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Research paper

Viscous Dissipation and Dufour Effects on MHD Free Convection Flow Through an Oscillatory Inclined Porous Plate with Hall and Ion-Slip Current

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Abstract

In this paper the viscous dissipation and Dufour effects on Unsteady MHD free convective flow through a semi-infinite Oscillatory porous inclined plate of time dependent permeability with Chemical reaction and Hall and Ion-Slip Current in a Rotating System was investigated. The dimensionless governing equations for this investigation are solved analytically by using multiple regular perturbation law. The effects of different parameters on velocity, temperature and concentration fields are shown graphically.

Keywords: *chemical reaction; Dufour; Hall Effect; Ion-Slip effects; Radiation absorption; viscous dissipation*

1. Introduction

Magneto hydrodynamic flow of heat and mass transfer processes occur in many of the industrial applications: such as cooling of geothermal systems, aerodynamic processes, chemical catalytic reactors and processes, electromagnetic pumps, and Magneto Hydrodynamic power generators etc Viscous dissipation expects a basic part in changing the temperature movement, much the same as an imperativeness source, which impacts the heat transfer rates fundamentally. Shankar Goud *et al.* [1] analyzed of viscous dissipation and diffusion thermo on effects on unsteady Magneto hydrodynamic flow past an impulsively started inclined oscillating plate with mass diffusion and variable temperature. Alivene *et al.* [2] examined the viscous dissipation, radiation and Hall effects on convective heat and mass transfer flow of a fluid past a stretching sheet. Subhakanthi *et al.* [3] Analyzed the viscous dissipation and chemical reaction effects on heat and mass transfer in Magneto Hydrodynamic flow past an inclined porous plate. G.V. Reddy *et al*. [4] reported viscous dissipation and radiation effects on unsteady Magneto hydrodynamic free convection heat and mass transfer flow past a semi-infinite inclined moving plate. Rajput *et al* [5] considered effects of chemical reaction and Hall current on unsteady Magneto Hydrodynamic flow past through an oscillating inclined porous plate with mass diffusion and variable temperature. Rajput *et al* [6] examined the effects of Hall current and chemical reaction on unsteady Magneto Hydrodynamic flow past an impulsively started inclined plate with mass diffusion and variable wall temperature. The energy flux caused due to composition gradient is known as Dufour effect. Raj put *et al* [7] Hall effects on unsteady Magneto Hydrodynamic flow past over exponentially accelerated inclined porous plate with mass transfer and variable wall temperature was analyzed. In the investigation Dufour effect was not consider. Jithender Reddy *et al* [8] considered Dufour, thermal radiation and hall current on unsteady magneto hydrodynamic natural convective heat and mass transfer of a fluid flow past an impulsively moving vertical porous plate in the presence of ramped temperature. Ion-slip and Hall current are probably going to be fundamental in flows of lab plasma when a solid magnetic field of a uniform quality is connected and drawn the consideration of the analysts MD. Shah Alam et *al* [9]Magneto Hydrodynamic free convection heat and mass transfer of fresh as well as salt water flow on an infinite inclined plate with Hall current and constant heat flux. Sivaiah *et al* [10] studied hall current and radiation effects on Magneto Hydrodynamic free convective flow past an inclined porous plate with thermal diffusion and heat source. Remembering every one of these realities in this work the effect the Dufour, Radiation absorption, Chemical reaction, and viscous dissipation on Unsteady MHD free convective flow through a semi-infinite vertical Oscillatory inclined porous plate of time dependent permeability with Hall and Ion-Slip Current in a Rotating System was investigated. The perturbation technique is employed to solve governing coupled non-liner partial differential equations.

2. Mathematical Formulation

The unsteady flow of a electrically conducting incompressible viscous fluid past semi-infinite inclined porous plate y=0 has been considered, with the x-axis chosen along the plate, when the plate velocity U (t) oscillates in t with a frequency n and is given as $U(t)=U_0(1+\cos nt)$.Let the x*and y* are the dimensional distance along the perpendicular to the plate and t* is the time. The physical model of the flow problem is shown in figure A. u* is the component of dimensional velocities along x*and y* directions. The flow is assumed to be in x-direction and which is taken along

