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MHD Oscillatory Flow of Non Newtonian Fluid through Porous Medium in the Presence of Radiation and Chemical Diffusion with Hall Effects

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ABSTRACT: A study has been carried out to analyze MHD flow of fluid through vertical porous medium placed in a magnetic field with the effect of suction/injection on the unsteady second grade fluid flow through a vertical channel with non-uniform wall temperature. The governing equations under a flow parameters on velocity, temperature and concentration profiles, are solved using regular perturbation method and the results are represented graphically.

Keywords: Hall effects, oscillatory flow, porous medium, magnetic field, fluid slip, suction/injection.

I. INTRODUCTION

The study of oscillatory flow of an electrically conducting fluid through a porous channel saturated with porous medium is important in many physiological flows and engineering applications such as magneto hydrodynamic (MHD) generators, arterial blood flow, petroleum engineering, etc., Makinde and Mhone [17] investigated the combined magnetic field and heat transfer in the presence of porous medium on unsteady flow in a non-uniform wall temperature. Mehmood and Ali [18] studied the slip effect condition on unsteady MHD oscillatory flow of viscous fluid in a planer channel with a saturated porous medium. Chauchan and Kumar [7] theoretically analyzed about a fully developed mixed convection viscous fluid flow between two infinite vertical parallel plane walls, in the presence of radiation and viscous dissipation effects. Palani and Abbas [19] investigated numerically the free convection flow past by isothermal vertical plate with the combined effects of magneto hydrodynamics and radiation using finite element method. Hussain *et al.* [9] developed the second grade fluid in a porous medium using modified Darcy's law on account of hall current. Umavathi *et al.,* [23] presented an unsteady oscillatory flow and heat transfer in a horizontal composite channel consisting of two parallel permeable plates one filled by a fluid saturated porous layer and another by viscous fluid. Jha and Ajibade [12-14] presented a free convective flow of viscous incompressible fluid between two periodically heated infinite vertical parallel plates by suction/injection through heat generating /absorbing fluid with boundary condition using time dependent. Adesanya *et al.,* [1-2] represented a domain decomposition method for dimensionless partial differential equation by the effect of radiative heat transfer on the pulsatile couple stress fluid flow due to periodic heat input at the heated wall and the slip condition holds at lower wall. Adesanya *et al.*, [3] investigated by taking the effects of joule dissipation with boundary valued problem. Adesanya [4] presented unsteady free convective flow of fluid through a porous vertical channel with velocity slip and temperature jump. Adesanya Falade, Makinde, [5] investigated the mixed convective pulsatile fluid flow through a heated porous channel with time periodic boundary conditions. Adesanya, Falade, [6] presented a third grade fluid through a porous medium in times of thermodynamics analysis. Siva raj Rushi Kumar [20-21] studied heat absorbing and chemically reacting dusty viscoelastic fluid couette flow between vertical long wavy wall and parallel flat wall saturated with porous medium with temperature and mass diffusion. Jasmine Benazir, Siva raj, Rashidi, [10, 11, 22] presented an incompressible Caisson fluid over a vertical cone and flat plate saturated with porous medium with variable viscosity and electrical conductivity. Veera Krishna *et al.*, [24] investigated unsteady two dimensional flow of blood in a porous arteriole of transverse magnetic field under heat and mass transfer. Veera Krishna *et al.,* [25-26] discussed about an electrically conducting incompressible viscous second grade fluid bounded by a loosely packed porous medium. Veera Krishna and Chamkha [8] investigate the effect on suction/injection due to the unsteady oscillatory flow with transverse magnetic field and velocity slip at lower plate. Veera Krishna and Chamkha [27] presented a rotating flow of Nano-fluids on semi-infinite permeable plate with heat source. Veera Krishna [28] discussed an infinite vertical porous plate in terms of soret, joule and effect, hall current on mixed convective flow of an incompressible and electrically conducting viscous fluid. Veera Krishna and Chamkha [29] presented a water based Nano fluid through a saturated porous medium between two parallel disks. Kalpana and BhuvanaVijay [15] studied the effect of suction/injection on the unsteady oscillatory second grade fluid flow through a vertical channel with non-uniform wall temperature and taking hall current into account. Karuna Dwivedi, khare and Ajit Paul [16] discussed about the MHD free convective flow through porous medium in the presence of hall current, radiation and thermal diffusion.

Keeping the above mentioned facts, in this paper, we considered the effect of suction/injection on the unsteady oscillatory second grade fluid flow through a vertical channel filled with saturated porous medium in the presence of hall current, radiation, thermal and molecular diffusion.

