

Hall effects on MHD Oscillatory flow of Non-Newtonian Fluid through porous medium in a Vertical channel with suction/injection

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Abstract

In this paper, we investigate the effect of suction/injection on the unsteady MHD oscillatory second grade fluid flow through a vertical channel with non-uniform wall temperature. The fluid is subjected to Hall effects and the velocity slip at the lower plate is taken into consideration. Exact solutions of the dimensionless equations governing the fluid flow are obtained and the effects of the flow parameters on temperature, velocity profiles, skin friction and rate of heat transfer are discussed and shown graphically. It is interesting to note that skin friction increases on both channel plates as injection increases on the heated plate.

Keywords: Hall effects, Oscillatory flow, Porous medium, Magnetic field, Fluid slip, Suction/injection

1. 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 magnetohydrodynamic (MHD) generators, arterial blood flow, petroleum engineering. Makinde and Mhone [1] investigated the forced convective MHD oscillatory fluid flow through a channel filled with porous medium, and analyses were based on the assumption that the plates are impervious. In a related study, Mehmood and Ali [2] investigated the effect of slip on the free convective oscillatory flow through vertical channel with periodic temperature and dissipative heat. In addition, Chauchan and Kumar [3] studied the steady flow and heat transfer in a composite vertical channel. Palani and Abbas [4] investigated the combined effects of magneto-hydrodynamics and radiation effect on free convection flow past an impulsively started isothermal vertical plate using the Rossel and approximation. Hussain et al. [5] presented analytical study of oscillatory second grade fluid flow in the presence of a transverse magnetic field. Umavathi et al. [6] investigated the unsteady flow of viscous fluid through a horizontal composite channel. Ajibade and Jha [7] presented the effects of suction and injection on hydrodynamics of oscillatory fluid through parallel plates. Ajibade and Jha [8] extended the problem to heat generating/absorbing fluids, the effect of viscous dissipation of the free convective flow with time dependent boundary condition was investigated (Ajibade and Jha [9]). More recently, Adesanya and Makinde [10]

discussed the radiative heat transfer on the pulsatile couple stress fluid flow with time dependent boundary condition. Adesanya and Gbadeyan [11] studied the flow and heat transfer of steady non-Newtonian fluid flow noting the fluid slip in the porous channel. Many authors [12-20] discussed some problems on MHD flows in different physical configurations. Veera Krishna et al. [21] discussed heat and mass transfer on unsteady MHD oscillatory flow of blood through porous arteriole. The effects of radiation and Hall current on MHD flow through porous medium have studied by Veera Krishna et al. [22]. The heat generation/absorption and thermo-diffusion on MHD flow of radiating and chemically reactive second grade fluid near an infinite vertical plate through a porous medium with Hall effect have studied by Veera Krishna and Chamkha [23]. Veera Krishna and Chamkha [25] investigated The diffusion-thermo, radiation-absorption and Hall and ion slip effects on MHD free convective rotating flow of nano-fluids (Ag and TiO₂) past a semi-infinite permeable moving plate with constant heat source. Veera Krishna et al.[26] discussed the Soret and Joule effects of MHD mixed convective flow of an incompressible and electrically conducting viscous fluid past an infinite vertical porous plate taking Hall effects into account. Veera Krishna and Chamkha [27] discussed the MHD squeezing flow of a water-based nanofluid through a saturated porous medium between two parallel disks, taking the Hall current into account.

Motivated by the above studies, we investigate 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.

2. FORMULATION AND SOLUTION OF THE PROBLEM

We consider mass transfer on the unsteady laminar flow of an incompressible viscous electrically conducting second grade fluid through a channel with slip at the cold plate. An external magnetic field is placed across the normal to the channel and taking Hall current into account. It is assumed that the fluid has small electrical conductivity and the electro-magnetic force produced is also very small. The flow is subjected to suction at the cold wall and injection at the heated wall. We choose a Cartesian coordinate system (x, y, z) where x lies along the centre of the channel, and z is the distance measured

in the normal section such that $z = d$ is the channel's half width as shown in the Fig.1.