the plate in upward direction and y-axis is normal to it. Initially the fluids as well as the plate are at rest but for time t >0 the whole system is allowed to rotate with a constant angular velocity Ω about the y-axis. Assumed transverse magnetic field of the uniform strength B_0 is to be utilizable normal to the plate. Viscous dissipation, Radiation absorption, the heat source, and Dufour effects are considered. The physical configuration of the problem is shown in the Figure A.
Hence dimensional governing equations are;
Equation of Momentum:

$$\left[\frac{\partial u^*}{\partial \tau^*}\right] = \vartheta\left[\frac{\partial^2 u^*}{\partial {y^*}^2}\right] + g\beta\left[\left(T^* - T^*_\infty\right)\cos\psi + \frac{\beta^*}{\beta}\left(C^* - C^*_\infty\right)\cos\psi\right]$$
$$+2\Omega\, w^* - \frac{\nu}{k^*}\left[u^*\right] - \frac{B_0^2\sigma_e\left[\alpha_e u^* + \beta_e w^*\cos\psi\right]\cos^2\psi}{\rho\left[\alpha_e^2+\beta_e^2\cos\psi\right]} \quad (1)$$

$$\left[\frac{\partial w^*}{\partial \tau^*}\right] = \vartheta\left[\frac{\partial^2 w^*}{\partial {y^*}^2}\right] - 2\Omega\left[u^*\right] - \frac{\vartheta}{k^*}\left[w^*\right]$$
$$+\frac{B_0^2\sigma_e\left[\beta_e u^*\cos\psi - \alpha_e w^*\right]\cos^2\psi}{\rho\left[\alpha_e^2+\beta_e^2\cos\psi\right]} \quad (2)$$

Equation of Energy:

$$\left[\frac{\partial T^*}{\partial \tau^*}\right] = \frac{K}{\rho C_p}\left[\frac{\partial^2 T^*}{\partial {y^*}^2}\right] + \frac{D_m K_T}{C_S C_P}\left[\frac{\partial^2 C^*}{\partial {y^*}^2}\right] + \frac{Q_0}{\rho C_p}\left[T^* - T^*_\infty\right]$$
$$-\frac{1}{k\rho C_p}\left[\frac{\partial q_r^*}{\partial y^*}\right] + \frac{\vartheta}{C_p}\left[\left(\frac{\partial u^*}{\partial y^*}\right)^2 + \left(\frac{\partial w^*}{\partial y^*}\right)^2\right] + R^*\left[C^* - C^*_\infty\right] \quad (3)$$

Concentration species diffusion equation:

$$\left[\frac{\partial C^*}{\partial \tau^*}\right] = D_m\left[\frac{\partial^2 C^*}{\partial {y^*}^2}\right] - K_r\left[C^* - C^*_\infty\right] \quad (4)$$

The initial and boundary conditions are as

$$\left.\begin{array}{l} at\;\; y^* = 0 \Rightarrow \begin{cases} u^* = U_0\left[1+\frac{\varepsilon}{2}\left(e^{in^*t^*} + e^{-in^*t^*}\right)\right], w^* = 0, \\ T^* = T^*_w + \varepsilon(T^*_w - T^*_\infty)e^{in^*t^*}, \\ C^* = C^*_w + \varepsilon(C^*_w - C^*_\infty)e^{in^*t^*} \end{cases} \\ as\;\; y^* \to \infty\;\; u^* = 0, w^* = 0,\; T^* = T^*_\infty, C^* = C^*_\infty \end{array}\right\} \quad (5)$$

Using the relation in the radiative heat flux (q_r) for the optically thin non gray gas near equilibrium is given by

$\frac{\partial q_r}{\partial y} = 4I^1 T\left[T - T_1\right],\quad I^1 = \int_0^\infty K_{\lambda_1 w}\frac{\partial e_{b\lambda_1}}{\partial T}d\lambda_1$ Where q_r is the radiative heat flux, $K_{\lambda_1 w}$ is the radiation absorption coefficient at the wall and $e_{b\lambda_1}$ is Plank's constant. The permeability of the porous medium is assumed to be $k^* = k_0\left[1+\varepsilon e^{-nt}\right]$, here k_0 is the constant permeability of the medium. Introducing the following non-dimensional quantities in the (1)-(4)

$$\left.\begin{array}{l} U_0 u = u^*, U_0 w = w^*, \vartheta y = y^* U_0, t\vartheta = U_0^2\tau^*, \\ n{U_0}^2 = \vartheta n^*, T^* - T^*_\infty = \left(T^*_w - T^*_\infty\right)\theta, \\ C^* - C^*_\infty = \left(C^*_w - C^*_\infty\right)\phi, \end{array}\right\} \quad (6)$$