II. MATHEMATICAL FORMULATION

Consider the MHD flow of mass transfer through unsteady laminar flow of an incompressible viscous electrically conduction second grade fluid through vertical porous channel filled with porous medium having inclined magnetic field with slip at the cold plate. The fluid flow put through the suction at the cold wall and injection at the heated wall. Consider a Cartesian coordinate system (x, y, z) where x lies along the center of the channel, and z is the distance measured in the normal section such that z = d is the channel's half width.

By the Boussinesq's approximation the governing equations flow are as follows:

Equations of continuity

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \quad (1)$$

Momentum of equations

$$\frac{\partial u}{\partial t}-w_0\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+v\frac{\partial^2 u}{\partial z^2}+\frac{\alpha_1}{\rho}\frac{\partial^3 u}{\partial z^2\partial t}+B_0J_y-\frac{v}{k_1}u +g\beta(T-T_0)+g\beta^*(C-C_0) \quad (2)$$

$$\frac{\partial v}{\partial t}-w_0\frac{\partial v}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+v\frac{\partial^2 v}{\partial z^2}+\frac{\alpha_1}{\rho}\frac{\partial^3 v}{\partial z^2\partial t}+B_0J_x-\frac{v}{k_1}v \quad (3)$$

Equations of energy

$$\frac{\partial T}{\partial t}-w_0\frac{\partial T}{\partial z}=\frac{k_f}{\rho C_p}\frac{\partial^2 T}{\partial z^2}-\frac{1}{\rho C_p}\frac{\partial q}{\partial y}+\frac{4\alpha^2}{\rho C_p}(T-T_0) \quad (4)$$

Equations of concentration

$$\frac{\partial C}{\partial t}-w_0\frac{\partial C}{\partial z}=D_m\frac{\partial^2 C}{\partial z^2}+D_T\frac{\partial^2 T}{\partial z^2}+k_1(C-C_0) \quad (5)$$

If the strength of the magnetic field is very large, the generalized ohm's law is changed to hall current so that

$$\mathbf{J}+\frac{\omega_e\tau_e}{B_0}(\mathbf{J}\times\mathbf{B})=\sigma\left[\mathbf{E}+\mathbf{V}\times\mathbf{B}+\frac{1}{e\eta_e}\nabla P_e\right] \quad (6)$$

Further it is assumed that $\omega_e\tau_e$ ~ 0 (1) and $\omega_i\tau_i \ll 1$, where ω_i and τ_i are the cyclotron frequency and collision time for ions respectively. In the equation (6) the electron pressure gradient, the ion-slip and thermo-electric effects are neglected. Suppose that the electric field E=0 under assumptions reduces to

$$J_x+ m J_y=\sigma B_0 v \quad (7)$$

$$J_y- m J_x=-\sigma B_0 v \quad (8)$$

By equating (7) and (8) we get,

$$J_x=\frac{\sigma B_0}{1+m^2}(v+mu) \quad (9)$$

$$J_y=\frac{\sigma B_0}{1+m^2}(mv-u) \quad (10)$$

Substitute equations (9) and (10) in (3) and (2), we obtain

$$\frac{\partial u}{\partial t}-w_0\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+v\frac{\partial^2 u}{\partial z^2}+\frac{\alpha_1}{\rho}\frac{\partial^3 u}{\partial z^2\partial t}+\frac{\sigma B_0^2}{1+m^2}(mv-u)-\frac{v}{k_1}u+g\beta(T-T_0)+g\beta^*(C-C_0) \quad (11)$$

$$\frac{\partial v}{\partial t}-w_0\frac{\partial v}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+v\frac{\partial^2 v}{\partial z^2}+\frac{\alpha_1}{\rho}\frac{\partial^3 v}{\partial z^2\partial t}-\frac{\sigma B_0^2}{1+m^2}(v+mu)-\frac{v}{k_1}v \quad (12)$$

On combining Eqns. (11) and (12), in terms of q = u + iv and ξ = x + iy, we obtain

$$\frac{\partial q}{\partial t}-w_0\frac{\partial q}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial \xi}+v\frac{\partial^2 q}{\partial z^2}+\frac{\alpha_1}{\rho}\frac{\partial^3 q}{\partial z^2\partial t}-\frac{\sigma B_0^2}{\rho(1-im)}q-\frac{v}{k_1}q+g\beta(T-T_0)+g\beta^*(C-C_0) \quad (13)$$

