MHD Flow of a Newtonian Fluid Through a Porous Medium in Planer Channel

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Abstract
This manuscript is an investigation on the effects of slip condition, chemical reaction, radiation and unsteady MHD periodic flow of a viscous, incompressible, electrically conducting fluid through a porous medium in in two cases viz. Case–I: Uniform plate Temperature and Uniform Concentration and Case–II: Constant heat and mass flux. The governing equations have been solved by perturbation technique. The skin friction and rate of heat transfer and mass transfer are also derived. The effects of various physical parameters like magnetic parameter, Reynolds number, Grashof number, modified Grashof number, permeability parameter, chemical reaction parameter, and Schmidt number are analyzed though graphs. Shear stress increases with the increase in magnetic parameter or permeability parameter and it shows a reverse effect in the case of slip parameter or Schmidt number in both cases of the study.

Keywords: MHD, Chemical reaction, Radiation, Periodic flow, Planer channel and Slip flow regime.

1. INTRODUCTION:
The phenomenon of slip-flow regime has attracted the attention of a large number of scholars due to its wide ranging applications. The problem of the slip flow regime is very important in this era of modern science, technology and vast ranging...
industrialization. In many practical applications, the particle adjacent to a solid surface no longer takes the velocity of the surface. The particle at the surface has a finite tangential velocity, it slips along the surface. The flow regime is called the slip flow regime and its effect cannot be neglected. The fluid slippage phenomenon at the solid boundaries appear in many applications such as micro channels or Nano channels and in applications where a thin film of light oils is attached to the moving plates or when the surface is coated with special coating such as thick monolayer of hydrophobic mechanical device where a thin film of lubricant is attached to the surface slipping over one another or when the surfaces are coated with special coating to minimize the friction between them. The effect of the fluid slip page at the wall for Coutte flow are considered by Marques et al. [2] under steady state conditions and only for gases. The closed form solutions for steady periodic and transient velocity field under slip condition have been studied by Khaled and Vafai [3]. The effect of slip condition on MHD steady flow in a channel with permeable boundaries has been discussed by Makinde and Osalusi [4]. Anil Kumar et.al.[5] discussed the perturbation technique to unsteady MHD periodic flow of viscous fluid through a planer channel. The effect of slip condition on unsteady MHD oscillatory flow of a viscous fluid in a planer channel is investigated by Mehmood and Ali [6].

Mageto-hydrodynamics is attracting the attention of the many authors due to its applications in geophysics and astrophysics, it is applied to study the stellar and solar structures, interstellar matter, radio propagation through the ionosphere etc. In engineering in MHD pumps, MHD bearings etc. Since some fluids can also emit and absorb thermal radiation, it is of interest to study the effect of magnetic field on the temperature distribution and heat transfer when the fluid is not only an electrical conductor but also when it is capable of emitting and absorbing thermal radiation. This is of interest because heat transfer by thermal radiation is becoming of greater importance when we are concerned with space applications and higher operating temperatures. Soundalgekar and Takhar [7] first, studied the effect of radiation on the natural convection flow of a gas past a semi-infinite plate using the Cogly-Vincentine-Gilles equilibrium model. For the same gas Takhar et al. [8] investigated the effects of radiation on the MHD free convection flow past a semi-infinite vertical plate. Later, Hossain et al. [9] studied the effect of radiation on free convection from a porous vertical plate. Muthumarumswamy and Kumar [10] studied the thermal radiation effects on moving infinite vertical plate in presence of variable temperature and Mass diffusion. An analytical solution for unsteady free convection in porous media has been studied by Magyari et al. [11]. Chamkha et al. [12] studied the effects of Hydro magnetic combined heat and mass transfer by natural convection from a permeable surface embedded in a fluid saturated porous medium. Mzumdar and Deka [13] studied MHD flow past an impulsively started infinite vertical plate in presence of thermal radiation. The growing need for chemical reactions in chemical and hydrometallurgical industries require the study of heat and mass transfer with chemical reaction. The effect of chemical reaction on heat and mass transfer in a laminar boundary layer flow has been studied under different conditions by several authors [14-47].
In this paper the influence of slip on MHD periodic flow of viscous fluid in presence of radiation and chemical reaction in a planer channel is discussed in two cases viz., Case (I) with uniform temperature and concentration, Case (II) with heat and mass flux have been studied. The coupled non-linear partial differential equations are solved using a perturbation scheme. And a series of solutions are expressed in terms and hyperbolic sine and cosine functions for velocity, temperature and concentration fields for both cases of this study.

