Heat and Mass Transfer on Unsteady M.H.D Oscillatory Flow of Non-Newtonian Fluid through Porous Medium in Parallel Plate Channel

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Abstract: ***We have considered the unsteady two dimensional MHD oscillatory flow of non-Newtonian fluid through a porous medium under the influence of uniform transverse magnetic field. A mathematical model is developed and analyzed by using appropriate mathematical techniques. The mathematical expressions for the velocity profile, wall shear stress and rates of heat and mass transfer have been obtained and computationally discussed with respect to the different parameters in detail.***

Keywords: Heat and mass transfer, MHD Oscillatory flows, porous medium

1. Introduction

The effect of heat and mass transfer on unsteady MHD oscillatory flow of fluid in horizontal media are encountered in a wide range of engineering and industrial applications such as molten iron flow, recovery extraction of crude oil, geothermal systems. Many chemical engineering processes like metallurgical and polymer extrusion processes involve cooling of a molten liquid being stretched in a cooling system; the fluid mechanical properties of penultimate product depend mainly on the cooling liquid used and the rate of stretching. Some polymers fluids like polyethylene oxide and polysobutylene solutions in a cetane, having better electromagnetic properties are normally used as cooling liquid as their flow can be regulated by external magnetic fields in order to improve the quality of the final product. Also, the radiative heat transfers is an important factor of thermodynamics of very high temperature systems such as electric furnaces, solar collectors, storage of nuclear wastes packed bed catalytic reactors, satellites, steel rolling, cryogenic engineering etc. The study of such flow under the influence of magnetic field and heat transfer has attracted the interest of many investigators and researchers.

Asadullah et al.,[2] consider the MHD flow of a Jeffrey fluid in converging and diverging channels. The flows between non parallel walls have a very significant role in physical and biological sciences. Kavita et al.,[12] investigated the influence of heat transfer on MHD oscillatory flow of Jeffery fluid in a Channel. An analysis of first order homogeneous chemical reaction and heat source on MHD oscillatory flow of viscous – elastic fluid through a channel filled with saturated porous medium are reported by Devika et al.,[8]. An oscillatory flow of a Jeffrey Fluid in an elastic tube of variable cross – section has been investigated at low Reynolds number by Badari et al.,[4]. Their main concentration is on the excess pressure of the tube. The equation has been solved numerically and investigations are made for different cases on the tube. Aruna Kumari et al.,[1] studied the effect of heat transfer on MHD oscillatory flow of Jeffrey fluid in a channel with slip effect at a lower wall where the expressions for the velocity and temperature are obtained analytically.

Israel-Cookey et al.,[10] investigated the combined effects of radiative heat transfer and a transverse magnetic field on steady flow of an electrically conducting optically thin fluid through a horizontal channel filled with porous medium and non-uniform temperatures at the walls. Closed form analytical solutions for the problem. The unsteady MHD free convective flow through porous medium sandwiched between electrically conducting viscous incompressible fluids in a horizontal channel with isothermal walls temperature using Brinkman model has been investigated by Kumar et al.,[14]. The forced convection in a horizontal double – passage with uniform wall heat flux has been studied by Joseph et al.,[11] by taking into account the effect of magnetic parameter where the flow of the fluid is assumed to be laminar, two dimensional, steady and fully developed. The fluid is incompressible and the physical properties are constants and the walls are kept at uniform heat flux. Bodosa and Borkakati [7] analysed the problem of an unsteady two – dimensional flow of a viscous incompressible and electrically conducting fluid between two parallel plates in the presence of uniform transverse magnetic field. The lower plate is a stretched sheet while the upper one is an oscillating porous plate, which is oscillating in its own plane. The effect of radiation on unsteady free convection flow bounded by an oscillating plate with variable wall temperature was studied by Pathak and Maheshwari [18]. The flow and heat transfer between two horizontal parallel plates, where the lower plate is a stretching sheet and the upper one is a porous solid plate in the presence of transverse magnetic field was discussed by Bharali and Borkakati [5]. Also Bharali and Borkakati [6] studied the heat transfer in an axisymmetric flow between two parallel porous disk under the effect of a transverse magnetic field. Sharma and Deka [21] studied the effects of plate temperature oscillation on the unsteady conducting fluid along a semi-infinite vertical porous plate subjected to a transverse magnetic field in the presence of a first order chemical reaction and thermal radiation. Israel-Cookey and Nwaigwe [9] studied the unsteady MHD flow of a radiating fluid over a moving heated plate with time dependent suction. Kim [13] discussed the unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction. The problem of unsteady MHD periodic flow of viscous fluid through a planar channel in porous medium using perturbation techniques was considered by Kumar et al.,[15]. Makinde and Mhone [17] studied the heat transfer to MHD oscillatory flow in a channel filled with porous medium. Rita et al.,[20] investigated the visco-elastic unsteady MHD flow between two horizontal parallel plates taking into hall current account. Maen Al-Rashdan [16] presented an analytical investigation to the problem of fully – developed natural convective heat mass transfer through porous medium in a channel in the presence of a first order chemical reaction.