The boundary conditions are

$$q=\frac{\sqrt{k}}{\alpha_s}\frac{\partial q}{\partial z},\ T=T_0,\ C=C_0 \text{ at } z=0 \quad (14)$$

$$q=0,\ T=T_1,\ C=C_1 \text{ at } z=d \quad (15)$$

Introducing the dimensionless parameters, variables are given as

$(x^*,y^*)=\frac{(x,y)}{d}$, $q^*=\frac{qv}{d}$, $t=\frac{t^*d^2}{v}$, $p^*=\frac{p\rho v^2}{d^2}$, $\theta=\frac{T-T_0}{T_1-T_0}$, $\emptyset=\frac{C-C_0}{C_1-C_0}$, $G_r=\frac{g\beta(T-T_0)d^3}{v^2}$, $G_m=\frac{g\beta^*(C-C_0)d^3}{v^2}$, $P_r=\frac{\rho c_p v}{k}$, $\delta=\frac{4\alpha^2 d^2}{\rho C_p v}$, $\gamma=\frac{\sqrt{k}}{\alpha_s d}$, $M^2=\frac{\sigma B_0^2 d^2}{\rho v}$, $K=\frac{K_1}{d^2}$, $s=\frac{\omega_0 d}{\gamma}$, $N=\frac{2ad}{\sqrt{k}}$, $s_c=\frac{v}{D_m}$, $s_0=\frac{D_T(T_1-T_0)}{V(C_1-C_0)}$, $x^*=\frac{x}{d}$, $y^*=\frac{y}{d}$, $z^*=\frac{z}{d}$

Where,*: Represents the dimensional quantity, v: Kinematics Viscosity of fluid, t^*: Time, ρ: Density of fluid, p^*: Pressure of fluid, T^*: Temperature of fluid, C_P: Specific heat at constant pressure, κ: Thermal conductivity of fluid, g: Acceleration due to gravity, β: Volumetric coefficient of thermal expansion, C^*: Concentration of fluid, β^*: Volumetric coefficient of thermal expansion with concentration, D_m: Chemical molecular diffusivity, D_T: Thermal diffusivity, G_r: Grashof number, G_m: Modified Grashof number, M: Hartman number, P_r: Prandtl number, N: Radiation Parameter, γ: Suction parameter, S_0: Soret number, S_C: Schmidt number, $\frac{\partial q}{\partial y^*}=4\alpha^2 T$,where 'a' is mean radiation absorption coefficient.

Using a non -dimensional variables in equation (4), (5) and (13 – 15), we get a dimensionless governing equations,

$$\frac{\partial q}{\partial t}-s\frac{\partial q}{\partial z}=-\frac{\partial p}{\partial \xi}+\frac{\partial^2 q}{\partial z^2}+\alpha\frac{\partial^3 q}{\partial z^2\partial t}-\left(\frac{M^2}{1-im}+\frac{1}{K}\right)q+G_r\theta+G_m\emptyset \quad (16)$$

$$\frac{\partial \theta}{\partial t}-s\frac{\partial \theta}{\partial z}=\frac{1}{P_r}\frac{\partial^2 \theta}{\partial z^2}-\frac{N^2}{P_r}\theta+\delta\theta \quad (17)$$

$$\frac{\partial \emptyset}{\partial t}-s\frac{\partial \emptyset}{\partial z}=\frac{1}{S_C}\frac{\partial^2 \emptyset}{\partial z^2}+S_0\frac{\partial^2 \theta}{\partial z^2}-K_C S_C\emptyset \quad (18)$$

With the appropriate boundary conditions

$$q=\frac{\partial q}{\partial z},\ \theta=0,\ \emptyset=0 \quad \text{at } z=0 \quad (19)$$

$$q=0,\ \theta=1,\ \emptyset=1 \quad \text{at } z=1 \quad (20)$$

III. METHOD OF SOLUTION

The governing equation with dimensionless parameter under boundary conditions can be solved using the regular perturbation method and the following form is considered.

$$-\frac{dp}{d\xi}=Pe^{iwt}, \quad (21)$$

$$q(z,t)=q_0(z)\,e^{iwt}, \quad (22)$$

$$\theta(z,t)=\theta_0(z)\,e^{iwt}, \quad (23)$$

$$\emptyset(z,t)=\emptyset_0(z)\,e^{iwt} \quad (24)$$

In view of (21)-(24) equations (16) - (18) reduced to a boundary value-problem in the following form.

$$(1+\alpha i\omega)\,q_0''+sq_0'-\left(\frac{M^2}{1-im}+\frac{1}{K}+i\omega\right)q_0=-P+G_r\theta_0+G_m\emptyset_o \quad (25)$$

$$\theta_0''+sP_r\theta_0'+\left((\delta-i\omega)P_r-N^2\right)\theta_0=0 \quad (26)$$

$$\emptyset_0''+SS_C\emptyset_0'-(K_C S_C-i\omega)S_C\emptyset_0=-S_0S_C\theta_0'' \quad (27)$$