2. NOMENCLATURE:

- \( u^* \) : Velocity along x-axis
- \( C^* \) : Concentration
- \( C_0 \) : Fluid concentration at the boundary \( y = 0 \)
- \( C_w \) : Fluid concentration at the boundary \( y = a \)
- \( T_0 \) : Fluid temperature at the boundary \( y = 0 \)
- \( T_w \) : Fluid temperature at the boundary \( y = a \)
- \( P^* \) : Fluid pressure
- \( \tau^* \) : Time
- \( \mathcal{G} \) : Kinematic viscosity coefficient
- \( H_0 \) : Intensity of magnetic field
- \( \kappa \) : Thermal conductivity
- \( D \) : Mass diffusivity
- \( G_m \) : Modified Grashof number
- \( g \) : Gravitation due to acceleration
- \( K_c \) : Non-dimensional rate of chemical reaction
- \( R_e \) : Reynolds number
- \( \alpha \) : The mean radiation absorption coefficient
- \( \beta_T \) : Coefficient of volume expansion
- \( \beta_c \) : Coefficient of volume expansion with concentration

GREEK SYMBOLS

- \( \kappa \) : Thermal conductivity
- \( \nu \) : Kinematic viscosity
- \( \sigma \) : Electrical conductivity
- \( \beta_T \) : Coefficient of volume expansion
- \( \alpha \) : The mean radiation absorption coefficient

NOMENCLATURE:

- \( u^* \) : Velocity along x-axis
- \( k \) : Permeability of porous medium
- \( C^* \) : Concentration
- \( Nu \) : Nusselt number
- \( C_0 \) : Fluid concentration at the boundary \( y = 0 \)
- \( P_e \) : Peclet number
- \( C_w \) : Fluid concentration at the boundary \( y = a \)
- \( T_0 \) : Fluid temperature at the boundary \( y = 0 \)
- \( Sc \) : Schmidt number
- \( T_w \) : Fluid temperature at the boundary \( y = a \)
- \( D_a \) : Darcy number
- \( P^* \) : Fluid pressure
- \( t^* \) : Time
- \( \mathcal{G} \) : Kinematic viscosity coefficient
- \( H_0 \) : Intensity of magnetic field
- \( \kappa \) : Thermal conductivity
- \( C_p \) : Specific heat at constant pressure
- \( q^* \) : The radiative heat flux
- \( D \) : Mass diffusivity
- \( E \) : Eckert number
- \( G_m \) : Modified Grashof number
- \( G_r \) : Thermal Grashof number
- \( g \) : Gravitation due to acceleration
- \( M \) : Magnetic parameter
- \( K_c \) : Non-dimensional rate of chemical reaction
- \( K_c^* \) : Rate of chemical reaction
- \( R_e \) : Reynolds number
- \( n \) : Frequency of the periodic flow
- \( \alpha \) : The mean radiation absorption coefficient
- \( \beta_T \) : Coefficient of volume expansion
- \( \beta_c \) : Coefficient of volume expansion with concentration

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3. FORMULATION OF THE PROBLEM:

Here we consider an unsteady MHD flow of viscous, incompressible, electrically non-conducting fluid in a planer channel in the presence of transverse applied magnetic field. The \( x^* \)-axis is taken along the plate in vertical upward direction against to the gravitational field and the \( y^* \)-axis is taken normal to it. Initially, one plate is heated at constant temperature \( T_w \) and another one is heated to the temperature \( T_0 \). A transverse magnetic field of uniform strength \( B_0 \) is applied normal to the direction of the flow.