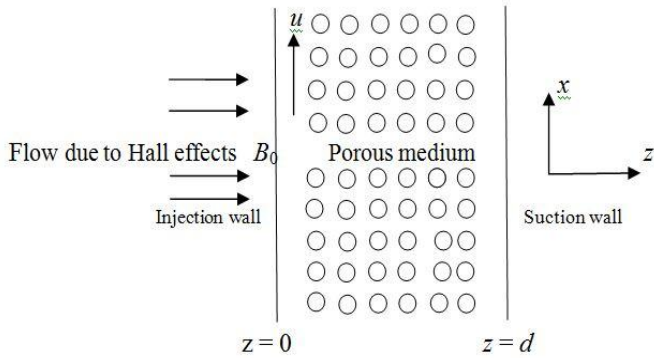


Fig. 1 Physical Configuration of the Problem

Under the usual Bousinesq approximation the equations governing the flow are as follows:

Equation of continuity:

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

Momentum of equations

$$\frac{\partial u}{\partial t} - w_0 \frac{\partial u}{\partial z} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + \nu \frac{\partial^2 u}{\partial z^2} + \frac{\alpha_1}{\rho} \frac{\partial^3 u}{\partial z^2 \partial t} + B_0 J_y - \frac{\nu}{K_1} u + g\beta(T - T_0) + g\beta^*(C - C_0) \quad (2)$$

$$\frac{\partial v}{\partial t} - w_0 \frac{\partial v}{\partial z} = -\frac{1}{\rho} \frac{\partial p}{\partial y} + \nu \frac{\partial^2 v}{\partial z^2} + \frac{\alpha_1}{\rho} \frac{\partial^3 v}{\partial z^2 \partial t} - B_0 J_x - \frac{\nu}{K_1} v \quad (3)$$

Equation of energy

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

Equation of concentration

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

Where, all the physical quantities are their usual meaning. When the strength of the magnetic field is very large, the generalized Ohm's law is modified to include the Hall current so that

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

The ion-slip and thermo electric effects are not included. Further it is assumed that $\omega_e \tau_e \sim 0$ (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. We also assume that the electric field $\mathbf{E} = 0$ under assumptions reduces to

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

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

On solving equations (7) and (8) we obtain,

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

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

Substituting the equations (9) and (10) in (3) and (2) respectively, we obtain

$$\frac{\partial u}{\partial t} - w_0 \frac{\partial u}{\partial z} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + \nu \frac{\partial^2 u}{\partial z^2} + \frac{\alpha_1}{\rho} \frac{\partial^3 u}{\partial z^2 \partial t} + \frac{\sigma B_0^2}{1 + m^2} (mv - u) - \frac{\nu}{K_1} u + g\beta(T - T_0) + g\beta^*(C - C_0) \quad (11)$$

$$\frac{\partial v}{\partial t} - w_0 \frac{\partial v}{\partial z} = -\frac{1}{\rho} \frac{\partial p}{\partial y} + \nu \frac{\partial^2 v}{\partial z^2} + \frac{\alpha_1}{\rho} \frac{\partial^3 v}{\partial z^2 \partial t} - \frac{\sigma B_0^2}{1 + m^2} (v + mu) - \frac{\nu}{K_1} v \quad (12)$$

Combining Eqns. (11) and (12), Let $q = u + iv$ and $\xi = x - iy$, we obtain

$$\frac{\partial q}{\partial t} - w_0 \frac{\partial q}{\partial z} = -\frac{1}{\rho} \frac{\partial p}{\partial \xi} + \nu \frac{\partial^2 q}{\partial z^2} + \frac{\alpha_1}{\rho} \frac{\partial^3 q}{\partial z^2 \partial t} - \frac{\sigma B_0^2}{\rho(1 - im)} q - \frac{\nu}{K_1} q + g\beta(T - T_0) + g\beta^*(C - C_0) \quad (13)$$

