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Effect of Heat and Mass Transfer on Free Convective Couette Dissipative Fluid Flow through a Porous Medium with Chemical Reaction and Slip Conditions

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Abstract

The effect of heat and mass transfer on free convective couette dissipating fluid flow through a porous medium with chemical reaction and slip condition has been studied. The governing equations of the flow field are solved employing perturbation technique and the expressions for the velocity, temperature, concentration distribution, skin friction, rate of heat transfer i.e heat flux in terms of Nusselts number Nu and mass transfer i.e shear stress in terms of Sherwood number Sh are obtained. The effects of pertinent parameters such as suction parametersα_1, α_2 ; Grashof number for heat and mass transfer G_r, G_c; slip flow parameters h_1, h_2; radiation parameterF, permeability parameter K_p, Chemical reaction K_c Schmidt numberS_c, Prandtl numberP_r, Eckert number E_c on the flow field have been studied and the results are presented graphically and discussed quantitatively.

Key words: Free convection, MHD, Chemical reaction, porous medium, Slip condition, Fluid dissipation, heat and mass transfer, couette flow.

I . Introduction:

Free convection flow of heat and mass transfer occurs frequently in nature and industrial processes. Many fields of interest in which combined heat and mass transfer performs an important role is in the field of science and engineering such as designing chemical processing equipment, crop damages due to freezing and environmental pollution. Example of free convection is the atmospheric flow due to temperature difference etc.

Magneto hydrodynamic (MHD) free convection of a viscous incompressible fluid along a vertical porous medium channel plates must be studied if we are to understand the behaviour of fluid flow parameters. MHD free convection flow and heat and mass transfer have become more important in recent years because of its applications in agricultural engineering and petroleum industries. Recently, considerable attention has also been focused on new applications of MHD and heat and mass transfer such as metallurgical processing Kishore et al (2013). In melt refining, the magnetic field is used to control excessive heat and mass transfer rate. The effect of radiative heat and mass transfer on unsteady natural convection coquette flow of a viscous incompressible fluid in the slip flow regime in present of variable suction and radiative heat source was analyzed by Das et al (2012). Rao et al (2013), analyzed the unsteady free convection heat and mass transfer flow through a non-homogeneous porous medium with variable permeability bounded by an infinite porous vertical plate in slip flow regime taking in to account the radiation, chemical reaction and temperature gradient dependent heat source.

Viscous dissipation past a parallel vertical porous plate is always neglected and it is characterized by the Eckert number (E_C) especially when the flow is at low temperature or in high gravitational field. This effect is essentially in geophysical flow and many certain industrial operations, where highly viscous fluids with low thermal conductivity are consider. The property that comes in to play in free convection is the coefficient of thermal expansion of the fluid, β and Grashof number, Gr. A numerical study on the effect of chemical reaction, radiation and magnetic field on the unsteady free convection flow of heat and mass transfer characteristics in a viscous incompressible and electrically conductivity fluid past an exponentially accelerated vertical plate by taking in to account the heat due to viscous dissipation was analyzed by Kishore et al (2013). Khan (2014) investigated the effects of an arbitrary wall shear stress on unsteady MHD flow of a Newtonian fluid with conjugate effects of heat and mass transfer in a porous medium over a vertical plate with ramped temperature. Singh et al (2013) investigated the effects of heat source and thermal diffusion on an unsteady free convection flow along a porous vertical plate in a rotating system subjected to constant heat and mass flux. Ecgunjobi and Makinde (2012) investigated the combined effects of buoyancy force and Navier slip on the entropy generation rate in a vertical porous channel with wall suction/injection. Sarada and Shanker (2013) studied the effect of chemical reaction on an unsteady magneto hydrodynamic flow past an infinite vertical porous plate with variable suction and heat convective mass transfer, where the plate temperature oscillates with the frequency as that of variable suction velocity.

The aim of this paper is to study the effect of heat and mass transfer on free convective couette dissipating fluid flow through a porous medium with chemical reaction and slip condition.

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2. Formulation of the problem:

Let us consider a two-dimensional unsteady MHD free convection flow and viscous incompressible fluid past through parallel vertical porous medium channel plates placed at a distance h apart in the presence of chemical reaction and slip conditions.