The fluid has small electrical conductivity and the electromagnetic force produced is very small, so the induced magnetic field is neglected and there is no applied voltage which implies the absence of an electrical field. Viscous and Joules dissipations are neglected in energy equation. The fluid considered here is gray, absorbing/emitting radiation but a non-scattering medium. There is a first order chemical reaction between the diffusing species and the fluid. Then under usual Boussinesq’s approximation the fully developed flow is governed by the following set of equations as described by Reddy et al. [25, 26]:

\[
\frac{\partial u^*}{\partial t} = -\frac{1}{\rho} \frac{\partial P^*}{\partial x^*} + \frac{\partial}{\partial y^*} \left( \frac{\partial u^*}{\partial y^*} - \frac{\partial v^*}{\partial x^*} \right) - \frac{\beta \sigma B_0^2}{\rho} + g \beta \left( T^* - T_{eq} \right) + g \beta_c (C^* - C_0^*) \tag{1}
\]

\[
\frac{\partial T^*}{\partial t} = \kappa \frac{\partial^2 T^*}{\partial y^*^2} - \frac{1}{\rho C_p} \frac{\partial q^*}{\partial y^*} \tag{2}
\]

\[
\frac{\partial C^*}{\partial t} = D \frac{\partial^2 C^*}{\partial y^*^2} - K_c (C^* - C_0^*) \tag{3}
\]

The relevant boundary conditions are given as follows

**Case I: Uniform plate Temperature and Concentration:**

\[
U^* = h \left( \frac{\partial U^*}{\partial y^*} \right), \quad T^* = T_{eq}^*, \quad C^* = C_{eq}^* \quad \text{at} \quad y^* = 0
\]

\[
U^* = 0, \quad T^* = T_0^*, \quad C^* = C_0^* \quad \text{at} \quad y^* = a \tag{4}
\]

**Case II: Constant heat and mass flux:**

\[
U^* = h \left( \frac{\partial U^*}{\partial y^*} \right), \quad \frac{\partial T^*}{\partial y^*} = -\frac{q^*}{k}, \quad \frac{\partial C^*}{\partial y^*} = -\frac{q_{eq}^*}{\kappa} \quad \text{at} \quad y^* = 0
\]

\[
U^* = 0, \quad T^* = T_0^*, \quad C^* = C_0^* \quad \text{at} \quad y^* = a \tag{5}
\]
Consider the fluid which is optically thin with a relatively low density and radiative heat flux is given by

$$\frac{\partial q}{\partial y} = 4\alpha^2 (T^* - T_0^*)$$

(6)

Where \( \alpha \) is the mean radiation absorption coefficient.

On introducing the following non-dimensional quantities,

**Case I:**

$$x = \frac{x^*}{a}, \quad y = \frac{y^*}{a}, \quad u = \frac{u^*}{v}, \quad t = \frac{t^*}{a}, \quad \theta = \frac{T^* - T_0^*}{a^2}, \quad C = \frac{C^* - C_0^*}{a^2}, \quad P = \frac{aP^*}{v\rho\theta},$$

$$F^2 = \frac{4\alpha^2 a^2}{K}, \quad G_r = \frac{g\beta_r(T^* - T_0^*)a^2}{v\theta}, \quad G_m = \frac{g\beta_m(C^*_w - C_0^*)a^2}{v\theta}, \quad D_a = \frac{K^*}{a^2},$$

$$K_c = \frac{K_c^*}{v}, \quad S_c = \frac{v\alpha}{D}, \quad R_c = \frac{v\alpha \rho C_p}{\kappa}, \quad P_e = \frac{v\alpha \rho C_p}{\kappa}, \quad M = \sqrt{\frac{a^2 \sigma B_t^2}{\rho \theta}}$$

