12}' \\ \qquad + 4(\theta_{01} + \phi)^2\theta_0''\theta_{11} + \Pr(\eta - i\omega)\theta_{12} = 0 \end{array}\right\} \tag{38}$$

The corresponding boundary conditions are

$$\left.\begin{array}{l} F_{01} = 0, F_{02} = 0, \theta_{01} = 1, \theta_{02} = 0, F_{11} = 0, F_{12} = 0\,\theta_{11} = 0, \theta_{12} = 0 \quad at\ y = 0 \\ F_{01} = 1, F_{02} = 1, \theta_{01} = 0, \theta_{02} = 0, F_{11} = 1, F_{12} = 0\,\theta_{11} = 0, \theta_{12} = 0 \quad at\ y \to \infty \end{array}\right\} \tag{39}$$

Solve (31) – (38) subject to boundary condition (39), & (29) we get velocity, temperature and concentration

$$F = \left(A_1\ e^{-R_3 y} + N_1 e^{-R_2 y} + N_{10} e^{-l\ y} + 1\right) + R\begin{pmatrix} A_3\ e^{-R_3 y} + N_6 e^{-R_2 y} + N_7 e^{-4R_2 y} \\ + N_8 e^{-3R_2 y} + N_9 e^{-2R_2 y} \end{pmatrix} + \varepsilon e^{i\omega t}\left(e^{-R_4 y}\right) \tag{40}$$

$$\theta = e^{-R_2 y} + R\left(A_2\ e^{-R_2 y} + N_2 e^{-4R_2 y} + + N_3 e^{-R_2 y} + N_4 e^{-3R_2 y} + N_5 e^{-2R_2 y}\right) \tag{41}$$

$$C = e^{-\left(\sqrt{ScKr}\right)y} \tag{42}$$

2.1 *Skin friction:*

$$\tau_w = \left.\frac{\partial F}{\partial y}\right|_{y=0} = \left(-R_3 A_1\ - R_2 N_1 - l\ N_{10} + 1\right) + R\begin{pmatrix} -R_3 A_3\ - R_2 N_6 - 4R_2 N_7 e^{-4R_2 y} \\ -3R_2 N_8 - 2R_2 N_9 e^{-2R_2 y} \end{pmatrix} - R_4 \varepsilon e^{i\omega t} \tag{43}$$

2.2 *Nusselt number:*

$$N_w = \left.\frac{\partial \theta}{\partial y}\right|_{y=0} = -R_2 + R\left(-R_2 A_2 \ -4R_2 N_2 - R_2 N_3 - 3R_2 N_4 - 2R_2 N_5\right) \tag{44}$$

2.3 *Sherwood number:*

$$S_h = \left.\frac{\partial c}{\partial y}\right|_{y=0} = -\left(\sqrt{ScKr}\right) \tag{45}$$

III. RESULTS AND DISCUSSION

Fig 1: Represents the behaviour of velocity for disparate values of Hall parameter β_e. From this figure it was found that the enhancement of various values of hall parameter it leads to reduced in velocity and it is very near to the plate. Fig 2: Reflects that the velocity diminished owing to enhancement of distinct values of Ion-slip parameter β_i owing to the fact that the β_i reduced the resistive force inflict by magnetic field.