2. Mathematical formulation and solution of the Problem

As in many other similar theoretical studies, the formulation analysis that follows, we use Cartesian coordinates. The flow is considered symmetric about the axis of the channel and driven by the stretching of the channel wall, such that the velocity of each wall is proportional to the axial coordinate. In order to study the second-order effects of unsteady MHD flow of non-Newtonian, let us first consider the flow of a second-order fluid between two parallel plates at z=0 and z=h, where the x-axis is taken parallel length of plates and z-axis along a direction perpendicular to the plates. A magnetic field of constant intensity B_0 is considered to be applied in the *y*-direction. The physical configuration of the problem is as shown in Fig. 1.

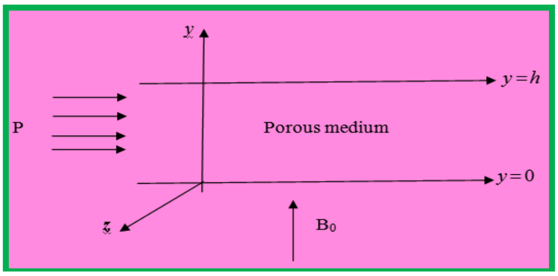

Figure 1: Physical configuration of the Problem

The unsteady hydromagnetic equations of the momentum, heat transfer and mass transfer for the MHD oscillatory flow of second grade fluid through a porous medium in the parallel plate system are considered in the form,

$$\frac{\partial u}{\partial t}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\nu\frac{\partial^2 u}{\partial z^2}+\frac{\alpha_1}{\rho}\frac{\partial^3 u}{\partial z^2\partial t}-\frac{\sigma B_0^2}{\rho}u-\frac{\nu}{k}u+g\beta(T-T_\infty)+g\beta^*(C-C_\infty) \tag{2.1}$$

$$\frac{\partial v}{\partial t}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\nu\frac{\partial^2 v}{\partial z^2}+\frac{\alpha_1}{\rho}\frac{\partial^3 v}{\partial z^2\partial t}-\frac{\sigma B_0^2}{\rho}v-\frac{\nu}{k}v \tag{2.2}$$

$$\frac{\partial T}{\partial t}=\frac{K_1}{\rho C_p}\frac{\partial^2 T}{\partial z^2}-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial z} \tag{2.3}$$

$$\frac{\partial C}{\partial t}=D\frac{\partial^2 C}{\partial z^2}-K_c(C-C_0) \tag{2.4}$$

The boundary conditions for the problem under consideration are given by the corresponding boundary conditions are

$$u=\lambda\frac{\partial u}{\partial z},\ v=\lambda\frac{\partial v}{\partial z},\ T=T_0+(T_w-T_0)e^{i\omega t},\ C=C_0+(C_w-C_0)e^{i\omega t}\quad \text{at}\quad z=h \tag{2.5}$$

$$u=\lambda\frac{\partial u}{\partial z},\ v=\lambda\frac{\partial u}{\partial z},\ T=T_0,\ C=C_0\quad \text{at}\quad z=0 \tag{2.6}$$

Using Rosseland approximation [19], the radiative transfer term q_r in Equation (2.3) may be expressed as

$$q_r=-\frac{4\sigma^*}{3\alpha_r}\frac{\partial T^4}{\partial z} \tag{2.7}$$

We assume that the temperature differences within the flow are such that T^4 can be expressed as a linear function of the temperature *T*. This is accomplished by expanding T^4 in a Taylor series about T_0 (which is assumed to be independent of *z*) and neglecting powers of *T* higher than the first. Thus we have

$$T^4=4T_0^3T-3T_0^4 \tag{2.8}$$

Then the heat transfer equation becomes

$$\frac{\partial T}{\partial t}=\frac{K_1}{\rho C_p}\frac{\partial^2 T}{\partial z^2}-\frac{16\sigma^* T_0^3}{3\rho C_p\alpha_r}\frac{\partial^2 T}{\partial z^2} \tag{2.9}$$

Combining the equations (2.1) and (2.2), $q=u+iv$ and we obtain

$$\frac{\partial q}{\partial t}=-\frac{1}{\rho}\frac{\partial p}{\partial \xi}+\nu\frac{\partial^2 q}{\partial z^2}+\frac{\alpha_1}{\rho}\frac{\partial^3 q}{\partial z^2\partial t}-\frac{\sigma B_0^2}{\rho}q-\frac{\nu}{k}q+g\beta(T-T_\infty)+g\beta^*(C-C_\infty) \tag{2.10}$$

We now introduce the following non-dimensional variables:

$$x^*=\frac{x}{h},\ y^*=\frac{y}{h},\ z^*=\frac{z}{h},\ q^*=\frac{q}{U_0},\ t^*=\frac{tU_0}{h},\ \theta=\frac{T-T_0}{T_w-T_0},$$

$$\phi = \frac{C - C_0}{C_w - C_0},\ \omega^* = \frac{\omega h}{U_0},\ t^* = \frac{t w_0^2}{\nu},\ \xi^* = \frac{\xi}{h},\ p^* = \frac{p}{\rho U_0^2}$$