(7)

**Case II:**

$$x = \frac{x^*}{a}, \quad y = \frac{y^*}{a}, \quad u = \frac{u^*}{v}, \quad t = \frac{t^*}{a}, \quad \theta = \frac{T^* - T_0^*}{a^2}, \quad C = \frac{C^* - C_0^*}{a^2},$$

$$F^2 = \frac{4\alpha^2 a^2}{K}, \quad G_r = \frac{-g\beta_r a^3 q}{v\theta \kappa}, \quad G_m = \frac{-g\beta_m a^3 q_m}{v\theta \kappa}, \quad P = \frac{aP^*}{v\rho \theta}, \quad D_a = \frac{k^*}{a^2},$$

$$K_c = \frac{K_c^*}{v}, \quad S_c = \frac{v\alpha}{D}, \quad R_c = \frac{v\alpha \rho C_p}{\kappa}, \quad P_e = \frac{v\alpha \rho C_p}{\kappa}, \quad M = \sqrt{\frac{a^2 \sigma B_t^2}{\rho \theta}}$$

(8)

The non-dimensional form of the governing equations (3.1) to (3.3) reduce to

$$R_e \frac{\partial u}{\partial t} = -\frac{\partial P}{\partial x} + \frac{\partial^2 u}{\partial y^2} - (K^2 + M^2)u - G_r \theta - G_m C$$

(9)

$$P_e \frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial y^2} - F^2 \theta$$

(10)

$$S_c \frac{\partial C}{\partial t} = \frac{\partial^2 C}{\partial y^2} - K_c S_c C$$

(11)
Where \( K^2 = \frac{1}{D_a} = \frac{a^2}{K} \), the corresponding boundary conditions are

**Case I:**

\[
\begin{align*}
 u &= h \left( \frac{\partial u}{\partial y} \right), \quad \theta = 1, \quad C = 1 \text{ at } y = 0 \\
 u &= 0, \quad \theta = 0, \quad C = 1 \text{ at } y = 1
\end{align*}
\]

(12)

**Case II:**

\[
\begin{align*}
 u &= h \left( \frac{\partial u}{\partial y} \right), \quad \frac{\partial \theta}{\partial y} = -1, \quad \frac{\partial C}{\partial y} = -1 \quad \text{at} \quad y = 0 \\
 u &= 0, \quad \theta = 0, \quad C = 1 \quad \text{at} \quad y = 1
\end{align*}
\]

(13)

For purely periodic flow, let the pressure gradient be of the form, \( \frac{-\partial P}{\partial x} = \lambda e^{j\omega} \) where \( \lambda \) is a constant and \( \omega \) is the frequency of oscillations.

**4. SOLUTION OF THE PROBLEM:**

In order to solve the governing equations (9) to (11) subject to the boundary conditions (12) and (13), the following perturbation technique is used. The governing equations (9) to (11) are expanded in small perturbation parameter \( \varepsilon (\ll 1) \).

Let

\[
\begin{align*}
 u(y,t) &= u_o(y) + \varepsilon e^{j\omega t} u_1(y) + o(\varepsilon^2) + \ldots \\
 \theta(y,t) &= \theta_o(y) + \varepsilon e^{j\omega t} \theta_1(y) + o(\varepsilon^2) + \ldots \\
 C(y,t) &= c_o(y) + \varepsilon e^{j\omega t} c_1(y) + o(\varepsilon^2) + \ldots
\end{align*}
\]

(14)

(15)

(16)

Using equations (14) to (16) into the equations (9) to (11) and we get

**Zero-th order terms:**

\[
\begin{align*}
 u_0'' - m_1^2 u_0 &= -G, \quad \theta_0'' - G_m C_0 \\
 \theta_0'' - F^2 \theta_0 &= 0 \\
 C_0'' - m_5^2 C_0 &= 0
\end{align*}
\]