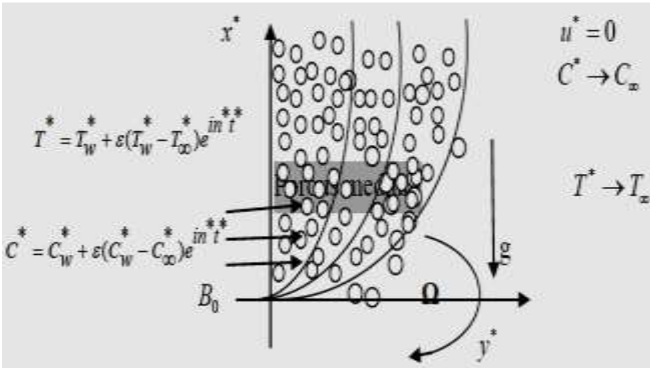

Figure A: The physical model in the problem

Then the equation (1), (2), (3) and (4) reduce to the following non-dimensional form of equations

$$\left[\frac{\partial u}{\partial t}\right] = \left[\frac{\partial^2 u}{\partial y^2}\right] + G_r\left[\theta\right]\cos\psi + G_m\left[\phi\right]\cos\psi + 2R\left[w\right]$$
$$-\gamma\left[u\right] - \frac{M\left[\alpha_e u + \beta_e w\cos\psi\right]C\,os^2\psi}{\left[\alpha_e^2 + \beta_e^2\cos\psi\right]} \quad (7)$$

$$\left[\frac{\partial u}{\partial t}\right] = \left[\frac{\partial^2 u}{\partial y^2}\right] + G_r\left[\theta\right]\cos\psi + G_m\left[\phi\right]\cos\psi + 2R\left[w\right]$$
$$-\gamma\left[u\right] - \frac{M\left[\alpha_e u + \beta_e w\cos\psi\right]C\,os^2\psi}{\left[\alpha_e^2 + \beta_e^2\cos\psi\right]} \quad (8)$$

$$\left[\frac{\partial\theta}{\partial t}\right] = \frac{1}{\Pr}\left[\frac{\partial^2\theta}{\partial y^2}\right] - N\left[\theta\right] + Dr\left[\frac{\partial^2\phi}{\partial y^2}\right] + R_a\left[\phi\right]$$
$$+Ec\left(\left(\frac{\partial u^*}{\partial y^*}\right)^2 + \left(\frac{\partial w^*}{\partial y^*}\right)^2\right) \quad (9)$$

$$\left[\frac{\partial\phi}{\partial t}\right] = (Sc)^{-1}\left[\frac{\partial^2\phi}{\partial y^2}\right] - K_r\left[\phi\right] \quad (10)$$

$$\left.\begin{aligned}
&\xi = \frac{\vartheta Q_0}{\rho U_0^2 C_P}, M = \frac{\sigma_e B_0^2 \vartheta}{\rho U_0^2}, G_m = \frac{\vartheta \beta^* g\left[C_w^* - C_\infty^*\right]}{U_0^2} \\
&, G_r = \frac{\vartheta \beta g\left[T_w^* - T_\infty^*\right]}{U_0^2}, \eta = \frac{4\vartheta I'}{K_p C_p U_0^2}, R = \frac{\Omega \vartheta}{U_0^2} \\
&Sc = \frac{\vartheta}{D_m}, R_a = \frac{R^* \vartheta\left[C_w^* - C_\infty^*\right]}{U_0^2\left[T_w^* - T_\infty^*\right]}, \Pr = \frac{\rho \vartheta C_p}{\sigma}, \\
&Dr = \frac{D_m K_T\left[C_w^* - C_\infty^*\right]}{\vartheta C_S C_P\left[T_w^* - T_\infty^*\right]}, \alpha_e = 1 + \beta_e \beta_i, \gamma = \frac{\vartheta^2}{k^* U_0^2} \\
&Ec = \frac{U_0^2}{C_p\left[T_w^* - T_\infty^*\right]}, K_r = \frac{k_1 \vartheta}{V_0^2}, N = \left[\xi + \eta\right], \\
&\lambda = \left[\left[2Ri + \gamma\right] + \frac{M\left[-\alpha_e + i\beta_e \cos\psi\right]\cos^2\psi}{\left[\alpha_e^2 + \beta_e^2 \cos\psi\right]}\right],
\end{aligned}\right\} \quad (11)$$