The boundary conditions are

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

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

Introducing the dimensionless parameters variables are given as

$$(x^*, z^*) = \frac{(x, z)}{d}, q = \frac{q^* v}{d}, t = \frac{t^* d^2}{\nu}$$

$$p = \frac{p^* \rho v^2}{d^2}, \theta = \frac{T - T_0}{T_1 - T_0}, \phi = \frac{C - C_0}{C_1 - C_0}$$

$$Gr = \frac{g \beta (T_1 - T_0) d^3}{\nu^2}, Gm = \frac{g \beta (C - C_0) d^3}{\nu^2}$$

$$Pr = \frac{\rho c_p \nu}{k}, \delta = \frac{4 \alpha^2 d^2}{\rho c_p \nu}, \gamma = \frac{\sqrt{k}}{\alpha_s d}$$

$$M^2 = \frac{\sigma B_0^2 d^2}{\rho \nu}, K = \frac{K_1}{d^2}, s = \frac{\omega_0 d}{\gamma}$$

$$x^* = \frac{x}{d}, y^* = \frac{y}{d}, z^* = \frac{z}{d}$$

Making use of non-dimensional variables, we obtain the dimensionless governing equations (Dropping asterisks) and are

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

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

$$\frac{\partial \phi}{\partial t} - s \frac{\partial \phi}{\partial z} = \frac{1}{Sc} \frac{\partial^2 \phi}{\partial z^2} - Kc Sc \phi \quad (18)$$

With the appropriate boundary conditions

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

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

We assume that an oscillatory pressure gradient such that solution of the dimensionless equations (16) - (18) is in the following form:

$$-\frac{dp}{d\xi} = P e^{i\omega t}, q(z, t) = q_0(z) e^{i\omega t}, \quad (21)$$

$$\theta(z, t) = \theta_0(z) e^{i\omega t}, \phi(z, t) = \phi_0(z) e^{i\omega t}$$

In view of (21) equations (10) - (14) reduced to a boundary value-problem in the following form.

$$(1 + \alpha i \omega) \frac{d^2 q_0}{dz^2} + s \frac{dq_0}{dz} - \left(\frac{M^2}{1 - im} + \frac{1}{K} + i \omega \right) q_0 = -P + Gr \theta_0 + Gm \phi_0 \quad (22)$$

$$\frac{d^2 \theta_0}{dz^2} + s Pr \frac{d\theta_0}{dz} + (\delta - i \omega) Pr \theta_0 = 0 \quad (23)$$

$$\frac{d^2 \phi_0}{dz^2} + s Sc \frac{d\phi_0}{dz} + (Kc Sc - i \omega) Sc \phi_0 = 0 \quad (24)$$

Corresponding boundary conditions are

$$q_0(0) = \gamma \frac{dq_0}{dz}, q_0(1) = 0, \theta_0(0) = 0, \theta_0(1) = 1, \phi_0(0) = 0, \phi_0(1) = 1 \quad (25)$$

The solutions of the (22) to (24) with respect to boundary conditions (25), we obtain the velocity, temperature and concentration.

For engineering interest, the shear stress, the rate of heat transfer and rate of mass transfer is given by

$$\tau = \frac{\partial q}{\partial z}, Nu = \frac{\partial \theta}{\partial z} \text{ and } Sh = \frac{\partial \phi}{\partial z}$$

3. RESULTS AND DISCUSSION

The Figs. (2-14), Figs. (15) and Figs. (16) represent the velocity profiles, temperature profiles and concentration profiles respectively. Tables (1-3) are shown Shear stress, Nusselt number (Nu), and Sherwood number (Sh). We have drawn the all profiles with respect to the different variation in the governing parameters being the other parameter fixed. $P = 1, t = 0.1$.