Figure 1

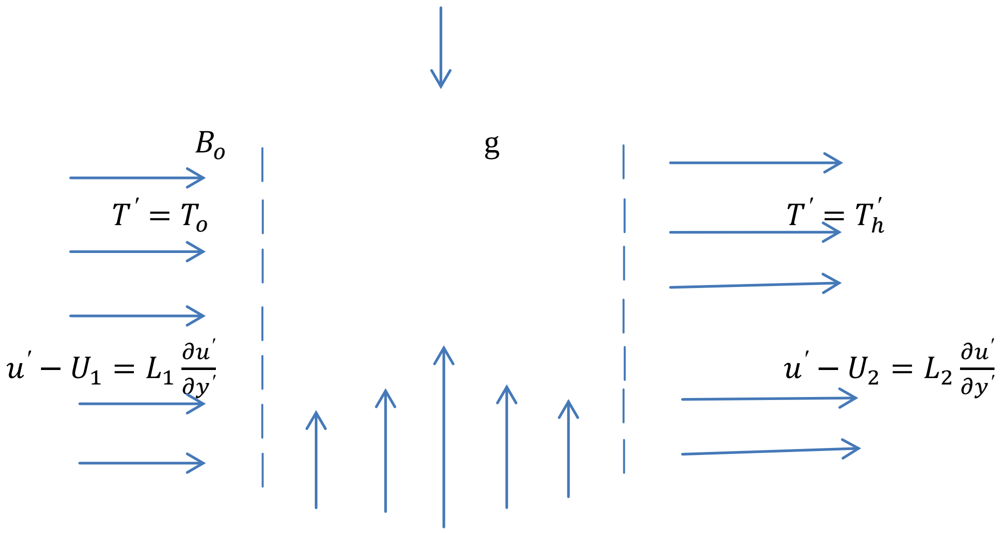

Figure 1: Flow configuration and coordinate system

In a Cartesian coordinate system, the x - axis is taken along the plates and the y-axis is taken normal to it. Since the plates are considered infinite in x –direction, then all flow quantities become self – similar. Therefore, all the physical variables become function of $t^{'}$ and $y^{'}$ only. Initially, both the plates and fluid are at stationary conditions with the constant temperature $T_h^{'}$ and concentration $C_h^{'}$. After time $t^{'} = 0$, the temperature of the plate is raised to $T_h^{'} + (T^{'} - T_h^{'})\frac{t^{'}}{t_o^{'}}$ when $t^{'} \leq t_o^{'}$, and thereafter, $T^{'}$ is maintained at constant temperature and concentration is raised to $C^{'}$. We assume that the flow is laminar and the reaction is assumed to takes place entirely in the stream where the slip parameters enhancing the velocity of the fluid. A uniform magnetic field B_o is applied in the $y^{'}$ - direction, the fluid is assumed to be electrically conducting (electrolyte). The fluid being electrolyte, the magnetic field Grashof number is taken to be very small and hence the induced magnetic field can be neglected in comparison with the applied magnetic field in the absence of any input electric field. The heat due to viscous dissipation is taken in to account. The flow in the medium is entirely due to buoyancy force caused by temperature difference between the porous plates and the fluid.

The medium between the porous plates of a permeable material is given as

$$k'(t') = k'_o(1 + \varepsilon A e^{iw't'}) \quad (1)$$

And a time dependent suction is

$$v'(t') = -v'_o(1 + \varepsilon A e^{iw't'}) \quad (2),$$

For $v'_o > 0$ is the suction velocity at a plate. The negative sign indicates that the suction velocity acts towards the plates.

Under the above assumption as well as Boussinesq's approximation, the equations governing the conservation of mass (continuity), momentum, energy and concentration can be written as follows:

Continuity equation:

$$\frac{\partial v'}{\partial y'} = 0$$

Momentum equation:

$$\frac{\partial u'}{\partial t'} - V'_O(1 + \varepsilon A e^{iw't'})\frac{\partial u'}{\partial y'} = g\beta(T' - T'_h) + g\beta^*(C' - C'_h) + v\frac{\partial^2 u'}{\partial y'^2} - v\frac{u'}{k'(t')} + \frac{\sigma B_O^2 u'}{\rho} \quad (3)$$

Energy equation:

$$\frac{\partial T'}{\partial t'} - V'_o(1 + \varepsilon A e^{iw't'})\frac{\partial T'}{\partial y'} = \frac{K}{\rho C_P}\frac{\partial^2 T'}{\partial y'^2} - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y'} + \frac{\mu}{\rho C_p}\left(\frac{\partial u'}{\partial y'}\right)^2 \quad (4)$$

Concentration equation:

$$\frac{\partial C'}{\partial t'} - V'_o(1 + \varepsilon A e^{iw't'})\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} + k_c(C' - C'_h) \quad (5)$$

With the following boundary conditions of the problem

$$u' - U_1 = L_1 \frac{\partial u'}{\partial y'}, \frac{\partial T'}{\partial y'} = -\frac{q}{K}, \quad \frac{\partial C'}{\partial y'} = -\frac{m}{D} \quad at\, y' = 0$$

$$u' - U_2 = L_2 \frac{\partial u'}{\partial y'}, \qquad T' = T_h', \qquad C' = C_h', \quad at\, y' = h$$