Making use of non-dimensional quantities (dropping asterisks), the governing equation (2.10), (2.2) and (2.3) can be written as

$$\mathrm{Re}\frac{\partial q}{\partial t} = -\frac{\partial p}{\partial \xi} + \frac{\partial^2 q}{\partial z^2} + \alpha \frac{\partial^3 q}{\partial z^2 \partial t} - \left(M^2 + \frac{1}{K}\right) q + \mathrm{Gr}\,\theta + \mathrm{Gm}\,\phi \tag{2.11}$$

$$\mathrm{Pr}\frac{\partial \theta}{\partial t} = (1+R)\frac{\partial^2 \theta}{\partial z^2} \tag{2.12}$$

$$\mathrm{Sc}\frac{\partial \phi}{\partial t} = \frac{\partial^2 \phi}{\partial z^2} - \mathrm{Kc}\,\phi \tag{2.13}$$

The corresponding non-dimensional boundary conditions assume the form

$$q = \lambda \frac{\partial q}{\partial z},\ \theta = e^{i\omega t},\ \phi = e^{i\omega t} \quad \text{at} \quad z = 1 \tag{2.14}$$

$$q = \lambda \frac{\partial q}{\partial z},\ \theta = 0,\ \phi = 0 \quad \text{at} \quad z = 0 \tag{2.15}$$

From Eq. (2.11), it follows that, $\partial p / \partial \xi$ is a function of t only. We consider it to be of the form,

$$\frac{\partial p}{\partial \xi} = P e^{i\omega t} \tag{2.16}$$

To solve Eqs. (2.11), (2.12) and (2.13) subject to the boundary conditions (2.14) and (2.15), we further write the velocity, temperature and concentration as

$$q(z,t) = q_1 e^{i\omega t} \tag{2.17}$$

$$\theta(z,t) = \theta_1 e^{i\omega t} \tag{2.18}$$

$$\phi(z,t) = \phi_1 e^{i\omega t} \tag{2.19}$$

Substituting these expressions (2.17), (2.18) and (2.19) in (2.11), (2.12) and (2.13) respectively and comparing the co-efficients of like terms we have the equations.

$$(1+\alpha i\omega)\frac{\partial^2 q_1}{\partial z^2} - \left(\mathrm{Re}\,i\omega + M^2 + \frac{1}{K}\right) q_1 = -P - \mathrm{Gr}\,\theta_1 - \mathrm{Gm}\,\phi_1 \tag{2.20}$$

$$(1+R)\frac{\partial^2 \theta_1}{\partial z^2} - \mathrm{Pr}\,i\omega\theta_1 = 0 \tag{2.21}$$

$$\frac{\partial^2 \phi_1}{\partial z^2} - (\mathrm{Sc}\,i\omega + \mathrm{Kc})\,\phi_1 = 0 \tag{2.22}$$

With corresponding boundary conditions

$$q = \lambda \frac{\partial q_1}{\partial z},\ \theta_1 = 1,\ \phi_1 = 1 \quad \text{at} \quad z = 1 \tag{2.23}$$

$$q = \lambda \frac{\partial q_1}{\partial z},\ \theta_1 = 0,\ \phi_1 = 0 \quad \text{at} \quad z = 0 \tag{2.24}$$

Solving (2.20) – (2.22) subject to the conditions (2.23) and (2.24), we have velocity field, temperature, concentration respectively, where the expressions for the constants $m_i (i = 1, 2, \ldots, 6)$ and $a_i (i = 1, 2, \ldots, 6)$

$$q(z,t) = \left(a_1 e^{m_1 z} + a_2 e^{m_2 z} - \frac{P}{\mathrm{Re}\,i\omega + M^2 + (1/K)} - \frac{\mathrm{Gr}}{e^{m_3} - e^{m_4}}\left[\frac{e^{m_3 z}}{a_3} - \frac{e^{m_4 z}}{a_4}\right] - \frac{\mathrm{Gm}}{e^{m_5} - e^{m_6}}\left[\frac{e^{m_5 z}}{a_5} - \frac{e^{m_6 z}}{a_6}\right] \right) e^{i\omega t} \tag{2.25}$$

$$\theta(z,t) = \frac{1}{e^{m_3} - e^{m_4}}\left(e^{m_3 z} - e^{m_4 z}\right) e^{i\omega t} \tag{2.26}$$

$$\phi(z,t) = \frac{1}{e^{m_5} - e^{m_6}}\left(e^{m_5 z} - e^{m_6 z}\right) e^{i\omega t} \tag{2.27}$$

Skin friction:

The wall shear stress at the wall of the upper plate is found as

$$\tau_w = \left[\frac{\partial q}{\partial z} + \alpha \frac{\partial^2 q}{\partial z \partial t}\right]_{z=1} = \left(a_1 m_1 e^{m_1} + a_2 m_2 e^{m_2} - \frac{\mathrm{Gr}}{e^{m_3} - e^{m_4}}\left[\frac{m_3 e^{m_3}}{a_3} - \frac{m_4 e^{m_4}}{a_4}\right] - \frac{\mathrm{Gm}}{e^{m_5} - e^{m_6}}\left[\frac{m_5 e^{m_5}}{a_5} - \frac{m_6 e^{m_6}}{a_6}\right] \right)(1+\alpha i\omega)\, e^{i\omega t} \tag{2.28}$$