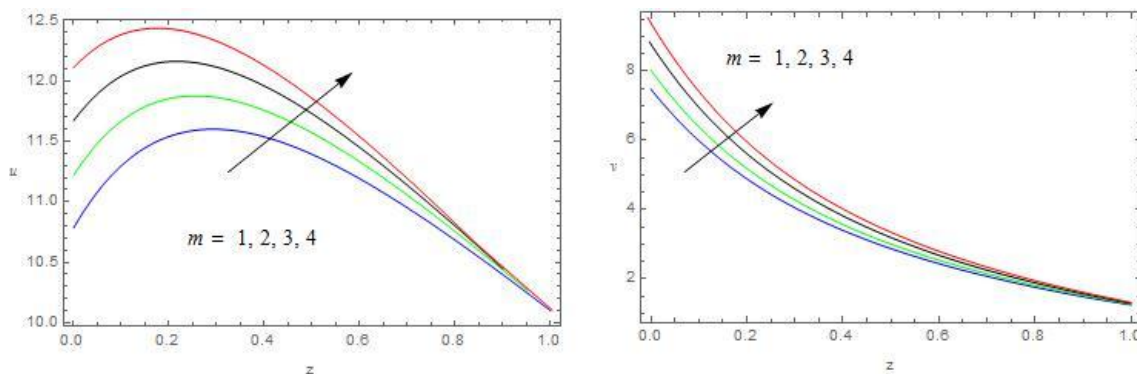
We noticed from the Figs. 2 and 3 that the magnitude of the velocity components u and v increases with increasing m and α . In Figs. 4, the effect of the retarding effect of Lorentz forces present in the magnetic field on the fluid flow is presented. It is observed that maximum flow occurs in the absence of the magnetic field, and further increase in the Hartmann's number is seen to decrease the fluid velocity components u and v . Figs. 5 present the plot of increase in channel porous permeability on the velocity profile. As observed, as the permeability of the medium increases there is increase in the fluid velocity since barriers placed on the flow path reduce as K increases allowing for free flow thus increasing the velocity.

The effect of the suction/injection parameter, Pr , the radiation parameter and the ω on the temperature of the fluid within the channel is shown in Figs. 6. From the plot, it is observed that fluid temperature is linearly distributed within the channel in the absence of suction/injection. However, as injection increases on the heated plate, fluid temperature increases within the channel. The concavity with increase in the suction/injection parameter is as a result of the direction of heat flow from the heated plate towards the cold plate. The magnitude of the temperature decreases with increasing Pr . Likewise as the radiation parameter increases, and the fluid temperature is seen to be increasing. This is due to the heat transfer from the heated wall to the fluid since the fluid absorbs its own radiations. An increase in the frequency of oscillation decreases the fluid temperature within the channel. This is attributed to a reduction in the heat transfer rate as the heating frequency.

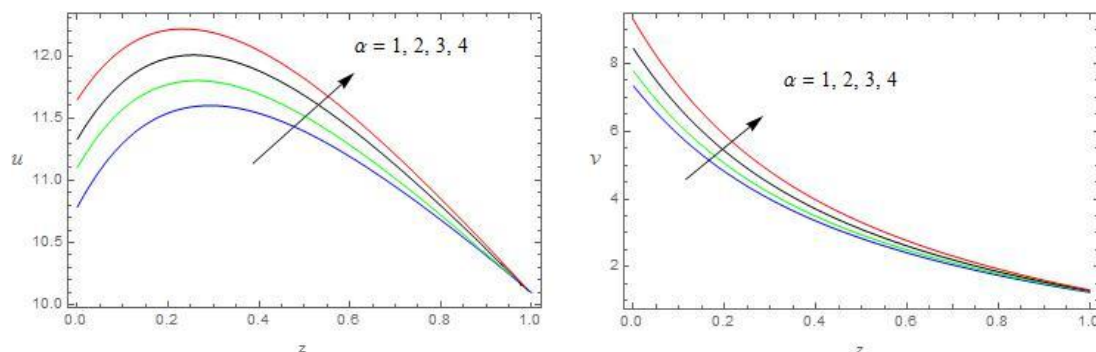
We noticed that, from the Figures 7, the concentration increases with increasing suction parameter s , Schmidt number Sc , or chemical reaction parameter Kc whereas it reduces with increasing the frequency of oscillation ω .

Finally, Table 1 shows that the skin friction at both the walls. The stress components τ_L and τ_R increase with increasing