Where $u' and v'$ are the components of velocity along x −axis and y −axis directions, t is time, g is the acceleration due to gravity, β and β^* are the coefficients of volume expansion of heat and mass transfer, v is the kinematic viscosity, $k'(t)$ is the permeability of the porous medium, ρ is the density of the fluid, σ is the electrical conductivity of the fluid, B_o is the uniform magnetic field, K is the thermal conductivity, C_p is the specific heat at constant pressure, q_r is the radioactive heat flux, q is the heat source, T' is the temperature of the wall as well as the temperature of the fluid at the plate, T_h' is the temperature of the fluid far away from the plate, $L_1 = \left(\frac{2-\mu_1}{\mu_1}\right)$ being the mean free path where μ_1 is the Maxwell's reflection coefficient, C' is the concentration of the wall as well as the concentration of the fluid at the plate, C_h' is the concentration of the fluid far away from the plate, D is the molecular dissipation, k_c is the chemical reaction parameter, A and B are the real positive constants, ε is the small positive number such that $\varepsilon A \ll 1$ and $\varepsilon B \ll 1$, ω' is a positive constant, t' is the time in x', y' coordinate system.

The radiactive heat flux q_r is given as

$\frac{\partial q_r}{\partial y'} = 4(T' - T_h')l$, where l is the absorption coefficient at the wall.

Introducing the dimensionless parameters as follows;

$$y = \frac{y' v_o'^2}{v}, \quad \omega = \frac{v\omega'}{v_o'^2}, u = \frac{u'}{v_o'}, k_p = \frac{v_o'^2 k_o'}{v^2}, \theta = \frac{k v_o'(T' - T_h')}{vq},$$

$$C = \frac{D v_o'(C' - C_h')}{vm}, P_r = \frac{\rho v c_p}{k}, G_r = \frac{g\beta q v^2}{k v_o'^4}, G_C = \frac{g m v^2 \beta^*}{D v_o'^4}, F = \frac{4vl}{\rho C_p v_o'^2},$$

$$S_c = \frac{v}{D}, \propto_1 = \frac{U_1}{v_o'}, \propto_2 = \frac{U_2}{v_o'}, k_c = \frac{v k_o'}{v_o'}, h_1 = \frac{l_1 v_o'}{v}, h_2 = \frac{l_2 v_o'}{v}, H_a^2 = \frac{\sigma l^2 B_O^2}{\mu},$$

$$E_c = \frac{v_o'^2}{C_P(T' - T_h')}, v = \frac{\mu}{\rho}$$

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We have the following

Momentum equation:

$$\frac{\partial u}{\partial t} - \left(1 + \varepsilon A e^{iwt}\right)\frac{\partial u}{\partial y} = G_r\theta + G_c C + \frac{\partial^2 u}{\partial y^2} - \frac{u}{k_p(1+\varepsilon A e^{iwt})} + mu \qquad (6)$$

Energy equation:

$$\frac{\partial \theta}{\partial t} - \left(1 + \varepsilon A e^{iwt}\right)\frac{\partial \theta}{\partial y} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial y^2} - F\theta + E_c\left(\frac{\partial u}{\partial y}\right)^2 \qquad (7)$$

Concentration equation:

$$\frac{\partial C}{\partial t} - \left(1 + \varepsilon A e^{iwt}\right)\frac{\partial C}{\partial y} = \frac{1}{S_c}\frac{\partial^2 C}{\partial y^2} + k_c C \qquad (8)$$

And the boundary conditions

$$u = \propto_1 + h_1\frac{\partial u}{\partial y}, \frac{\partial \theta}{\partial y} = -1, \frac{\partial C}{\partial y} = -1, at\ y = 0$$

$$u = \propto_2 + \frac{\partial u}{\partial y}, \theta = 0, C = 0\ at\ y = h$$

3. Method of solution

In order to solve equation (6 – 8), we assume

$$U(y,t) = U_o(y) + \varepsilon e^{iwt}U_1(y) + O(\varepsilon^2) \qquad (9)$$

$$\theta(y,t) = \theta_o(y) + \varepsilon e^{iwt}U_1(y) + O(\varepsilon^2) \qquad (10)$$

$$C(y,t) = C_o(y) + \varepsilon e^{iwt}C_1(y) + O(\varepsilon^2) \qquad (11)$$

Replacing the above in to the governing equations to have the zero and the first order differential equations respectively

For equation (6)

$$U_o'' + U_o' - \left(\frac{1}{k_p} - m\right)U_o = -G_r\theta_o - G_c C_o \qquad (12)$$

$$U_1'' + U_1' + \left(iw + \frac{B}{K_p} - m\right)U_1 = -G_r\theta_1 - G_c C_1 - AU_o' \qquad (13)$$