(17)

(18)

(19)
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First order terms:

\[ u_i'' - m_2^2 u_i = -\lambda / \varepsilon - G, \theta_1'' - G_m C_1 \]
\[ \theta_1'' - m_4^2 \theta_1 = 0 \]
\[ C_1'' - m_4^2 C_0 = 0 \]

The corresponding boundary conditions are

Case I:

\[ u_0 = h \frac{du_0}{dy}, u_i = h \frac{du_i}{dy}, \theta_0 = 1, \theta_0 = 0, C_0 = 1, C_1 = 0 \]
\[ u_0 = 0, u_i = 0, \theta_0 = 0, \theta_0 = 0, C_0 = 0, C_1 = 0 \]

at \( y = 0 \)

Case II:

\[ u_0 = h \frac{du_0}{dy}, u_i = h \frac{du_i}{dy}, \partial \theta_0 = -1, \partial \theta_1 = 0, \partial C_0 \]
\[ = -1, \partial C_1 = 0 \]

at \( y = 0 \)

Solving equations (17) to (22) under the boundary conditions (23) and (24), the following solutions are obtained.

Case I:

\[ u_0(y) = c_1 \cosh(m_2 y) + c_2 \sinh(m_2 y) + k \cosh(Ny - k_1 \sinh(Ny)) + k_4 \cosh(m_5 y - k_2 \sinh(m_5 y)) \]
\[ \theta_0(y) = \cosh(Fy - k_1 \sinh(Fy)) \]
\[ C_0(y) = \cosh(m_3 y - k_2 \sinh(m_3 y)) \]
\[ u_i(y) = c_3 \cosh(m_4 y) + c_4 \sinh(m_4 y) + k_5 \]
\[ \theta_1(y) = 0 \]
\[ C_1(y) = 0 \]

Finally the expressions for velocity, Temperature and concentration are given by

\[ \theta(y, t) = \cosh(Fy - k_1 \sinh(Fy)) \]
\[ C(y, t) = \cosh(m_3 y - k_2 \sinh(m_3 y)) \]
\[ u(y,t) = \left( c_1 \cosh m_2y + c_2 \sinh m_2y + k_3 (\cosh Fy - k_1 \sinh Fy) + \right) \] 
\[ k_4 (\cosh m_3y - k_2 \sinh m_3y) + \] 
\[ \epsilon e^{i\omega t} (c_3 \cosh(m_4y) + c_4 \sinh(m_4y) + k_6) \] 
(33)

**Case II:**

\[ u_0(y) = c_5 \cosh(m_2y) + c_6 \sinh m_2y + k_8 (\cosh N_y - k_1 \sinh N_y) + k_9 (\cosh m_5y - k_2 \sinh m_5y) \]  
(34)

\[ \theta_0(y) = \frac{1}{k_1 F} (\cosh Fy - k_1 \sinh Fy) \] 
(35)

\[ C_0(y) = \frac{1}{k_2 m_5} (\cosh m_3y - k_2 \sinh m_3y) \] 
(36)

\[ u_1(y) = c_3 \cosh m_1y + c_4 \sinh m_1y + k_5 \] 
(37)

\[ \theta_1(y) = 0 \] 
(38)

\[ C_1(y) = 0 \] 
(39)

Finally the expressions for velocity, Temperature and concentration are given by

\[ \theta(y,t) = \frac{1}{k_1 F} (\cosh Fy - k_1 \sinh Fy) \] 
(40)

\[ C(y,t) = \frac{1}{k_2 m_5} (\cosh m_3y - k_2 \sinh m_3y) \] 
(41)

\[ u(y,t) = \left( c_5 \cosh(m_2y) + c_6 \sinh m_2y + k_8 (\cosh N_y - k_1 \sinh N_y) + \right) \] 
\[ k_9 (\cosh m_5y - k_2 \sinh m_5y) + \epsilon e^{i\omega t} (c_3 \cosh(m_1y) + c_4 \sinh(m_1y) + k_6) \] 
(42)