Corresponding boundary conditions are

$$q_0=\gamma\frac{dq_0}{dz},\ q_0(1)=0,\ \theta_0(0)=0,\ \theta_0(1)=1,\emptyset_0(0)=0,\ \emptyset_0(1)=1 \quad (28)$$

The solution of the (25) to (27) with respect to the boundary conditions(28), in terms of obtain the velocity, temperature and concentration as follows:

$$q_0 = -\frac{e^{m5y}}{e^{m6\gamma}-e^{m5\gamma}} - \Big\{(e^{m6y}-e^{m5y})(1-b_1(e^{m4\gamma}-1) + b_2(e^{m3\gamma}-1)+b_3(e^{m1\gamma}-1) + b_4(e^{m2\gamma}-1)+b_5e^{m1\gamma}-b_6e^{m2\gamma} + b_7e^{m1\gamma}-b_8e^{m2\gamma}+b_9e^{m2\gamma}-b_{10}e^{m4\gamma} - b_{11}e^{m2\gamma}+b_{12}e^{m3\gamma}) - \frac{e^{m6\gamma}}{e^{m6\gamma}-e^{m5\gamma}} + (b_1e^{m4y}-b_2e^{m3y}+b_3e^{m1y}-b_4e^{m2y} - b_5e^{m1y}+b_6e^{m2y}+b_7e^{m1y} - b_8e^{m2y}+b_9e^{m2y}-b_{10}e^{m4y}-b_{11}e^{m2y} + b_{12}e^{m3y})\Big\} \qquad (29)$$

$$\theta_0 = \frac{e^{m4y}-e^{m3y}}{e^{m4}-e^{m3}} \qquad (30)$$

$$\emptyset_0 = \{(h_1)(1-A_3h_2+A_4h_3+A_3h_4-A_4h_5)\} \qquad (31)$$

IV. RESULTS AND DISCUSSION

The computational data have been presented in graphical form were evaluated analytically in the following Fig.s (1) – (4) represents the velocity profiles for u & v, Fig. (5) represents the temperature profiles for θ, Fig. (6) shows the concentration profiles for $\emptyset$. The governing flow by dimensionless parameters M Hartmann's number, K permeability parameter, m hall parameter, α viscoelastic parameter, Gr thermal Grashof number, Gm mass Grash of number, Sc Schmidt number, ω the frequency of oscillation, Kc chemical reaction parameter, γ slip velocity are discussed. In Fig. 1(a & b), the velocity u and v, increases with increasing hall parameter due to the effect of inclined magnetic field in terms of hall parameter which have no significance effect in velocity profile. Fig. 2(a & b), represents the velocity u and v, decreasing by Hartmann number or due to the increasing magnetic field then the resultant velocity also reduces with increase in the intensity of the magnetic field. The effect of inclined magnetic field on an electrically conducting fluid (Lorentz force) similar to drag force will increase the drag force and slow down the motion of the fluid. Fig. 3 (a & b), the velocity u and v, reduces with the v increasing by radiation parameter N because of the left half of the channel, the effect of N on the velocity is insignificant while in the right half of the channel velocity decreases with increase of N. Fig. 4 (a & b), the velocity u and v, increasing the permeability parameter K, such that increasing the permeability higher the fluid speed, in the absence of γ , there is no flow and separation does not take place at boundary. In Fig. 5(a, b, c, d), the temperature magnitude is decreasing with suction parameter, frequency of oscillation δ . By the fluid temperature increases with increasing the channel, injection increases the plate heated and suction increases the plate while cooled. Thus, the temperature magnitude is increasing with the Prandtl parameter Pr and suction parameter s. In Fig. 6 (a, b, c, d), the concentration magnitude is decreasing with suction parameter, chemical reaction parameter, frequency of oscillation, therefore it increases with Schmidt number Sc. When Schmidt number increases the diffusivity will be small, it decreases the diffusivity which will be high.