For equation (7)

$$\theta_o'' + P_r\theta_o' - P_rF\theta_o = -P_rE_c(U_o')^2 \quad (14)$$

$$\theta_1'' + P_r\theta_1' + P_r(iw - F)\theta_1 = -P_rA\theta_1' - 2P_rE_cU_o'U_1' \quad (15)$$

For equation (8)

$$C_o'' + S_cC_o' + S_cK_cC_o = 0 \quad (16)$$

$$C_1'' + S_cC_1' + S_c(iw + K_c)C_1 = -AC_o' \quad (17)$$

Now, the boundary conditions are

$$U_o = \propto_1 + h_1U_1',\ U_1 = h_1U_1',\ \theta_o' = -1, \theta_1' = 0, C_o' = -1, C_1' = 0\ at\ y = 0$$

$$U_o = \alpha_2 + h_2U_o', \quad U_1 = h_2U_1', \quad \theta_o = 0, \theta_o - 0, C_1 = 0, C_o = 0\ at\ y = 1$$

4. Further simplification

In order to obtain the solution of the above differential equations, we expand $U_o, U_1, \theta_o, \theta_1, C_o$ and C_1 in the powers of Eckert numberE_c, assuming that it is very small.

$$U_O(y) = U_{OO}(y) + E_CU_{O1}(y) + O(E_C^2)$$

$$U_1(y) = U_{1O}(y) + E_CU_{11}(y) + O(E_C^2)$$

$$\theta_O(y) = \theta_{OO}(y) + E_C\theta_{O1}(y) + O(E_C^2)$$

$$\theta_1(y) = \theta_{1O}(y) + E_C\theta_{11}(y) + O(E_C^2) \quad (18)$$

$$C_O(y) = C_{OO}(y) + E_CC_{O1}(y) + O(E_C^2)$$

$$C_1(y) = C_{1O}(y) + E_CC_{11}(y) + O(E_C^2)$$

Using (18) in (12 - 17), we have the following equation;

For moment, we have

$$U_{OO}'' + U_{OO}' - L_2U_{OO} = -G_r\theta_{OO} - G_cC_{OO} \quad (19)$$

$$U_{O1}'' + U_{O1}' - L_2U_{O1} = -G_r\theta_{O1} - G_CC_{O1} \quad (20)$$

$$U''_{10} + U'_{10} - L_3 U_{10} = -AU'_{00} - G_r\theta_{10} - G_c C_{10} \quad (21)$$

$$U''_{11} + U'_{11} - L_3 U_{11} = -AU'_{01} - G_r\theta_{11} - G_C C_{11} \quad (22)$$

With the following corresponding boundary conditions

$$U_{00} = \propto_1 + h_1 U'_{00},\ U_{01} = h_1 U'_{01},\quad U_{10} = h_1 U'_{10}\ ,\ U_{11} = h_1 U'_{11}, at\ y = 0\ \ and$$

$$U_{00} = \propto_2 + h_2 U'_{00},\ U_{01} = h_2 U'_{01},\ U_{10} = h_2 U'_{10},\ U_{11} = h_2 U'_{11}\ \ at\ y = 1$$

For energy, we have

$$\theta''_{00} + P_r\theta'_{00} - P_r F\theta_{00} = 0 \quad (23)$$

$$\theta''_{01} + P_r\theta'_{01} - P_r F\theta_{01} = -P_r(U'_{00})^2 \quad (24)$$

$$\theta''_{10} + P_r\theta'_{10} + L_4\theta_{10} = -P_r\theta'_{00} \quad (25)$$

$$\theta''_{11} + P_r\theta'_{11} + L_4\theta_{11} = -P_r A\theta'_{01} - 2U'_{00}U'_{10} \quad (26)$$

With the following corresponding boundary conditions

$$\theta'_{00} = -1, \theta'_{01} = 0, \theta'_{10} = 0, \theta'_{11} = 0\ at\ y = 0\ and$$

$$\theta_{00} = 0, \theta_{01} = 0, \theta_{10} = 0, \theta_{11} = 0\ at\ y = 1$$