**5. NUSSELT NUMBER:**

From temperature field, the rate of heat transfer in terms of Nusselt number is given in non-dimensional form as follows:

**For Case (I):** \[ \text{Nu} = -\left( \frac{\partial \theta}{\partial y} \right)_{y=0} = k_1 F \] 
(43)
For Case (II): \[ \text{Nu} = - \left( \frac{\partial \theta}{\partial y} \right)_{y=0} = 1 \] (44)

6. SHERWOOD NUMBER:

From concentration field, the rate of mass transfer in terms of Sherwood number is given in non-dimensional form as follows:

For Case (I): \[ Sh = - \left( \frac{\partial C}{\partial y} \right)_{y=0} = k_2 m_5 \] (45)

For Case (II): \[ Sh = - \left( \frac{\partial C}{\partial y} \right)_{y=0} = 1 \] (46)

7. SKIN-FRICTION:

From velocity field, the rate of change of velocity at the plate in terms of Skin-friction is given in non-dimensional form as follows:

For

Case (I): \[ \tau = \left( \frac{\partial u}{\partial y} \right)_{y=0} = [c_2 m_2 - (k_1 k_3 F + k_2 k_4 m_5)] + [\epsilon e^{i\alpha t} (c_4 m_1)] \] (47)

For Case (II): \[ \tau = \left( \frac{\partial u}{\partial y} \right)_{y=0} = [c_6 m_2 - (k_1 k_3 F + k_2 k_4 m_5)] + [\epsilon e^{i\alpha t} (c_4 m_1)] \] (48)

8. RESULTS AND DISCUSSIONS:

Case (I): In order to point out the effects of various parameters on flow characteristics, the following discussion is set out. The values of Prandtl number are chosen \( \text{Pr}_t = 7 \) (water) and \( \text{Pr}_t = 0.71 \) (air). The value of the Schmidt number is chosen to represent the presence of species by Carbon dioxide (1.00). Profiles for velocity, temperature and concentration fields in addition to skin-friction are presented in figures 1-18 for \( G_r > 0 \) and \( G_m > 0 \). Figure 1 shows the effect of wall slip \( h \) on the velocity field. From this figure it is observed that velocity increases as the slip parameter \( h \) increases. Velocity profiles for different values of time \( t \), Magnetic parameter \( M \), Reynolds number \( R_e \), and permeability parameter \( k \) are presented in figures from 2-5 respectively. It is observed that velocity decreases with increasing values of time \( t \) or magnetic parameter \( M \) or Reynolds number \( R_e \) or permeability.
parameter \( k \). The effects of thermal Grashof number \( G_r \), modified Grashof number \( G_m \), radiation parameter \( F \), Schmidt number \( S_c \) and chemical reaction parameter \( K_c \) are shown in figures from 6-10 respectively. It is observed that velocity increases with increasing values of thermal Grashof number \( G_r \) or modified Grashof number \( G_m \) while decreases with increasing values radiation parameter \( F \) or Schmidt parameter \( S_c \) or chemical reaction parameter \( K_c \).

Temperature profiles for different values of radiation parameter \( F \) and Schmidt parameter \( S_c \) are shown in figures 11 and 12 respectively. From these figures it is seen that velocity increases with the decrease in radiation parameter \( F \) or Schmidt parameter \( S_c \). Concentration profiles for different values of chemical reaction parameter \( K_c \) are presented in figure 13. It is noticed that concentration increases a chemical reaction parameter \( K_c \) decreases. A variation in shear stress \( \tau \) is shown in figures 14-18 for different values of wall slip parameter \( h \), magnetic parameter \( M \), permeability parameter \( k \), radiation parameter \( F \) and chemical reaction parameter \( K_c \). It is found that skin friction decreases with the increase in wall slip parameter \( h \) or magnetic parameter \( M \) or permeability parameter \( k \) or radiation parameter \( F \) or chemical reaction parameter \( K_c \).