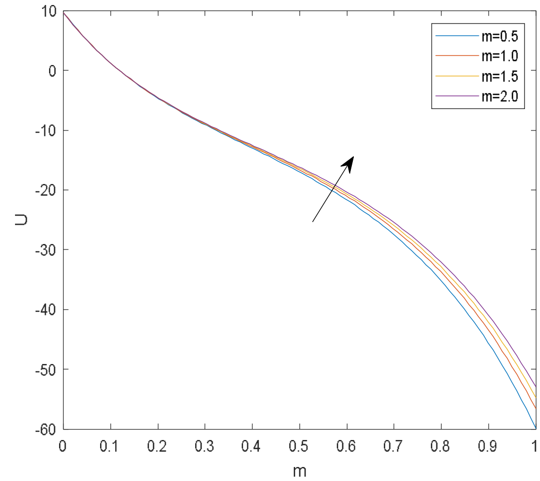

Fig. 1(a) The velocity u profiles against m with M=0.5; α=1; K=1; Gr=3; Gm=4; s=1; Pr=0.71; Sc=0.22; Kc=1; r=0.25; w=pi/6; d=0.5; So=1; i=1.0; N=3.0.

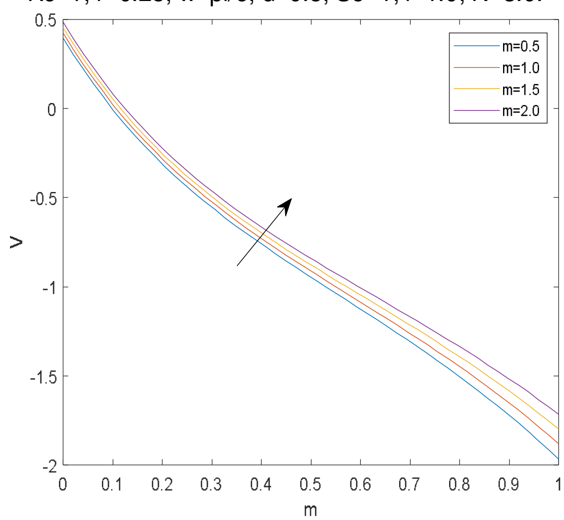

Fig. 1 (b) The velocity v profiles against m with M=0.5; α=1; K=1; Gr=3; Gm=4; s=1; Pr=0.71; Sc=0.22; Kc=1; r=0.25; w=pi/6; d=0.5; So=1; i=1.0; N=3.0.

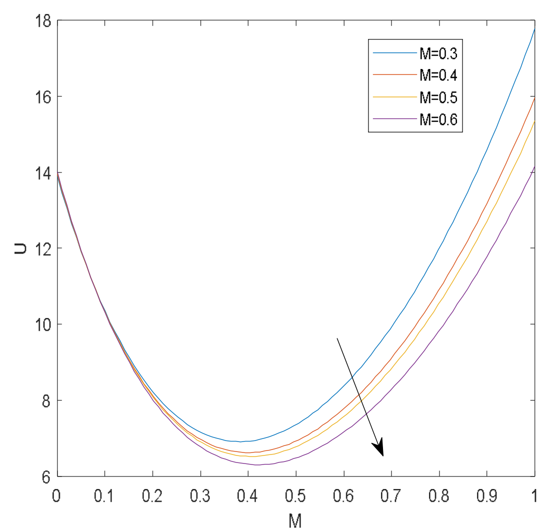

Fig. 2 (a) The velocity u profiles against M with m=0.5; α=1; K=1; Gr=3; Gm=4; s=1; Pr=0.71; Sc=0.22; Kc=1; r=0.25; w=pi/6; d=0.5; So=1; i=1.0; N=3.0.

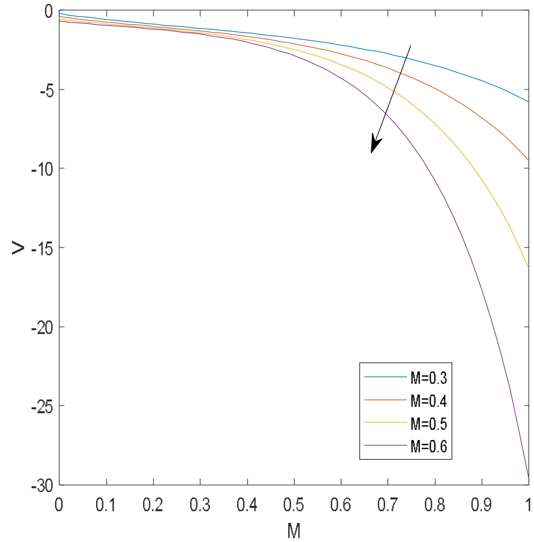

Fig. 2 (b) The velocity v profiles against M with m=0.5;=1;K=1;Gr=3;Gm=4;s=1;pr=0.71;Sc=0.22; Kc=1;r=0.25;w=pi/6;d=0.5;So=1;i=1.0;N=3.0.