Nusselt number:

The rates of heat transfer across the upper plate (upper wall) are calculated as

$$Nu = \left[-\frac{\partial \theta}{\partial z}\right]_{z=1} = -\frac{1}{e^{m_3} - e^{m_4}}\left(m_3 e^{m_3} - m_4 e^{m_4}\right) e^{i\omega t} \tag{2.29}$$

Sherwood number:

The rates of mass transfer across the upper plate (upper wall) are calculated as

$$Sh = \left[-\frac{\partial \phi}{\partial z}\right]_{z=1} = -\frac{1}{e^{m_5} - e^{m_6}}\left(m_5 e^{m_5} - m_6 e^{m_6}\right) e^{i\omega t} \tag{2.30}$$

3. Results and Discussion

We have considered the unsteady two dimensional MHD oscillatory flow of non-Newtonian fluid through a porous medium in a parallel plate channel under the influence of uniform transverse magnetic field. The governing equations for the velocity profile, wall shear stress and rates of heat and mass transfer have been obtained using perturbation technique and computationally discussed with respect to the different parameters namely viz. M is the Hartmann number (Magnetic field parameter), K is the Permeability parameter, α is the second grade fluid parameter, Gr is the thermal Grashof number, Gm is the mass Grashof number, Pr is Prandtl parameter, R is the Radiation parameter, Kc chemical reaction parameter and Sc is the Schmidt number. The Figures (2-23) represent the velocity profiles for u and v; the Figure (24-25) represent the temperature profiles for θ; the Figures (26-27) represent the concentration profiles for ϕ.

From the Figures (2-3) we noticed that, both the velocity components u and v reduces with increasing the intensity of the magnetic field or Hartmann number M. Also we have been seen that the resultant velocity q is experiences retardation throughout the fluid region. The velocity component u increases and v reduces with increasing permeability parameter K. The resultant velocity enhances with increasing K in the flow field. We also noticed that lower the permeability lesser the fluid speed is observed the entire fluid region (Figures 4-5). The similar behaviour is observed for the velocity components with radiation parameter R (Figures 14-15). The magnitude of the velocity components u and v as well as resultant velocity reduces in the entire fluid region with increasing second grade fluid parameter α, Pr, Sc and Kc (Figures 6-9, 16-17 & 22-23). From the Figures (10-13 & 20-21) the velocity components u and v as well as resultant velocity increase with increasing thermal Grashof number Gr, mass Grashof number Gm or λ. We also find that the magnitude of the velocity component u reduces and v enhances with increasing the frequency of oscillation ω. The resultant velocity reduces throughout the fluid region with increasing the frequency of oscillation (Figures 18-19).

We noticed that from the Figures (24-25) the magnitude of the temperature reduces with increasing radiation parameter, where as the reversal behaviour is observed throughout the fluid region with increasing Prandtl number.

Also we found that from the Figures (26-27) the magnitude of the concentration increases with increasing Schmidt number Sc, where as the reversal behaviour is observed throughout the fluid region with increasing chemical reaction parameter Kc.

The frictional force is determined from the velocity at the upper plate only. The magnitude of the stress components τ_x and τ_y enhances with increasing K, Gr, Gm and λ. The opposite nature is observed for the same components with increasing M and Kc. The magnitude of the stress component τ_x reduces and τ_y increases with increasing α, ω and R.The reversal behaviour is for the components τ_x and τ_y with increasing Pr and Sc (Table 1).We also noticed that from the Table (2) the Nusselt number Nu enhances with increasing Radiation parameter R and Prandtl number Pr. Likewise the rate of mass transfer is reduces with increasing Schmidt number Sc and increases with increasing chemical reaction parameter Kc (Table 3).

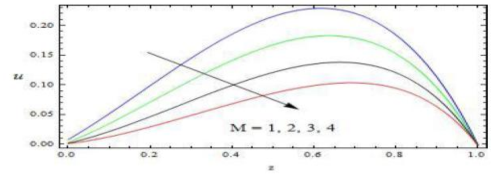

Figure 2. The Velocity Profile for u against M with $t = 1$, Re=1
$K = 1, \alpha = 0.5, Pr = 0.71, Gr = 2, Gm = 5, R = 0.5, Sc = 0.22, \omega = \frac{\pi}{4}, \lambda = 0.002, Kc = 0.5$

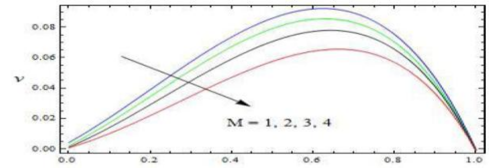

Figure 3. The Velocity Profile for v against M with $t = 1$, Re=1
$K = 1, \alpha = 0.5, Pr = 0.71, Gr = 2, Gm = 5, R = 0.5, Sc = 0.22, \omega = \frac{\pi}{4}, \lambda = 0.002, Kc = 0.5$