**Case (II):** In order to know the influence of different physical parameters, viz., wall slip parameter \( h \), magnetic parameter \( M \), permeability parameter \( k \), radiation parameter \( F \), chemical reaction parameter \( K_c \), Reynolds number \( R_e \), thermal Grashof number \( G_r \), modified Grashof number \( G_m \), Schmidt number \( S_c \) and time \( t \) on the physical flow field, computations carried out for velocity, temperature, concentration and skin-friction and they are represented through figures 19-36 for \( G_r > 0 \) and \( G_m > 0 \). The values of Prandtl number are chosen \( P_r = 7 \) (water) and \( P_r = 0.71 \) (air). The value of the Schmidt number is chosen to represent the presence of species by Carbon dioxide (1.00). Figure 19 represents the effect of wall slip \( h \) on the velocity field. From this figure it is observed that velocity increases as an increase in slip parameter \( h \). Velocity profiles for different values of time \( t \), Magnetic parameter \( M \), Reynolds number \( R_e \), and permeability parameter \( k \) are presented in figures from 20-23 respectively. It is noticed that as \( t \) or \( M \) or \( R_e \) or \( k \) increases velocity also increases. The effects of thermal Grashof number \( G_r \), modified Grashof number \( G_m \), radiation parameter \( F \), Schmidt number \( S_c \) and chemical reaction parameter \( K_c \) are shown in figures from 24-28 respectively. It is found that velocity increases with increasing values of thermal Grashof number \( G_r \) or modified Grashof number \( G_m \) while it a reverse effect with increasing values radiation parameter \( F \) or Schmidt parameter \( S_c \) or chemical reaction parameter \( K_c \).

Temperature profiles for different values of radiation parameter \( F \) is shown in figures 29. From this figure it is seen that velocity increases with the decrease in radiation parameter \( F \). Concentration profiles for different values of Schmidt parameter \( S_c \) and chemical reaction parameter \( K_c \) are presented in figures 30 and 31 respectively. It is observed that concentration increases with decrease in Schmidt parameter \( S_c \) or chemical reaction parameter \( K_c \). Shear stress is presented against time \( t \) for different values of wall slip parameter \( h \), magnetic parameter \( M \), permeability parameter \( k \), radiation parameter \( F \) and chemical reaction parameter \( K_c \) in figures 32-36.
respectively. It is observed that Shear stress decreases with the increase in wall slip parameter h or magnetic parameter M or permeability parameter k or radiation parameter F or chemical reaction parameter $K_c$.

**GRAPHS:**

**Case I:**

**Figure 1.** Effect of wall slip h and time t on velocity field when $S_c = 1, G_r = 1, R_e = 1, P_e = 0.7, k = 1, F = 1, \omega = 1, \lambda = 1, K_c = 1, M = 1$

**Figure 2.** Effect of Magnetic parameter M and Reynolds Number $R_e$ on velocity field when $S_c = 1, G_r = 1, P_e = 0.7, k = 1, F = 1, \omega = 1, \lambda = 1, K_c = 1, h = 1, t=0$
Figure 3. Effect of permeability parameter $k$ and Grashof number $Gr$ on velocity field when $S_c = 1, R_e = 1, P_e = 0.7, M = 1, F = 1, \omega = 1, \lambda = 1, K_c = 1, h = 1$.

Figure 4. Effect of Modified Grashof Number $G_m$ and Radiation parameter $F$ on velocity field when $S_c = 1, G_r = 1, P_e = 0.7, k = 1, M = 1, \omega = 1, \lambda = 1, K_c = 1, h = 1, t=0$.
**Figure 5.** Effect of Schmidt Number $S_c$ and chemical reaction parameter $K_c$ on velocity field when $G_m = 1, G_r = 1, P_e = 0.7, k = 1, F = 1, \omega = 1, \lambda = 1, h = 1, t=0, M=1$.