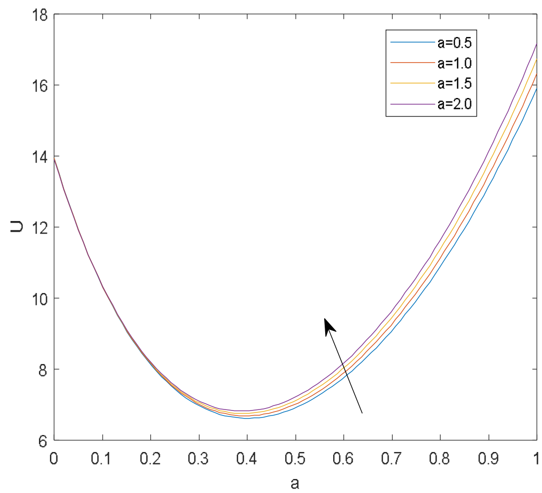

Fig. 3(a) The velocity u profiles against a with M=0.5; α=1; K=1; Gr=3; Gm=4; s=1; Pr=0.71; Sc=0.22; Kc=1; r=0.25; w=pi/6; d=0.5; So=1; i=1.0; N=3.0.

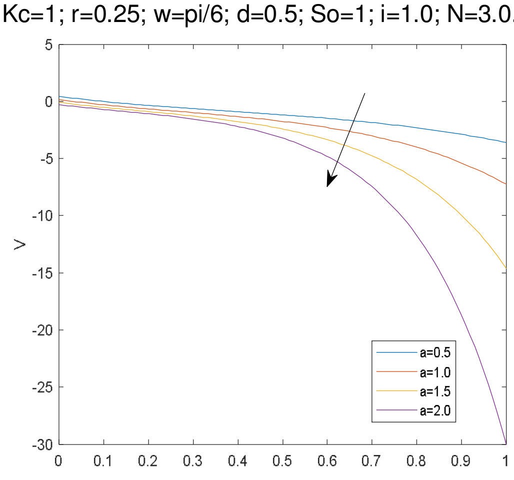

Fig. 3(b) The velocity v profiles against a with M=0.5; K=1; Gr=3; Gm=4; s=1; Pr=0.71; Sc=0.22; Kc=1; r=0.25; w=pi/6; d=0.5; So=1; i=1.0; N=3.0.

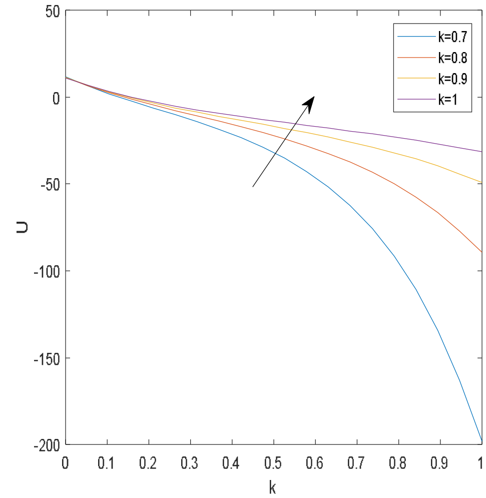

Fig. 4(a) The velocity u profiles against k with M=0.5; α=1; K=1; Gr=3; Gm=4; s=1; Pr=0.71; Sc=0.22; Kc=1; r=0.25; w=pi/6; d=0.5; So=1; i=1.0; N=3.0.

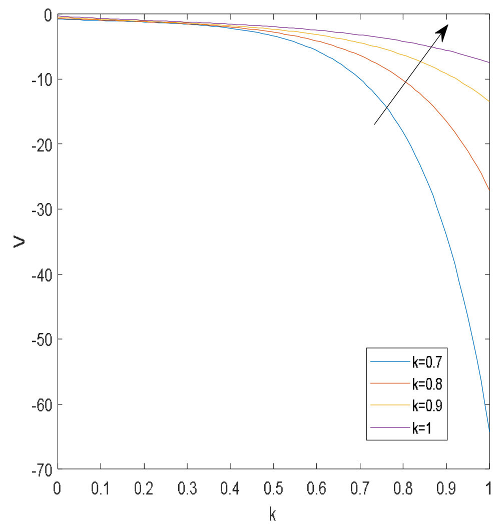

Fig. 4(b) The velocity v profiles against k with M=0.5; α=1; K=1; Gr=3; Gm=4; s=1; Pr=0.71; Sc=0.22; Kc=1; r=0.25; w=pi/6; d=0.5; So=1; i=1.0; N=3.0.