Equations (9) - (10) are displayed, in a reduced form, as

$$\frac{\partial U}{\partial t} = \frac{\partial^2 U}{\partial y^2} + G_r \theta \cos\psi + G_m \phi \cos\psi - \lambda U \quad (12)$$

Where $U = u + iw$

$$\left.\begin{aligned}
&At\ y=0\quad U = \left[1 + \frac{\varepsilon}{2}\left(e^{i\,\mathrm{nt}} + e^{-i\,\mathrm{nt}}\right)\right] = 1,\ \theta = 1 + \varepsilon e^{int},\ \phi = 1 + \varepsilon e^{int} \\
&As\ y \to \infty \quad F \to 0,\ \theta \to 0,\ \phi \to 0
\end{aligned}\right\} \quad (13)$$

3. Method of Solution:

The resulting system of nonlinear ODEs Esq. (11), (12) and (14) subject to the boundary conditions presented in Esq. (12) has been explored numerically through Multiple Regular Perturbation law.

$$\left.\begin{aligned}
F &= F_0(y) + \varepsilon e^{int} F_1(y) + o\left(\varepsilon^2\right)..... \\
\theta &= \theta_0(y) + \varepsilon e^{int} \theta_1(y) + o\left(\varepsilon^2\right)...... \\
\phi &= \phi_0(y) + \varepsilon e^{int} \phi_1(y) + o\left(\varepsilon^2\right)......
\end{aligned}\right\} \quad (14)$$

After Substitute (14) in the equations (9), (10) and (12) then we get

$$U_0'' - \lambda U_0 = -G_r \cos\psi \theta_0 - G_m \cos\psi \phi_0 \quad (15)$$

$$U_1'' - \left[\lambda + ni\right] U_1 = -G_r \cos\psi \theta_1 - G_m \cos\psi \phi_1 \quad (16)$$

$$\theta_1'' - \Pr\left[N + in\right]\theta_1 = -\Pr Dr \phi_1'' - 2\Pr Ec F_0' F_1' - \Pr R_a \phi_1 \quad (17)$$

$$\theta_0'' - \Pr N \theta_0 = -\Pr Dr \phi_0'' - \Pr Ec\left[U_0'\right]\left[U_0'\right] - \Pr Ra \phi_0 \quad (18)$$

$$\phi_0'' - S_c K_r \phi_0 = 0 \quad (19)$$

$$\phi_1'' - S_c\left[K_r + n\right]\phi_1 = 0 \quad (20)$$

The corresponding boundary conditions can be written as

$$\left.\begin{aligned}
&U_0 = 1, U_1 = 0, \theta_0 = 1\ \theta_1 = 1, \phi_0 = 1, \phi_1 = 1,\ at\ y = 0 \\
&U_0 = 0, U_1 = 0, \theta_0 \to 0, \theta_1 \to 0, \phi_0 \to 0, \phi_1 \to 0,\ as\ y \to \infty
\end{aligned}\right\} \quad (21)$$

First we solve the equations (19) and (20) by using equation (21) then we get

$$\phi_0 = e^{-\left(\sqrt{ScKr}\right)y} \quad (22)$$

$$\phi_1 = e^{-\left(\sqrt{Sc(Kr+n)}\right)y} \quad (23)$$

Now using multi parameter perturbation technique and assuming $Ec << 1$.

$$\left.\begin{aligned}
&F_0 = F_{00} + EcF_{01} + 0(\varepsilon)^2 ....\ \ \theta_0 = \theta_{00} + Ec\theta_{01} + 0(\varepsilon)^2 .... \\
&F_1 = F_{10} + EcF_{11} + 0(\varepsilon)^2 ....\ \ \theta_1 = \theta_{10} + Ec\theta_{11} + 0(\varepsilon)^2 .....
\end{aligned}\right\} \quad (24)$$