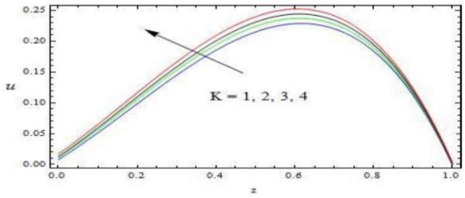

Figure 4. The Velocity Profile for u against K with $t = 1$, Re=1
$M = 1, \alpha = 0.5, Pr = 0.71, Gr = 2, Gm = 5, R = 0.5, Sc = 0.22, \omega = \frac{\pi}{4}, \lambda = 0.002, Kc = 0.5$

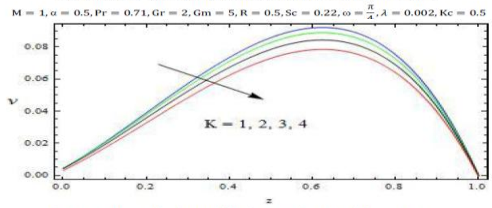

Figure 5. The Velocity Profile for v against K with $t = 1$, Re=1
$M = 1, \alpha = 0.5, Pr = 0.71, Gr = 2, Gm = 5, R = 0.5, Sc = 0.22, \omega = \frac{\pi}{4}, \lambda = 0.002, Kc = 0.5$

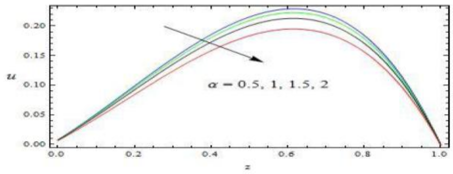

Figure 6. The Velocity Profile for u against α with $t = 1$, Re=1
$K = 1, M = 1, Pr = 0.71, Gr = 2, Gm = 5, R = 0.5, Sc = 0.22, \omega = \frac{\pi}{4}, \lambda = 0.002, Kc = 0.5$

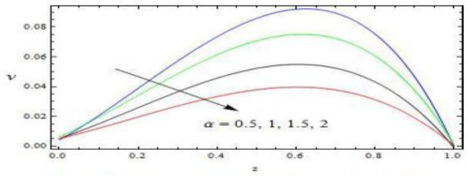

Figure 7. The Velocity Profile for v against α with $t = 1$, Re=1
$K = 1, M = 1, Pr = 0.71, Gr = 2, Gm = 5, R = 0.5, Sc = 0.22, \omega = \frac{\pi}{4}, \lambda = 0.002, Kc = 0.5$

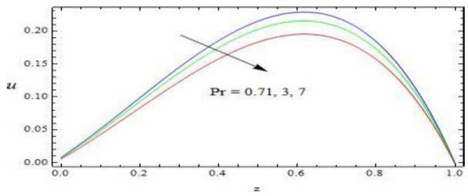

Figure 8. The Velocity Profile for u against Pr with $t = 1$, Re=1
$K = 1, \alpha = 0.5, M = 1, Gr = 2, Gm = 5, R = 0.5, Sc = 0.22, \omega = \frac{\pi}{4}, \lambda = 0.002, Kc = 0.5$

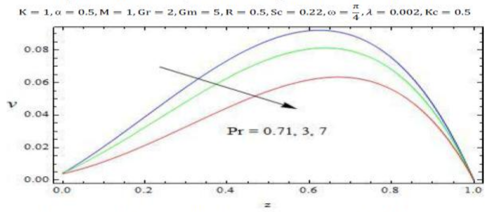

Figure 9. The Velocity Profile for v against Pr with $t = 1$, Re=1
$K = 1, \alpha = 0.5, M = 1, Gr = 2, Gm = 5, R = 0.5, Sc = 0.22, \omega = \frac{\pi}{4}, \lambda = 0.002, Kc = 0.5$

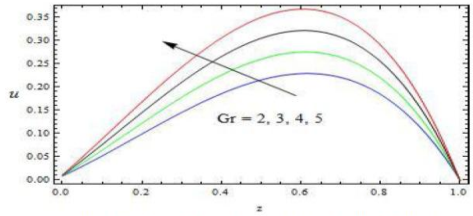

Figure 10. The Velocity Profile for u against Gr with $t = 1$, Re=1
$K = 1, \alpha = 0.5, Pr = 0.71, M = 1, Gm = 5, R = 0.5, Sc = 0.22, \omega = \frac{\pi}{4}, \lambda = 0.002, Kc = 0.5$

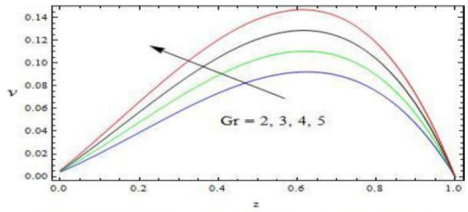

Figure 11. The Velocity Profile for v against Gr with $t = 1$, Re=1
$K = 1, \alpha = 0.5, Pr = 0.71, M = 1, Gm = 5, R = 0.5, Sc = 0.22, \omega = \frac{\pi}{4}, \lambda = 0.002, Kc = 0.5$