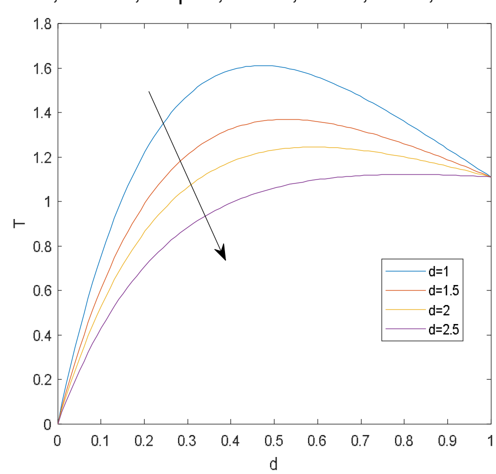

Fig. 5(a) The Temperature profiles against δ s=3; δ=2 ;ω=pi/6; Pr=0.71; i=1.0; t=0.2; N=1.0.

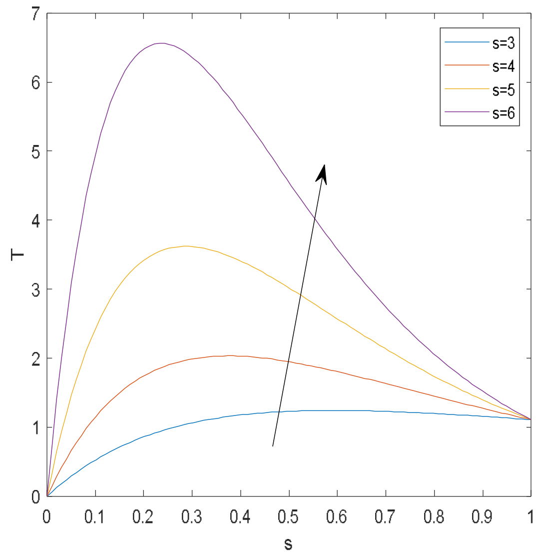

Fig. 5(b) The Temperature profiles against s
s=3; δ=2; ω=pi/6; Pr=0.71; i=1.0; t=0.2; N=1.0.

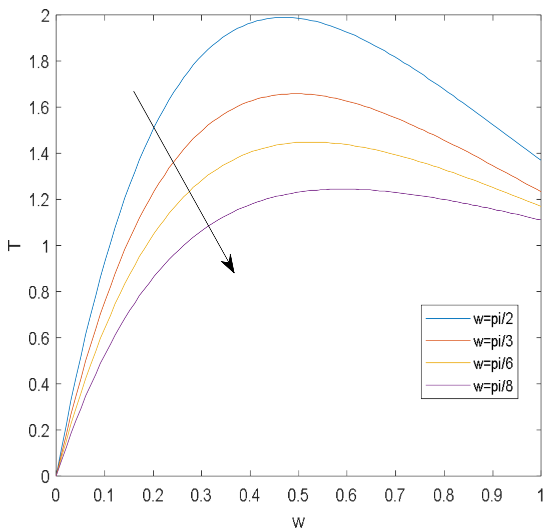

Fig. 5(c) The Temperature profiles against ω
s=3;δ=2; ω=pi/6; Pr=0.71; i=1.0;t=0.2;N=1.0.

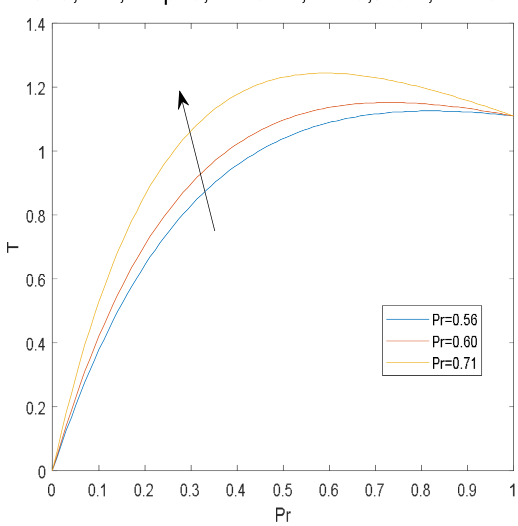

Fig. 5(d) The Temperature profiles against Pr
s=3; δ=2; ω=pi/6; Pr=0.71; i=1.0; t=0.2; N=1.0.

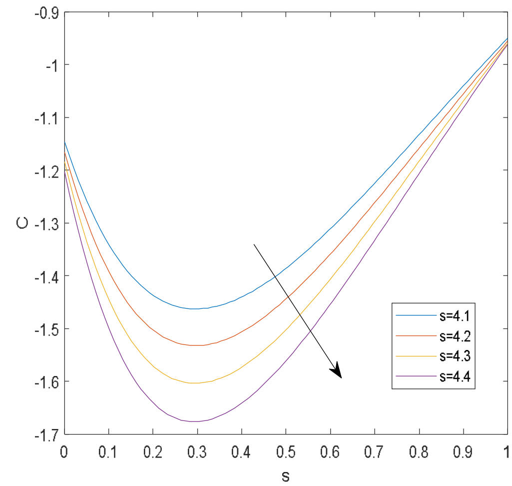

Fig. 6(a) The concentration profiles against s
s=3; δ=2; ω=pi/6; i=1.0; t=0.2; N=1.0; Sc=0.22; Kc=2; So=2; Pr=0.71.