**Figure 6.** Effect of Radiation parameter $F$ on Temperature field and Schmidt number $S_c$ on concentration field when $G_m = 1, G_r = 1, P_e = 0.7, k = 1, \omega = 1, \lambda = 1, h = 1, t=0, M=1$. 
Figure 7. Effect of the chemical reaction parameter $K_c$ on concentration field and $k$ on skin friction when $G_m = 1, G_r = 1, P_e = 0.7, k = 1, F = 1, \omega = 1, \lambda = 1, t=0, M=1$

Figure 8. Effects of $M$ and $k$ on Skin-friction

Figure 9. Effects of $F$ and $K_c$ Skin-friction
Case II:

Figure 10. Effect of wall slip h and time t on velocity field when $S_c = 1, G_r = 1, R_e = 1, P_e = 0.7, k = 1, F = 1, \omega = 1, \lambda = 1, K_c = 1, M = 1$

Figure 11. Effect of Magnetic parameter M and Reynolds Number $R_e$ on velocity field when $S_c = 1, G_r = 1, P_e = 0.7, k = 1, F = 1, \omega = 1, \lambda = 1, K_c = 1, h = 1, t=0$

Figure 13. Effect of permeability parameter k and Grashof number $G_r$ on velocity field when $S_c = 1, R_e = 1, P_e = 0.7, M = 1, F = 1, \omega = 1, \lambda = 1, K_c = 1, h = 1$
Figure 14. Effect of Modified Grashof Number $G_m$ and Radiation parameter $F$ on velocity field when $S_c = 1, G_r = 1, P_e = 0.7, k = 1, M = 1, \omega = 1, \lambda = 1, K_c = 1, h = 1, t=0$.

Figure 15. Effect of Schmidt Number $S_c$ and chemical reaction parameter $K_c$ on velocity field when $G_m = 1, G_r = 1, P_e = 0.7, k = 1, F = 1, \omega = 1, \lambda = 1, h = 1, t=0, M=1$.

Figure 16. Effect of Radiation parameter $F$ on Temperature field and Schmidt number $S_c$ on concentration field.
**Figure 17.** Effect of the chemical reaction parameter $K_c$ on concentration field and $h$ on Skin-friction

**Figure 33.** Skin-friction for different values of magnetic parameter $M$ and permeability parameter $k$

**Figure 35.** Skin-friction for different values of radiation parameter $F$ and $K_c$
9. CONCLUSIONS:
In this paper we have studied the effects of slip condition, chemical reaction and radiation on MHD free convection periodic flow through a saturated porous medium bounded by a vertical surface in a planer channel in two cases viz. Case–I: Uniform plate Temperature and Concentration and Case–II: Constant heat and mass flux. In the analysis of the flow the following conclusions are made.

1. In case (I) and (II) of the study, the velocity increases with an increase in slip parameter h, Grashof number $G_r$, modified Grashof number $G_m$, Schmidt number $Sc$, and Radiation parameter F, and it shows a reverse effect in the case of magnetic parameter $M$, time $t$, permeability parameter $k$ or Reynolds number $Re$.

2. Temperature decreases with the increase in radiation parameter F for Case (I) and (II).

3. Concentration decreases with an increase in chemical reaction parameter $k_c$ or Schmidt number $Sc$ in Case (I) as well as in Case (II) of the problem.

4. Shear stress increases with the increase in magnetic parameter $M$ or permeability parameter $k$ and it shows a reverse effect in the case of slip parameter $h$ or Schmidt number $Sc$ in both cases of the study.

REFERENCES


[34] V. Ravikumar, M.C. Raju, G.S.S. Raju,, Theoretical investigation of an unsteady MHD free convection heat and mass transfer flow of a non-