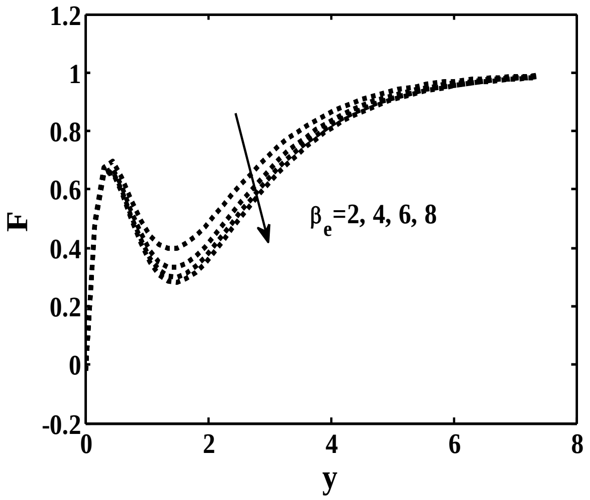

Figure 1: Influence of β_e on Velocity

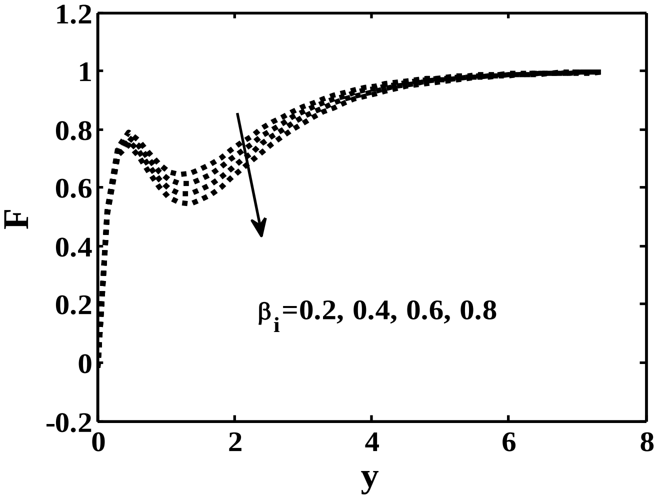

Figure 2: Influence of β_i on Velocity

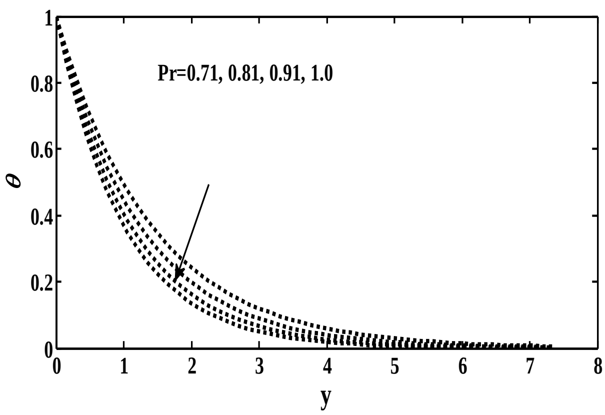

Figure 3: Effect of *Pr* on Temperature

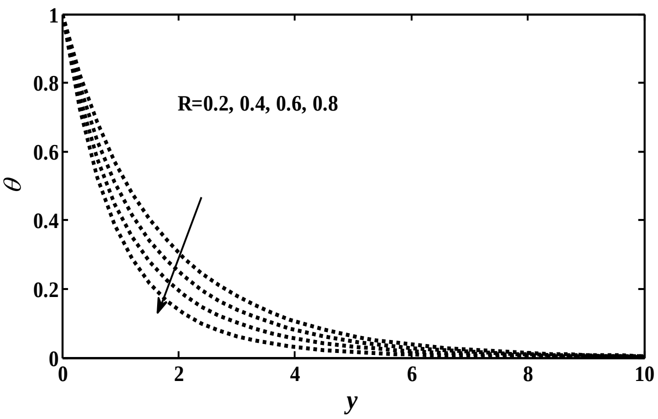

Figure 4: Effect of *R* on Temperature

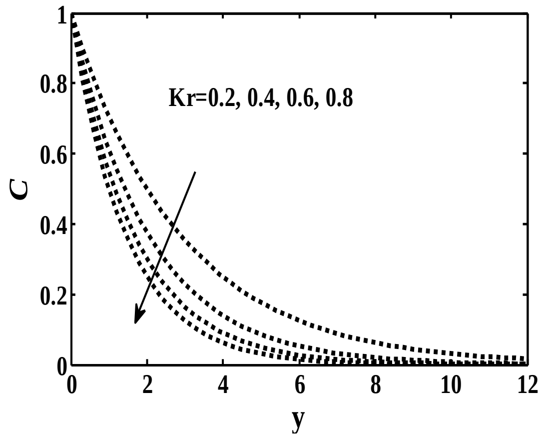

Figure 5: Effect of *Kr* on Concentration

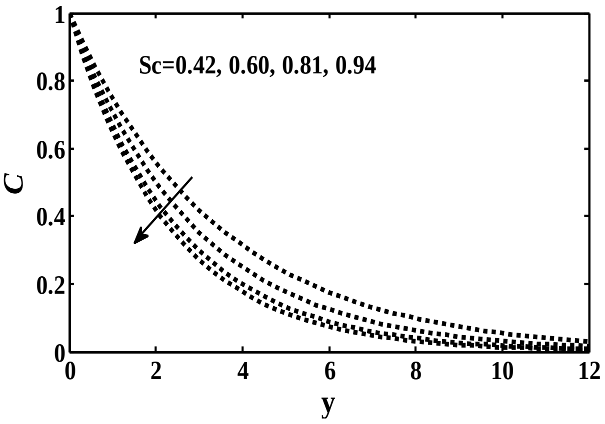

Figure 6: Effect of *Sc* on Concentration

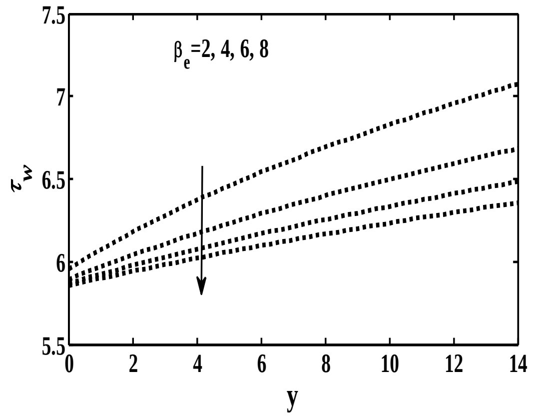

Figure 7: Effect of β_e on Skin-friction

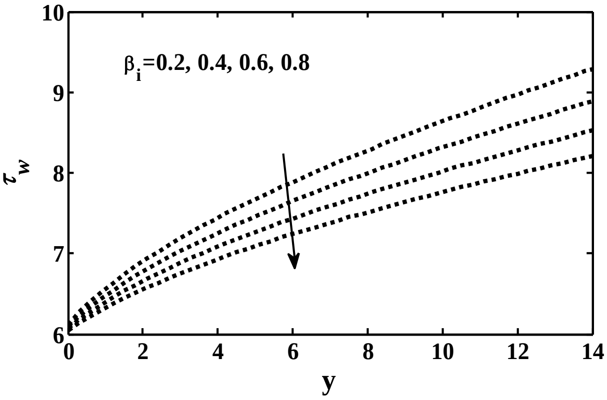

Figure 8: Effect of β_i on Skin-friction

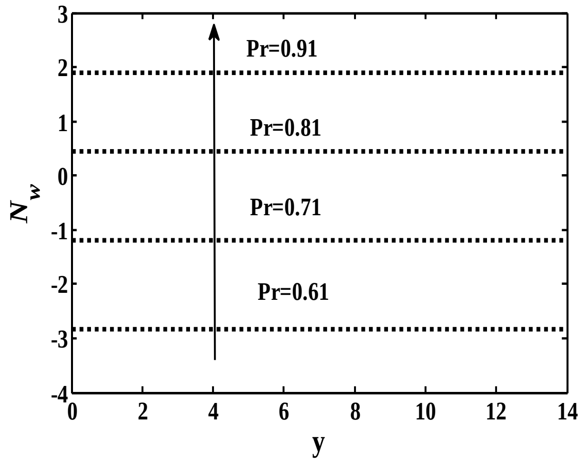

Figure 9: Effect of *Pr* on Nusselt number

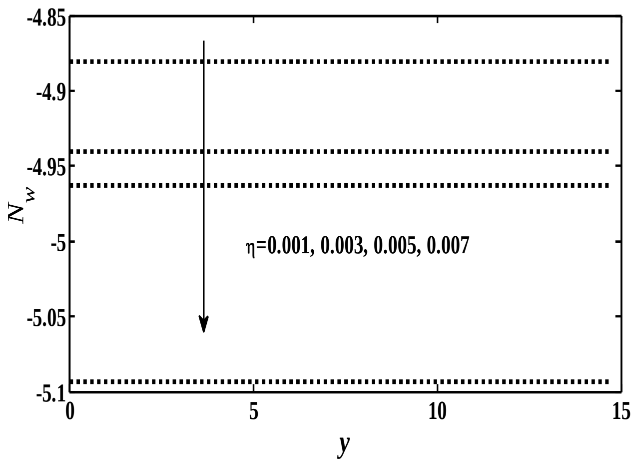

Figure 10: Effect of η on Nusselt number

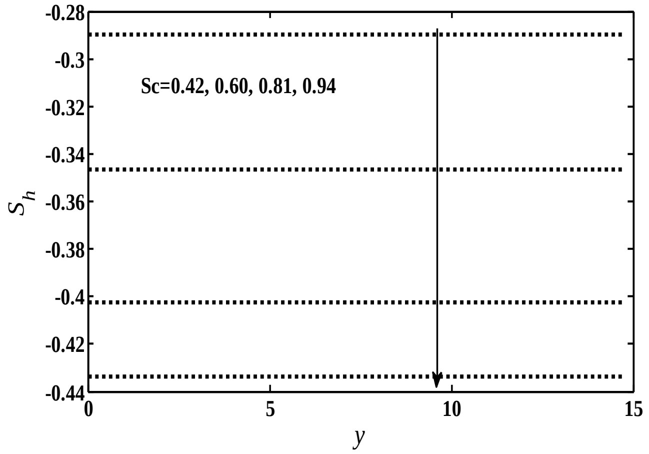

Figure 11: Effect of *Sc* on Sherwood numbers

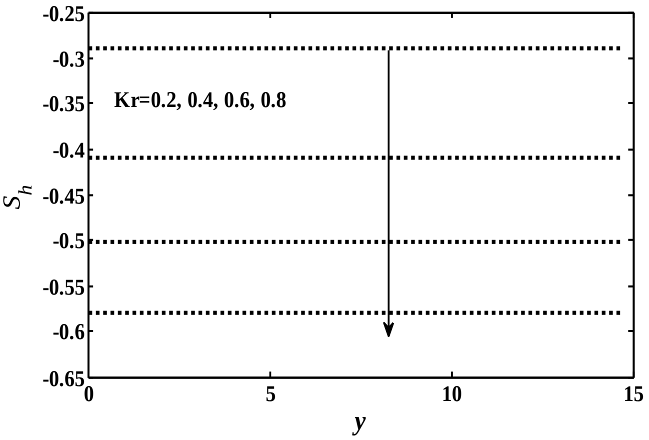

Figure 12: Effect of *Kr* on Sherwood number

Fig 3: Illustrated that for dissimilar values of radiation parameter rises that it leads to declined in temperature. Fig 4: Established that for disparate values of Prandtl number (*Pr*) rises then it leads to reduced in temperature. This is owing to the reality that a higher Prandtl number fluid has comparatively low thermal conductivity, which diminishes the conduction as an outcome temperature reduces. As a result higher Prandtl number *Pr* show the way to more rapidly cooling of the plate. Fig 5: Demonstrate the performance of concentration for disparate estimators of chemical reaction (*Kr)*. The results obtained