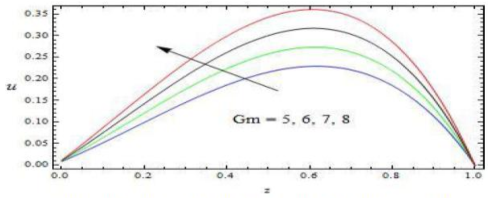

Figure 12. The Velocity Profile for u against Gm with $t = 1$, Re=1
$K = 1, \alpha = 0.5, Pr = 0.71, Gr = 2, M = 1, R = 0.5, Sc = 0.22, \omega = \pi/4, \lambda = 0.002, Kc = 0.5$

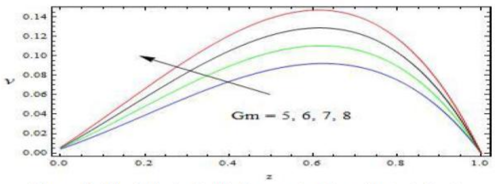

Figure 13. The Velocity Profile for v against Gm with $t = 1$, Re=1
$K = 1, \alpha = 0.5, Pr = 0.71, Gr = 2, M = 1, R = 0.5, Sc = 0.22, \omega = \pi/4, \lambda = 0.002, Kc = 0.5$

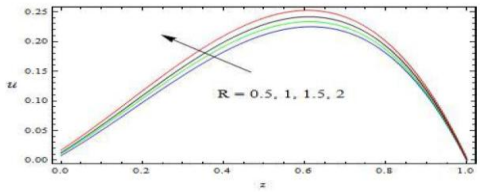

Figure 14. The Velocity Profile for u against R with $t = 1$, Re=1
$K = 1, \alpha = 0.5, Pr = 0.71, Gr = 2, Gm = 5, M = 1, Sc = 0.22, \omega = \frac{\pi}{4}, \lambda = 0.002, Kc = 0.5$

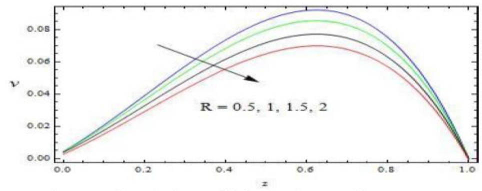

Figure 15. The Velocity Profile for v against R with $t = 1$, Re=1
$K = 1, \alpha = 0.5, Pr = 0.71, Gr = 2, Gm = 5, M = 1, Sc = 0.22, \omega = \frac{\pi}{4}, \lambda = 0.002, Kc = 0.5$

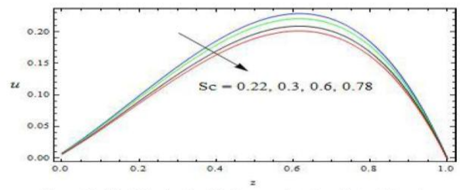

Figure 16. The Velocity Profile for u against Sc with $t = 1$, Re=1
$K = 1, \alpha = 0.5, Pr = 0.71, Gr = 2, Gm = 5, R = 0.5, M = 1, \omega = \frac{\pi}{4}, \lambda = 0.002, Kc = 0.5$

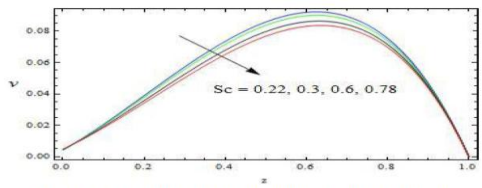

Figure 17. The Velocity Profile for v against Sc with $t = 1$, Re=1
$K = 1, \alpha = 0.5, Pr = 0.71, Gr = 2, Gm = 5, R = 0.5, M = 1, \omega = \frac{\pi}{4}, \lambda = 0.002, Kc = 0.5$

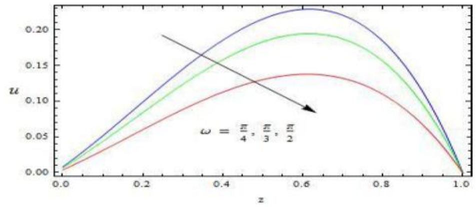

Figure 18. The Velocity Profile for u against ω with $t = 1$, Re=1
$K = 1, \alpha = 0.5, Pr = 0.71, Gr = 2, Gm = 5, R = 0.5, Sc = 0.22, M = 1, \lambda = 0.002, Kc = 0.5$

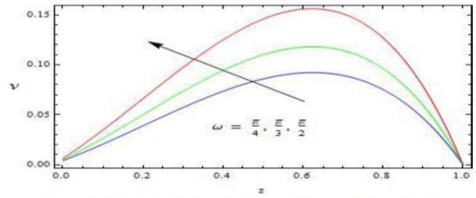

Figure 19. The Velocity Profile for v against ω with $t = 1$, Re=1
$K = 1, \alpha = 0.5, Pr = 0.71, Gr = 2, Gm = 5, R = 0.5, Sc = 0.22, M = 1, \lambda = 0.002, Kc = 0.5$