For concentration, we have

$$C''_{00} + S_C C'_{00} + S_C K_C C_{00} = 0 \quad (27)$$

$$C''_{01} + S_C C'_{01} + S_C K_C C_{01} = 0 \quad (28)$$

$$C''_{10} + S_C C'_{10} + L_1 C_{10} = -AC'_{00} \quad (29)$$

$$C''_{11} + S_C C'_{11} + L_1 C_{11} = -AC'_{01} \quad (30)$$

With the following boundary conditions

$$C'_{00} = -1, C'_{01} = 0, C'_{10} = 0, C'_{11} = 0\ \ at\ y = 0\ \ and$$

$$C_{00} = 0, C_{01} = 0, C_{10} = 0, C_{11} = 0\ \ at\ y = 1$$

The solution of equation (19 - 30) under boundary conditions are given by

CONCENTRATION:

$$C_0(y) = C_1e^{m_1y} + C_2e^{m_2y} + E_c(C_3e^{m_3y} + C_4e^{m_4y}) \quad (31)$$

$$C_1(y) = C_5e^{m_5y} + C_6e^{m_6y} + K_1e^{m_1y} + K_2e^{m_2y} + E_c(C_7e^{m_7y} + C_8e^{m_8y} + K_3e^{m_3y} + K_4e^{m_4y}) \quad (32)$$

ENERGY:

$$\theta_o(y) = C_9e^{m_9y} + C_{10}e^{m_{10}y} + E_c(C_{11}e^{m_{11}y} + C_{12}e^{m_{12}y} + K_5e^{2m_{17}y} + K_6e^{L_6y} + K_7e^{2m_{18}y}) \quad (33)$$

$$\theta_1(y) = C_{13}e^{m_{13}y} + C_{14}e^{m_{14}y} + K_8e^{m_9y} + K_9e^{m_{10}y} + E_c(C_{15}e^{m_{15}y} + C_{16}e^{m_{16}y} + K_{10}e^{m_{11}y} + K_{11}e^{m_{12}y} + K_{12}e^{L_8y} + K_{13}e^{L_{10}y} + K_{14}e^{L_{12}y} + K_{15}e^{L_{14}y}) \quad (34)$$

MOMENTUM:

$$U_o(y) = C_{17}e^{m_{17}y} + C_{18}e^{m_{18}y} + K_{16}e^{m_9y} + K_{17}e^{m_{10}y} + K_{18}e^{m_1y} + K_{19}e^{m_2y} + E_c(C_{19}e^{m_{19}y} + C_{20}e^{m_{20}y} + K_{20}e^{m_{11}y} + K_{21}e^{m_{12}y} + K_{22}e^{m_3y} + K_{23}e^{m_4y}) \quad (35)$$

$$U_1(y) = C_{21}e^{m_{21}y} + C_{22}e^{m_{22}y} + K_{24}e^{m_{17}y} + K_{25}e^{m_{18}y} + K_{26}e^{m_{13}y} + K_{27}e^{m_{14}y} + K_{28}e^{m_5y} + K_{29}e^{m_6y} + E_c(C_{23}e^{m_{23}y} + C_{24}e^{m_{24}y} + K_{30}e^{m_{19}y} + K_{31}e^{m_{20}y} + K_{32}e^{m_{15}y} + K_{33}e^{m_{16}y} + K_{34}e^{m_7y} + K_{35}e^{m_8y}) \quad (36)$$

Introducing (31 – 36) in to (9 - 11), we get the following fields;

$$U(y,t) = C_{17}e^{m_{17}y} + C_{18}e^{m_{18}y} + K_{16}e^{m_9y} + K_{17}e^{m_{10}y} + \varepsilon e^{iwt}(C_{21}e^{m_{21}y} + C_{22}e^{m_{22}y} + K_{24}e^{m_{17}y} + K_{25}e^{m_{18}y} + K_{26}e^{m_{13}y} + K_{27}e^{m_{14}y} + K_{28}e^{m_5y} + K_{29}e^{m_6y})$$

$$\theta(y,t) = C_9e^{m_9y} + C_{10}e^{m_{10}y} + \varepsilon e^{iwt}(C_{13}e^{m_{13}y} + C_{14}e^{m_{14}y} + K_8e^{m_9y} + K_9e^{m_{10}y}$$

$$C(y,t) = C_1e^{m_1y} + C_2e^{m_2y} + E_c(C_3e^{m_3y} + C_4e^{m_4y}) + \varepsilon e^{iwt}(C_5e^{m_5y} + C_6e^{m_6y} + K_1e^{m_1y} + K_2e^{m_2y})$$

SKIN FRICTION:

The expression for the skin friction (τ) i.e the shear stress is,

$$\tau = \left[\frac{\partial u}{\partial y}\right]_{y=0} = \left[\frac{\partial u_o}{\partial y}\right]_{y=0} + \varepsilon e^{iwt}\left[\frac{\partial u_1}{\partial y}\right]_{y=0}$$

$$= C_{17}m_{17} + \varepsilon e^{iwt}(C_{22}m_{22} + K_{24}m_{18})$$

RATE OF HEAT TRANSFER:

The expression for the rate of heat transfer i.e heat flux at the plate in terms of Nusselt number(Nu) is,

$$Nu = \left[\frac{\partial \theta}{\partial y}\right]_{y=0} = \left[\frac{\partial \theta_o}{\partial y}\right]_{y=0} + \varepsilon e^{iwt}\left[\frac{\partial \theta_1}{\partial y}\right]_{y=0}$$

$$= C_9m_9 + C_{10} + \varepsilon e^{iwt}C_{13}m_{13}$$

RATE OF MASS TRANSFER:

The expression for the rate of mass transfer at the plate in terms of Sherwood number Sh is given as

$$Sh = \left[\frac{\partial C}{\partial y}\right]_{y=0} = \left[\frac{\partial C_o}{\partial y}\right]_{y=0} + \varepsilon e^{iwt}\left[\frac{\partial C_1}{\partial y}\right]_{y=0}$$

$$= C_1m_1 + C_2 + \varepsilon e^{iwt}C_5m_5$$

Where

$m_{17} = -1 + \sqrt{\frac{1^2+4L_2}{2}}$, $m_{18} = -1 - \sqrt{\frac{1^2+4L_2}{2}}$, $m_{19} = -1 + \sqrt{\frac{1^2+4L_2}{2}}$, $m_{20} = -1 - \sqrt{\frac{1^2+4L_2}{2}}$, $m_{21} = -1 + \sqrt{\frac{1^2+4L_3}{2}}$, $m_{22} = -1 - \sqrt{\frac{1^2+4L_3}{2}}$, $m_{23} = -1 + \sqrt{\frac{1^2+4L_3}{2}}$, $m_{24} = -1 - \sqrt{\frac{1^2+4L_3}{2}}$, $m_9 = -P_r + \sqrt{\frac{P_r^2+4FP_r}{2}}$, $m_{10} = -P_r - \sqrt{\frac{P_r^2+4FP_r}{2}}$, $m_{13} = -P_r + \sqrt{\frac{P_r^2-4L_4}{2}}$, $m_{14} = -P_r - \sqrt{\frac{P_r^2-4L_4}{2}}$

$K_{16} = -\frac{G_rC_9}{m_9^2+m_9-L_2}$, $K_{17} = -\frac{G_rC_{10}}{m_{10}^2+m_{10}-L_2}$, $K_{18} = -\frac{G_rC_1}{m_1^2+m_1-L_2}$

$K_{19} = -\frac{G_rC_2}{m_2^2+m_2-L_2}$, $K_{20} = -\frac{G_rC_{11}}{m_{11}^2+m_{11}-L_2}$, $K_{21} = -\frac{G_rC_{12}}{m_{12}^2+m_{12}-L_2}$, $K_{22} = -\frac{G_rC_3}{m_3^2+m_3-L_2}$ and

$K_{23} = -\frac{G_r C_4}{m_4^2+m_4-L_2}$, $K_{24} = -\frac{AC_{17}m_{17}}{m_{17}^2+m_{17}-L_3}$,$K_{25} = -\frac{AC_{18}m_{18}}{m_{18}^2+m_{18}-L_3}$,$K_{26} = -\frac{G_r C_{13}}{m_{13}^2+m_{13}-L_3}$

$K_{27} = -\frac{G_r C_{14}}{m_{14}^2+m_{14}-L_3}$,$K_{28} = -\frac{G_c C_5}{m_5^2+m_5-L_3}$ and $K_{29} = -\frac{G_c C_6}{m_6^2+m_6-L_3}$, $K_{30} = -\frac{AC_{19}m_{19}}{m_{19}^2+m_{19}-L_3}$,$K_{31} = -\frac{AC_{20}m_{20}}{m_{20}^2+m_{20}-L_3}$,$K_{32} = -\frac{G_r C_{15}}{m_{15}^2+m_{15}-L_3}$

$K_{33} = -\frac{G_r C_{16}}{m_{16}^2+m_{16}-L_3}$,$K_{34} = -\frac{G_c C_7}{m_7^2+m_7-L_3}$ and$K_{35} = -\frac{G_c C_8}{m_8^2+m_8-L_3}$,

$K_5 = \frac{-P_r C_{17} m_{17}}{2m_{17}^2+2m_{17}P_r-P_r F}$,$K_6 = \frac{-P_r C_{17} m_{17} C_{18} m_{18}}{(m_{17}+m_{18})^2+P_r(m_{17}+m_{18})-P_r F}$, $K_7 = \frac{-P_r C_{18} m_{18}}{2m_{18}^2+2m_{18}P_r-P_r F}$

5.0 Results And Discussions:

This paper discusses the effect of heat and mass transfer on free convective couette dissipative fluid flow through a porous medium with chemical reaction and slip conditions. The governing equations of the flow field are solved for the velocity, temperature, concentration distribution, skin friction and the rate of heat and mass transfer and the effects of the various flow parameters on the flow field have been studied and the results are presented graphically and discussed quantitatively with the aid of velocity profiles in figures 1 – 11, temperature profile 13 – 14, and concentration distribution shown in figures 15 – 16.