from this figure it was perceived that the concentration reduced due to rise in chemical reaction parameter. For the reason that the chemical reaction reinforce momentum transfer and consequently accelerates the flow. For incongruent estimators of the Schmidt number on the fluid concentration is exposed in the Fig 6: From this figure it was found that the outcomes indicate that the enhancement of *Sc* leads to diminished in concentration. Due to the effect of concentration buoyancy to declined, yielding reduce in the velocity. The depletion in the concentration is accompanied by instantaneous depletion in the concentration boundary layers, which is perceptible from the Fig 6. The influence of hall (β_e) and ion slip (β_i) current was illustrated in the Fig 7: and Fig 8: Form these figures it was determined that for heterogeneous incremental values of hall (β_e) as well as ion slip (β_i) leads to declined in the Skin-friction. For incongruent values of Prandtl number (*Pr*) on the Nusselt number is showing in the Fig 9: From the figure it is obvious that the outcomes illustrates rise in the *Pr* outcome N_w becomes rises. The impact of heat source parameter(η) on the nusselt number is presented on Fig 10: From this figure it is evidently that as η rises subsequently it leads to diminish in N_w. Fig 11: & Fig 12: Described the influence of Schmidt number(*Sc*) as well as Chemical reaction (*Kr*) on the Sherwood number(S_h). Here the results indicated that Sherwood number diminished with the enhancement of *Sc* as well as *Kr.*

IV. CONCLUSIONS

- The velocity distribution declined with the enhancement of Hall and Ion-slip parameter.