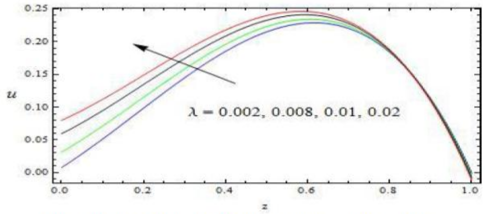

Figure 20. The Velocity Profile for u against λ with $t = 1$, Re=1
$K = 1, \alpha = 0.5, Pr = 0.71, Gr = 2, Gm = 5, R = 0.5, Sc = 0.22, \omega = \frac{\pi}{4}, M = 1, Kc = 0.5$

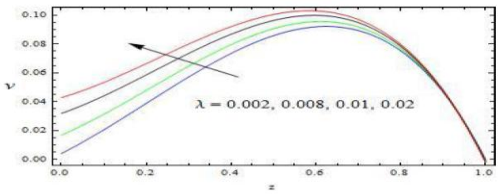

Figure 21. The Velocity Profile for v against λ with $t = 1$, Re=1
$K = 1, \alpha = 0.5, Pr = 0.71, Gr = 2, Gm = 5, R = 0.5, Sc = 0.22, \omega = \frac{\pi}{4}, M = 1, Kc = 0.5$

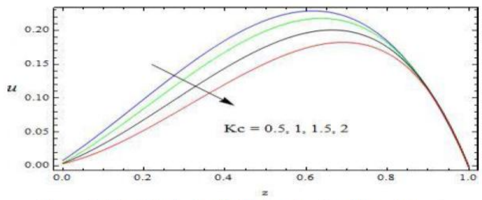

Figure 22. The Velocity Profile for u against Kc with $t = 1$, Re=1
$K = 1, \alpha = 0.5, Pr = 0.71, Gr = 2, Gm = 5, R = 0.5, Sc = 0.22, \omega = \frac{\pi}{4}, \lambda = 0.002, M = 1$

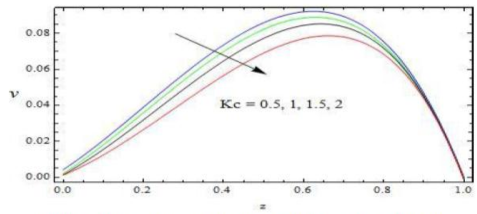

Figure 23. The Velocity Profile for v against Kc with $t = 1$, Re=1
$K = 1, \alpha = 0.5, Pr = 0.71, Gr = 2, Gm = 5, R = 0.5, Sc = 0.22, \omega = \frac{\pi}{4}, \lambda = 0.002, M = 1$

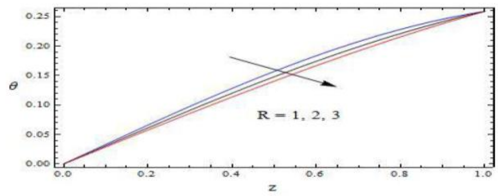

Figure 24. The Temperature Profile for θ against R with
$Pr = 0.71, \omega = 5\pi/12, t = 0.1$

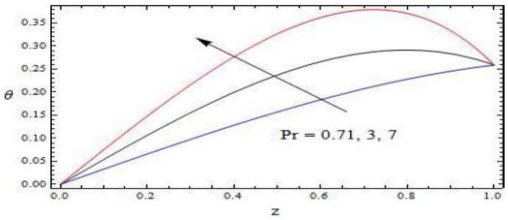

Figure 25. The Temperature Profile for θ against Pr with $R = 1, \omega = 5\pi/12, t = 0.1$

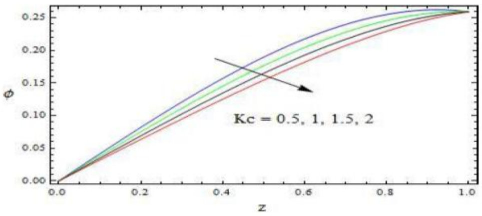

Figure 26. The Concentration Profile for ϕ against Kc with $Sc = 1, \omega = 5\pi/12, t = 0.1$

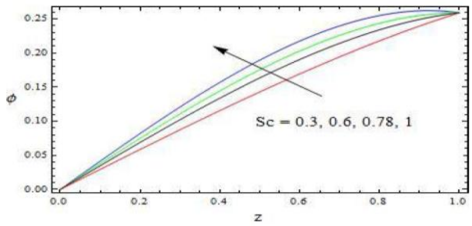

Figure 27. The Concentration Profile for ϕ against Sc with $Kc = 0.5, \omega = 5\pi/12, t = 0.1$