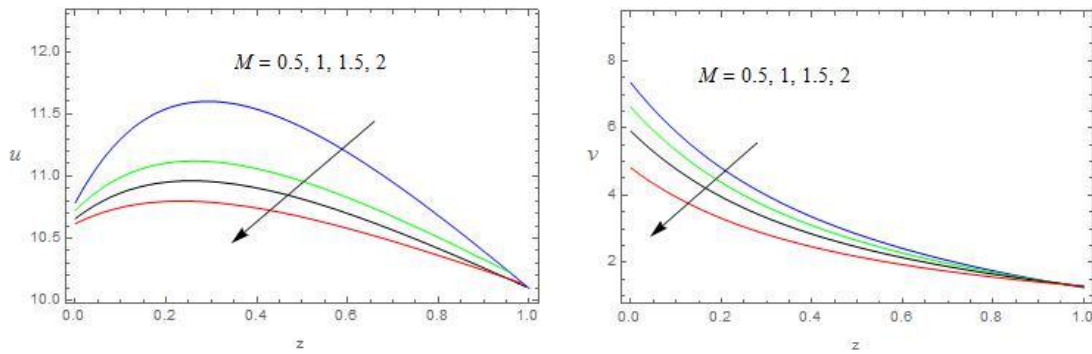
K , Gr , Gm and s and reduces with increasing M , Sc , Kc , γ and δ . The stress components τ_L enhances and τ_R retards with m , α , Pr and ω . Table 2 shows the plot of heat transfer rate across the channel, and as observed that, the rate of heat transfer Nu_L enhances and Nu_R decreases with increasing Pr , s , δ and ω in the fluid layer closer to the heated wall while it increases at the region close to the cold wall. The reason is that, heat is transferred from the heated plate to the fluid and from the fluid to the cold plate. Both Nu_L and Nu_R reduces with increasing time. Table 3 shows the mass transfer rate across the channel, and as observed that, the rate of mass transfer increases in the fluid layer closer to the heated wall while it decreases at the region close to the cold wall with increasing Schmidt number Sc , chemical reaction parameter Kc and Suction parameter s . Both Sh_L and Sh_R are reduces with increasing the frequency of oscillation and time t . Table 4 represents the comparison of the results for velocity component u where $\alpha \rightarrow 0, m \rightarrow 0$ with $Gm = 5, s = 1, Pr = 0.71, Sc = 0.22, Kc = 1, \gamma = 0.25, \omega = \pi / 6, \delta = 0.5$. The results are good agreement with Falade et al. [24].



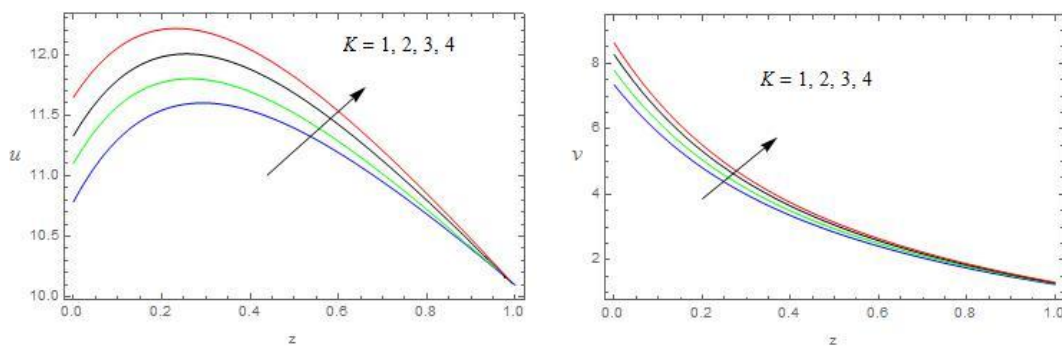
Figs. 2 The velocity profiles against m with $M = 0.5, \alpha = 1, K = 1, Gr = 4, Gm = 5, s = 1, Pr = 0.71, Sc = 0.22, Kc = 1, \gamma = 0.25, \omega = \pi / 6, \delta = 0.5$



Figs. 3 The velocity profiles against α with $m = 1, M = 0.5, K = 1, Gr = 4, Gm = 5, s = 1, Pr = 0.71, Sc = 0.22, Kc = 1, \gamma = 0.25, \omega = \pi / 6, \delta = 0.5$



Figs. 4 The velocity profiles against M with
 $m = 1, \alpha = 1, K = 1, Gr = 4, Gm = 5, s = 1, Pr = 0.71, Sc = 0.22, Kc = 1, \gamma = 0.25, \omega = \pi / 6, \delta = 0.5$



Figs. 5 The velocity profiles against K with
 $m = 1, \alpha = 1, M = 0.5, Gr = 4, Gm = 5, s = 1, Pr = 0.71, Sc = 0.22, Kc = 1, \gamma = 0.25, \omega = \pi / 6, \delta = 0.5$