5.1 VELOCITY FIELD

The velocity of the flow varies to a great extent with the variation of the flow parameters. The main factors affecting the velocity of the flow field are; suction parameters α_1 , α_2, Grashof number for heat and mass transfer G_r , G_c , slip parameters h_1 , h_2, radiation parameter F, permeability parameter K_p, Schmidt number S_c, chemical reaction K_c, magnetic parameter M and heat source q. The following graphs are important in checking the effect of such parameters.

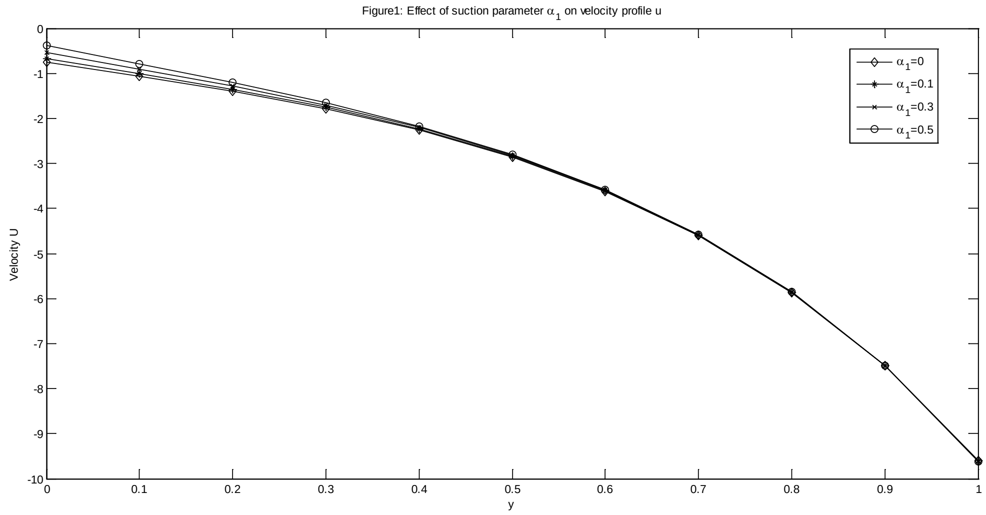

Figure 1: velocity profiles against y for different values of $\propto_1$=? with $P_r = 0.71, w = 0.1, t = 0.1, \varepsilon = 0.02, G_c = 2, G_r = 2,\ K_c = 0.1, M = 0.5, q\ 1, S_c = 0.6, K_p = 1, F = 0.1, A = 0.5, B = 0.5, h_1 = 0.1, h_2 = 0.1$ and $\propto_2 = 0.2$

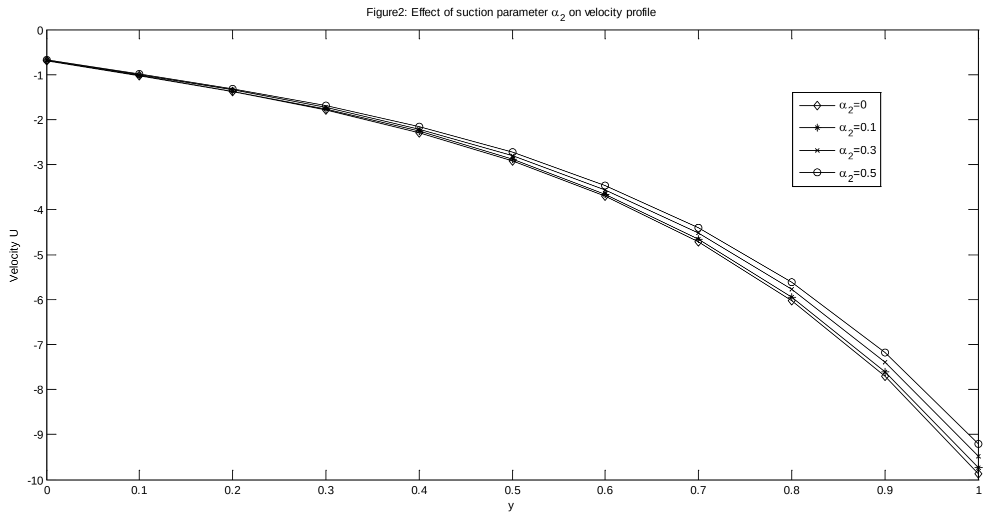

Figure 2: velocity profiles against y for different values of $\propto_2$=? with $P_r = 0.71, w = 0.1, t = 0.1, \varepsilon = 0.02, G_c = 2, G_r = 2,\ K_c = 0.1, M = 0.5, q\ 1, S_c = 0.6, K_p = 1, F = 0.1, A = 0.5, B = 0.5, h_1 = 0.1, h_2 = 0.1$ and $\propto_1 = 0.1$