By using equations (24) in equations (15)-(18) and equating the coefficients of like powers of Ec neglecting those of $\left[Ec\right]^2$ and $0\left[\varepsilon\right]^2$ we get the following set of differential equations,

$$\left.\begin{aligned}
&U_0 = 1, U_1 = 0, \theta_0 = 1\ \theta_1 = 1, \phi_0 = 1, \phi_1 = 1,\ at\ y = 0 \\
&U_0 = 0, U_1 = 0, \theta_0 \to 0, \theta_1 \to 0, \phi_0 \to 0, \phi_1 \to 0,\ as\ y \to \infty
\end{aligned}\right\} \quad (25)$$

$$U_{00}'' - \lambda U_{00} = -G_r \cos\psi \theta_{00} - G_m \cos\psi \phi_0 \quad (26)$$

$$U_{01}'' - \lambda U_{01} = -G_r \cos\psi \theta_{01} \quad (27)$$

$$U_{10}'' - \left[\lambda + ni\right] U_{10} = -G_r \cos\psi \theta_{10} - G_m \cos\psi \phi_1 \quad (28)$$

$$U_{11}'' - \left[\lambda + ni\right] U_{11} = -G_r \cos\psi \theta_{11} \quad (29)$$

$$\theta_{10}'' - \Pr\left[N + in\right]\theta_{10} = -R_a \phi_1 \Pr - \Pr Dr\ \phi_1'' \quad (30)$$

$$\theta_{11}'' - \Pr\left[N + in\right]\theta_{11} = -2\Pr F_{00}' F_{10}' \quad (31)$$

$$\theta_{00}'' - \Pr N\ \theta_{00} = -\Pr R_a\ \phi_0 - \Pr Dr\ \phi_0'' \quad (32)$$

$$\theta_{01}'' - \Pr N \theta_{01} = -\Pr\left[U_{00}'\right]\left[U_{00}'\right] \quad (33)$$

$$\left.\begin{aligned}
&at\ y = 0; \Rightarrow \begin{cases} U_{00} = 1, U_{01} = 0, U_{10} = 0, U_{11} = 0, \\ \theta_{00} = 1,\ \theta_{01} = 0, \theta_{10} = 1,\ \theta_{11} = 0 \end{cases} \\
&As\ y \to \infty \Rightarrow \begin{cases} U_{00} = 0,\ U_{01} = 0,\ U_{10} = 0, U_{11} = 0, \\ \theta_{00} = 0, \theta_{01} = 0, \theta_{10} = 0,\ \theta_{11} = 0 \end{cases}
\end{aligned}\right\} \quad (34)$$

3.1. Velocity (F), Temperature (θ) and Concentration (ϕ):

$$\left.\begin{aligned} F &= \left[\left(F_{00} + EcF_{01}\right) + \varepsilon e^{\text{int}}\left(F_{10} + EcF_{11}\right)\right] \\ \theta &= \left[\left(\theta_{00} + Ec\theta_{01}\right) + \varepsilon e^{\text{int}}\left(\theta_{10} + Ec\theta_{11}\right)\right] \\ \phi &= \phi_0 + \varepsilon e^{\text{int}}\phi_1 \end{aligned}\right\} \qquad (35)$$

4. Results and Discussion:

In the present study we have to select t=1.0, n=0.5, ϵ=0.03, η=0.03 ξ =0.03 while Gm, γ , M, Ra, Ec, β_i , β_e and Dr are varied over a range, which listed in the figure. Figure 1:, Figure 2: and Figure 3: from this figures reflects that for different values of inclination of magnetic field ψ , Dufour effect Dr and ion-slip parameter β_i increases then it lead to velocity profile increases. Figure 4: Figure 5: Depict the effect of Dufour affect Dr and Eckert number Ec on the temperature profile. It is observed that temperature scores increases with the increase of Dr and Ec. Figure 9: the velocity profile decreases with an increase in β_e .