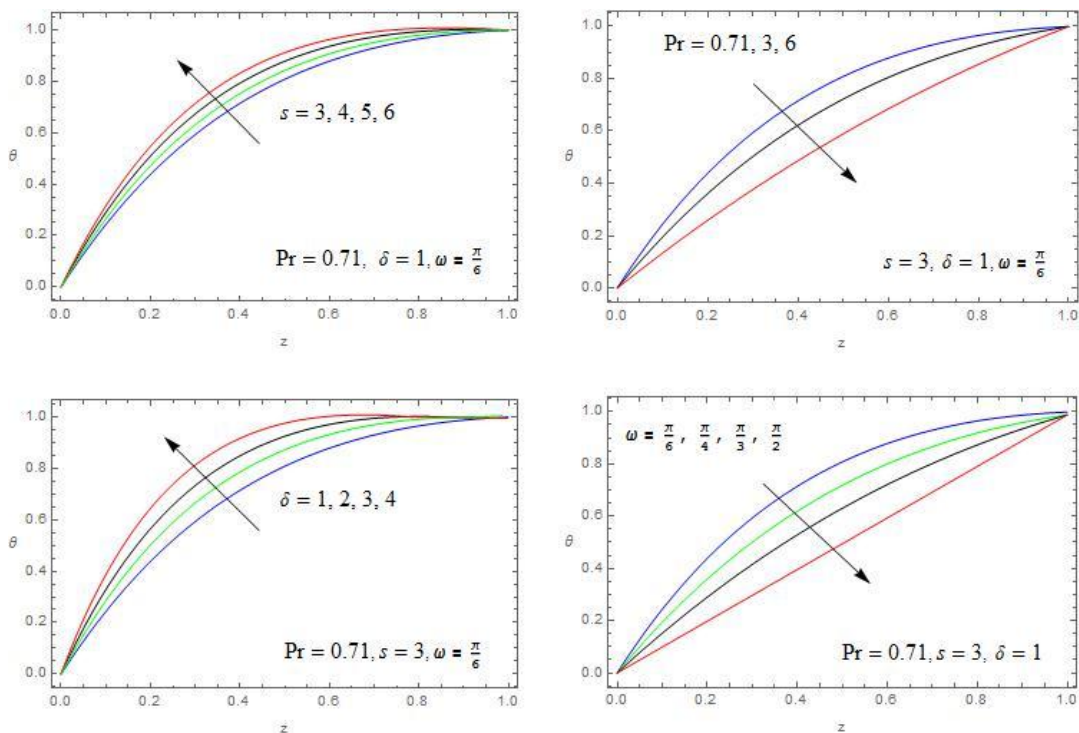


Fig 6: The Temperature profiles against s, Pr, δ, ω

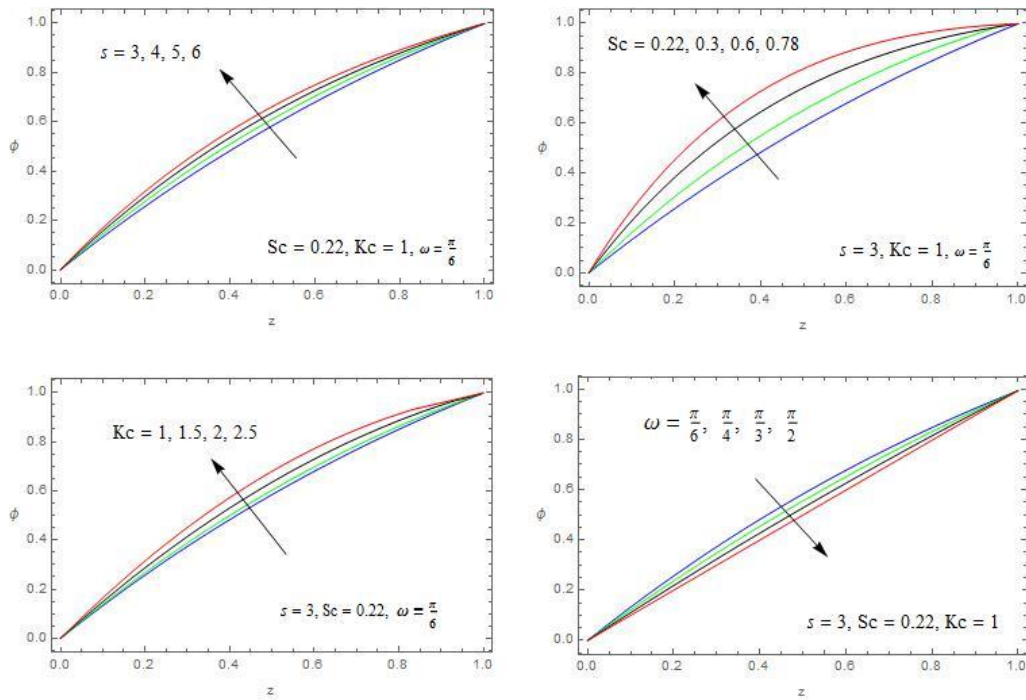


Fig. 7: The Concentration profiles against s , Sc , Kc and ω

Table 1: Shear stress

m	α	M	K	Gr	Gm	s	Pr	Sc	Kc	γ	ω	δ	Sh_L	Sh_R
1	1	0.5	0.1	1	2	1	0.71	0.22	1	0.5	$\pi/4$	0.5	0.554588	2.78025
2													0.688599	2.66015
3													0.799520	2.52001
	2												0.870114	2.57485
	3												1.267485	2.38545
		1											0.448955	2.64115
		1.5											0.414115	2.57485
			0.2										2.133622	2.78895
			0.3										3.241022	2.79999
				2									0.646625	2.97402
				3									0.700145	3.24452
					3								0.697440	3.00021
					4								0.737485	3.38554
						1.5							0.963662	3.00145
						2							1.518590	3.34521
							3						2.408595	2.64102
							6						2.807448	2.55201
								0.3					0.527401	2.73320
								0.6					0.429989	2.66201
									1.5				0.548500	2.75142
									2				0.545748	2.74156
										0.75			0.338744	2.39985
										1			0.240114	2.23325
											$\pi/3$		0.534748	2.67785
											$\pi/2$		0.918502	2.52214
												1	0.538023	2.73022
												1.5	0.526014	2.68899

Table 2: Nusselt number

Pr	δ	s	ω	t	Nu _L	Nu _R
0.71	1	5	$\pi/6$	0.2	2.02621	0.336515
3					2.40242	0.193257
7					2.93776	0.0825181
	2				2.12926	0.238023
	3				2.23981	0.135489
		6			2.26133	0.264963
		7			2.50735	0.204642
			$\pi/4$		2.02662	0.336292
			$\pi/3$		2.02680	0.336189