- The temperature profile is reduced with the enhancement of Radiation parameter and Prandtl number.
- The concentration diminished with amplifies in chemical reaction parameter and Schmidt number.
- As incremental values of β_e & β_i, Skin friction becomes declined.
- The Nusselt number rises with the enhancement of *Pr* but contrast effect was occurred in case of η.
- The Sherwood number reduced with the accelerated values of *Sc* as well as *Kr.*

Conflict of Interest

Both the authors have equal contribution in this work and it is declared that there is no conflict of interest for this publication.

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Nomenclature	
x^*, y^*	Coordinate axis along the plate*(m)*, Co-ordinate axis normal to the plate*(m)*
B_0	Magnetic induction *(A.m^{-1})*
T	Temperature of the fluid *(K)*
T_w	Fluid temperature at walls *(K)*
T_w^*	Fluid temperature at the wall *(K)*
T_∞	Dimensional free stream temperature *(K)*
u	components of velocity vector in x direction(m.S^{-1})
v	Velocity component in y direction *(m.S^{-1})*
g^*	acceleration due to gravity *(m.S^{-2})*
η	Heat generation parameter
Pr	Prandtl number
q_r^*	Radiation heat flux density *(W.m^{-2})*
ω	Frequency of vibration of the fluid
$t*$	Dimensional time *(S)*
M	Magnetic parameter
K	Permeability of porous medium
Gr	local temperature Grashof number
β	Spin gradient viscosity (K^{-1})
μ	Fluid dynamic viscosity
ρ	Density of the fluid *(kg.m^{-3})*
R	The radiative parameter
ϕ	Temperature difference parameter
β_i ,	Ion-slip parameter
β_e	Hall parameter
τ_w	Skin friction
N_w	Nusselt number
S_h	Sherwood number