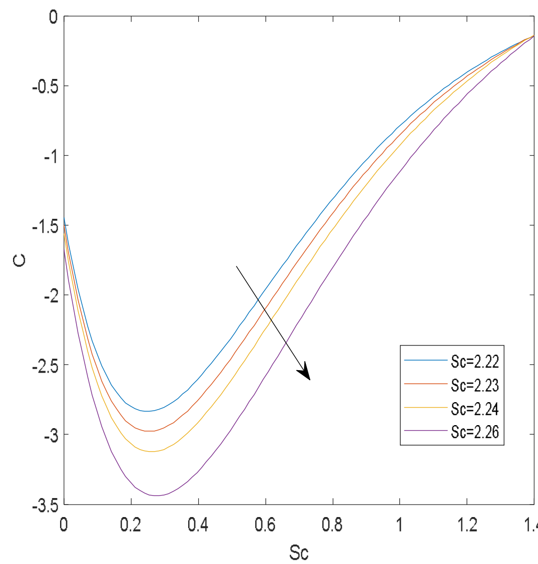

Fig. 6(b). The concentration profiles against Sc
s=3; δ=2; ω=pi/6; i=1.0; t=0.2; N=1.0; Sc=0.22; Kc=2; So=2; Pr=0.71.

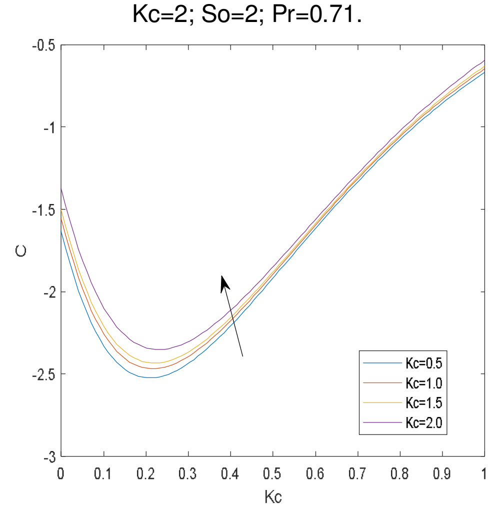

Fig. 6(c). The concentration profiles against Kc
s=3; δ=2; ω=pi/6; i=1.0; t=0.2; N=1.0; Sc=0.22; Kc=2; So=2; Pr=0.71.

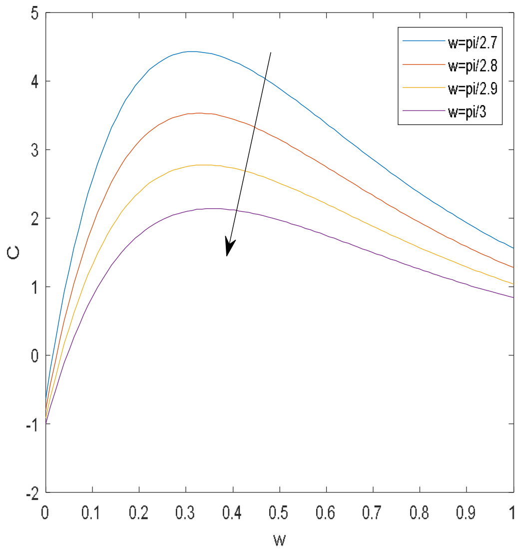

Fig. 6(d). The concentration profiles against s=3; δ=2; i=1.0; t=0.2; N=1.0; Sc=0.22; Kc=2; So=2; Pr=0.71.

V. CONCLUSION

We have concluded that MHD oscillatory flow of non-Newtonian fluid in the presence of radiation parameter and thermal diffusivity. The dimensionless governing equations are solved by analytical method due to,

— The velocity increases with increasing parameters m, K for heated plate.

— The velocity increases with decreasing parameters α for heated plate.

— The velocity decreases with decreasing parameters M for heated plate.

— The temperature decrease with increasing parameters Pr Prandtl number, when it increases with time.

— The concentration decrease with increasing parameters Sc Schmidt number, when it increases with time.

It can also further be extended in terms of introducing Soret and Dufour effects, slip conditions.

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