				0.4	1.78082	0.266138
				0.6	1.05827	0.124449

Table 3: Sherwood number

Sc	Kc	s	ω	t	Sh _L	Sh _R
0.22	2	5	$\pi/6$	0.2	1.67297	0.515315
0.3					1.98550	0.371924
0.4					2.43060	0.214464
	3				1.68636	0.499586
	4				1.69990	0.483757
		6			1.82723	0.448285
		7			1.98830	0.388109
			$\pi/4$		1.67169	0.514006
			$\pi/3$		1.66895	0.511179
				0.4	1.66425	0.510852
				0.6	1.64897	0.504372

Table 4. Comparison of the results

(Velocity component u at $z = 0.2$ level and $\alpha = 0, m = 0$)

M	K	Gr	Previous results Falade et al. [24]	Present results
2	0.5	3	0.258856	0.258788
3			0.201145	0.201014
4			0.152448	0.152390
	1		0.366552	0.366444
	1.5		0.452252	0.452102
		4	0.455895	0.455752
		5	0.644782	0.644745

4. CONCLUSIONS

We concluded that,

1. The resultant velocity enhances with increasing Hall parameter or second grade fluid parameter.
2. When increasing the intensity of the magnetic field, the resultant velocity retards throughout the flow field, where as it increases with increasing permeability parameter.
3. Also lifts the temperature, decreases the Nusselt number at the impassioned plate and increases it at the freezing wall.
4. The concentration reduces with increasing Schmidt number, whereas it enhances with increasing chemical reaction parameter or the frequency of oscillation.
5. Enlarges the skin friction on either plate with suction parameter.

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