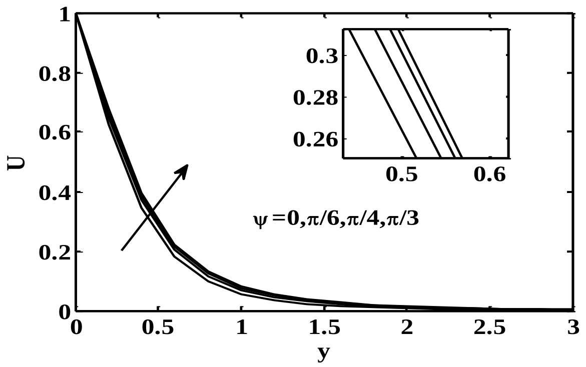

Fig 1: Effect of ψ for different values on Velocity

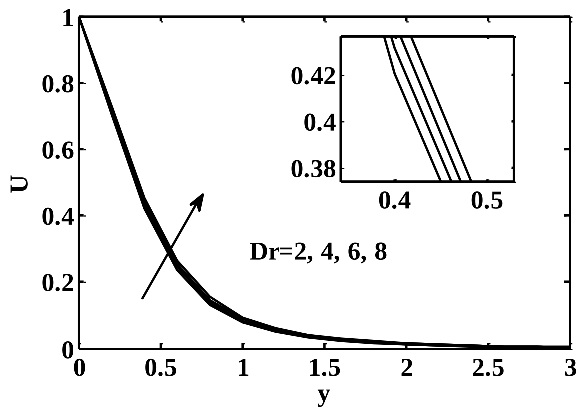

Fig 2: Effect of Dr for different values on Velocity

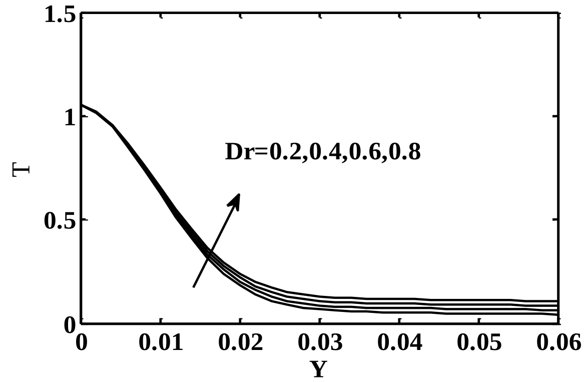

Fig 3: Effect of Dr for different values on Temperature

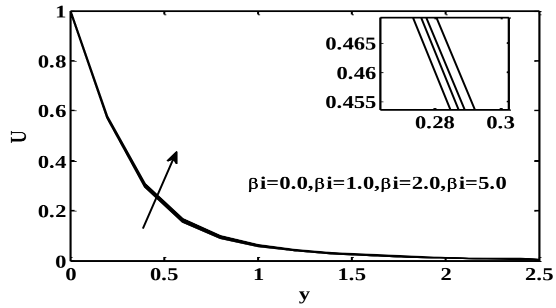

Fig 4: Effect of β_i for different values on Velocity

From the figure 7: for different values of Pr increase then it leads to decrease in temperature. From the Figure 8: For different values R increases then it lead to increases in temperature