Table 1: Skin Friction

M	K	α	R	Pr	Gr	Gm	Sc	ω	λ	Kc	τ_x	τ_y
1	**1**	**0.5**	**0.5**	**0.71**	**2**	**5**	**0.3**	$\pi/4$	0.002	**0.5**	−1.158248	−1.110498
2	1	0.5	0.5	0.71	2	5	0.3	$\pi/4$	0.002	0.5	−0.993490	−1.032042
3	1	0.5	0.5	0.71	2	5	0.3	$\pi/4$	0.002	0.5	−0.825037	−0.925141
1	**2**	0.5	0.5	0.71	2	5	0.3	$\pi/4$	0.002	0.5	−1.194155	−1.124449
1	**3**	0.5	0.5	0.71	2	5	0.3	$\pi/4$	0.002	0.5	−1.206993	−1.129143
1	1	**0.8**	0.5	0.71	2	5	0.3	$\pi/4$	0.002	0.5	−1.150947	−1.141803
1	1	**1**	0.5	0.71	2	5	0.3	$\pi/4$	0.002	0.5	−1.141225	−1.160365
1	1	0.5	**1**	0.71	2	5	0.3	$\pi/4$	0.002	0.5	−1.155959	−1.113099
1	1	0.5	**1.5**	0.71	2	5	0.3	$\pi/4$	0.002	0.5	−1.154563	−1.114641
1	1	0.5	0.5	**3**	2	5	0.3	$\pi/4$	0.002	0.5	−1.183234	−1.073887
1	1	0.5	0.5	7	2	5	0.3	$\pi/4$	0.002	0.5	−1.205218	−1.004365
1	1	0.5	0.5	0.71	**3**	5	0.3	$\pi/4$	0.002	0.5	−1.373218	−1.315673
1	1	0.5	0.5	0.71	**4**	5	0.3	$\pi/4$	0.002	0.5	−1.588188	−1.520847
1	1	0.5	0.5	0.71	2	**6**	0.3	$\pi/4$	0.002	0.5	−1.364969	−1.311586
1	1	0.5	0.5	0.71	2	**7**	0.3	$\pi/4$	0.002	0.5	−1.571689	−1.512675
1	1	0.5	0.5	0.71	2	5	**0.6**	$\pi/4$	0.002	0.5	−1.171335	−1.095456
1	1	0.5	0.5	0.71	2	5	**0.78**	$\pi/4$	0.002	0.5	−1.178868	−1.086146
1	1	0.5	0.5	0.71	2	5	0.3	$\pi/3$	0.002	0.5	−0.840718	−1.366166
1	1	0.5	0.5	0.71	2	5	0.3	$\pi/2$	0.002	0.5	−0.067415	−1.601359
1	1	0.5	0.5	0.71	2	5	0.3	$\pi/4$	**0.008**	0.5	−1.176488	−1.129584
1	1	0.5	0.5	0.71	2	5	0.3	$\pi/4$	**0.01**	0.5	−1.182637	−1.136019
1	1	0.5	0.5	0.71	2	5	0.3	$\pi/4$	0.002	**1.0**	−1.128424	−1.083484
1	1	0.5	0.5	0.71	2	5	0.3	$\pi/4$	0.002	**1.5**	−1.101043	−1.060133

Table 2: Nusselt number

R	Pr	ω	Nu
0.5	**0.71**	$5\pi/12$	−0.062010
1	0.71	$5\pi/12$	−0.110643
1.5	0.71	$5\pi/12$	−0.140021
2	0.71	$5\pi/12$	−0.159684
0.5	**3**	$5\pi/12$	0.512785
0.5	**7**	$5\pi/12$	1.209667

Table 3: Sherwood number

Sc	Kc	ω	Sh
0.3	**0.5**	$5\pi/12$	−0.182881
0.6	0.5	$5\pi/12$	−0.067315
0.78	0.5	$5\pi/12$	0.000764
1	0.5	$5\pi/12$	0.082496
0.3	**1**	$5\pi/12$	−0.228894
0.3	**1.5**	$5\pi/12$	−0.271903

4. Conclusions

We have discussed the unsteady two dimensional MHD oscillatory flow of non-Newtonian fluid through a porous medium under the influence of uniform transverse magnetic field. The conclusions are made as the following.

1. The resultant velocity q is experiences retardation throughout the fluid region with increase in M.
2. The velocity component u increases and v reduces with increasing permeability parameter K or R. The resultant velocity enhances with increasing K or R in the flow field.
3. Lower the permeability lesser the fluid speed is observed the entire fluid region.
4. The resultant velocity reduces in the entire fluid region with increasing second grade fluid parameter α , Pr , Sc and Kc

5. The resultant velocity increase with increasing thermal Grashof number Gr, mass Grashof number Gm or λ.
6. The resultant velocity reduces throughout the fluid region with increasing the frequency of oscillation.
7. The temperature reduces with increasing radiation parameter R, where as the reversal behaviour is observed throughout the fluid region with increasing Prandtl number Pr.
8. The concentration increases with increasing Schmidt number Sc, where as the reversal behaviour is observed throughout the fluid region with increasing chemical reaction parameter Kc.
9. The stress components τ_x and τ_y enhances with increasing K, Gr, Gm and λ.
10. τ_x and τ_y reduces with increasing M and Kc.
11. The stress component τ_x reduces and τ_y increases with increasing α, ω and R. The reversal behaviour is for the components τ_x and τ_y with increasing Pr and Sc.
12. The Nusselt number Nu enhances with increasing Radiation parameter R and Prandtl number Pr.
13. The Sherwood number is reduces with increasing Schmidt number Sc and increases with increasing chemical reaction parameter Kc.

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