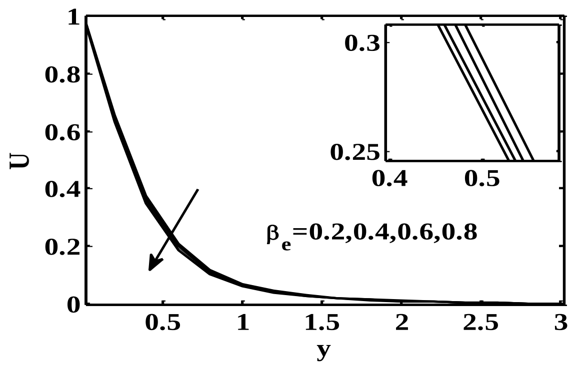

Fig 5: Effect of β_e for different values on Velocity

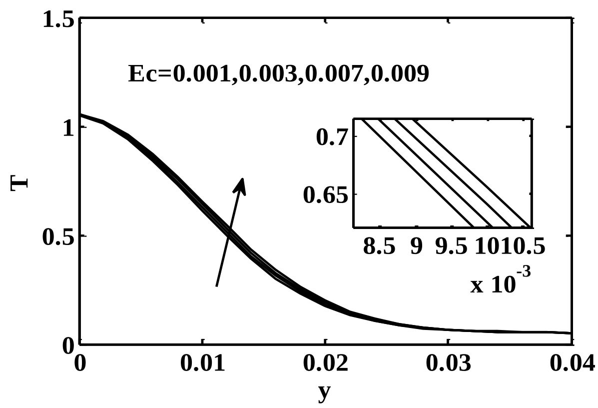

Fig 6: Effect of Ec for different values on Temperature

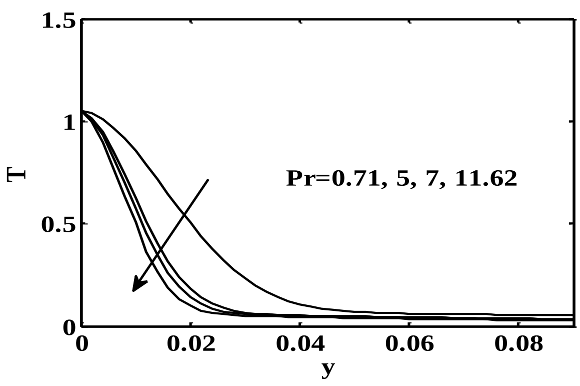

Fig 7: Effect of Pr for different values on Temperature

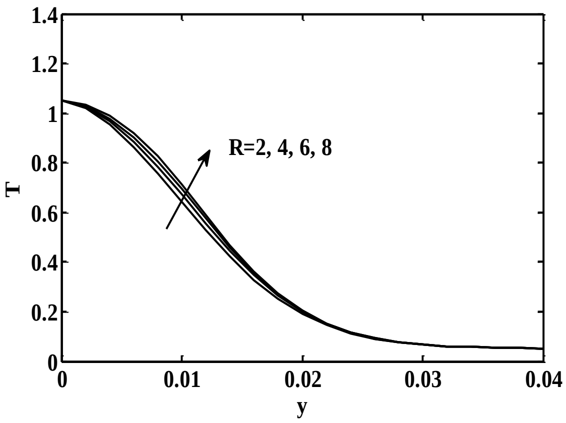

Fig 8: Effect of R for different values on Temperature

5. Conclusions:

The dimensionless governing equations for this investigation are solved analytically by using multiple regular perturbation law. The effects of different parameters on velocity, temperature and concentration fields are discussed in detail. As temperature profile increases with the increase of Eckert number Ec. Velocity increases with increase in inclined angle ψ .As the Ion-slip parameter β_i increases the Velocity profiles increases and velocity decrease with increases of Hall current parameter β_e .As the Dufour effect parameter Dr Increases the velocity and temperature increases.

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Nomenclature:

u	Velocity component
γ	Permeability of porous medium
T_w	Temperature at the plate
T_∞	Temperature outside of the boundary lyre(K)
C_w	Concentration at the plate
C_∞	Concentration outside of the plate($kg.m^{-3}$)
Ω	Rotational velocity component
U	Dimensionless primary velocity
W	Dimensionless secondary velocity
T^*	Dimensionless fluid temperature
C^*	Dimensionless fluid concentration
ψ	Inclined angle
B	Magnetic field
B_0	Magnetic component(A.m-1)
U_0	Uniform velocity
Gr	Grashof number
Gr	Modified Grashof number
n^*	Mining
Ec	Eckret number
R	Rotational parameter
η	Radiation parameter
τ_w	Skin-friction coefficient
ξ	Dimensional heat generation /absorption co-efficient
∞	Free stream condition
e	electron charge(C)
β_e	Hall parameter
β_i	Ion-slip parameter
k	Magnetic permeability of the porous medium
β	Thermal expansion co-efficient(K-1)
β^*	Concentration expansion co-efficient(m3.kg-1)
α	Heat source parameter
ϑ	Kinematic velocity(m2.S-1)
ρ	Density of the fluid (kg.m-3)
σ_ρ	Electrical conductivity($\Omega^{-1}m^{-1}$)
σ	Thermal conductivity(W.m-1 .K-1)
C_p	Specific heat at constant pressure(J. kg −1.K)
D_m	Co-efficient of mass diffusivity(m2.S-1)
Q_0	Heat absorption quantity
K_r	Chemical reaction parameter(m.S-1)
T_m	Mean fluid temperature(K)
Pr	Prandtl number
Dr	Dufour number
Sc	Schmidt number
ε	Arbitrary constant

Ra	Thermal radiation parameter
α_e	$= 1+\beta_e\beta_i$
N_u	Nusselt number
t^*	Dimensional time(S)
q_r^*	Radiation heat flux density(W.m-2)
g	acceleration due to gravity(m.S-2)
x,y	Cartesian co-ordinates