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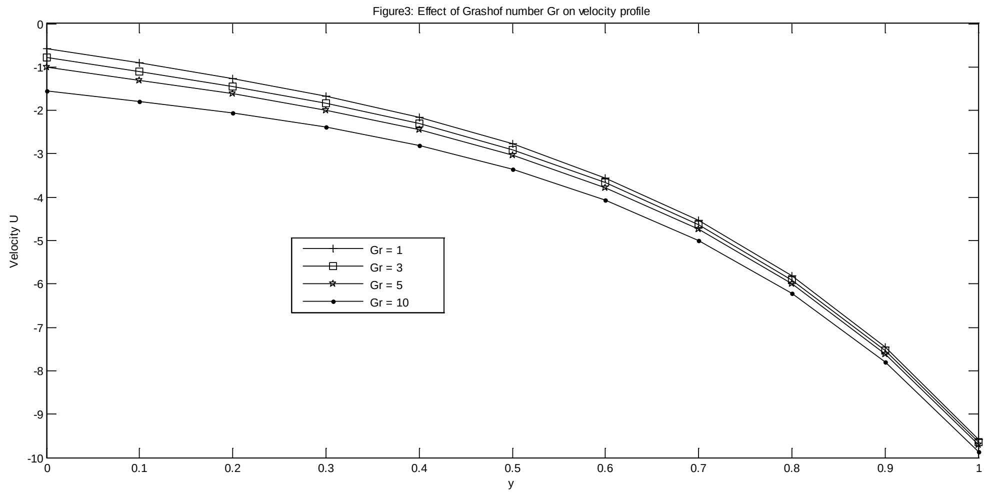

Figure 3**:** velocity profiles against y for different values of $G_r =?$ with $P_r = 0.71, w = 0.1, t = 0.1, \varepsilon = 0.02, G_c = 2,\ K_c = 0.1, M = 0.5, q\ 1, S_c = 0.6, K_p = 1, F = 0.1, A = 0.5, B = 0.5, h_1 = 0.1, h_2 = 0.1, \propto_1 = 0.1$ and $\propto_2 = 0.2$

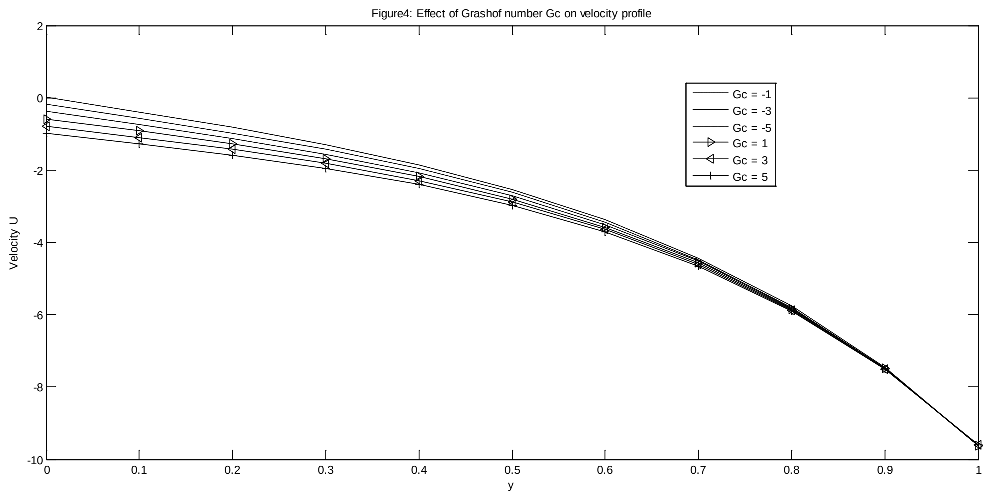

Figure 4: velocity profiles against y for different values of $G_c =?$ with $P_r = 0.71, w = 0.1, t = 0.1, \varepsilon = 0.02, G_r = 2,\ K_c = 0.1, M = 0.5, q\ 1, S_c = 0.6, K_p = 1, F = 0.1, A = 0.5, B = 0.5, h_1 = 0.1, h_2 = 0.1, \propto_1 = 0.1$ and $\propto_2 = 0.2$

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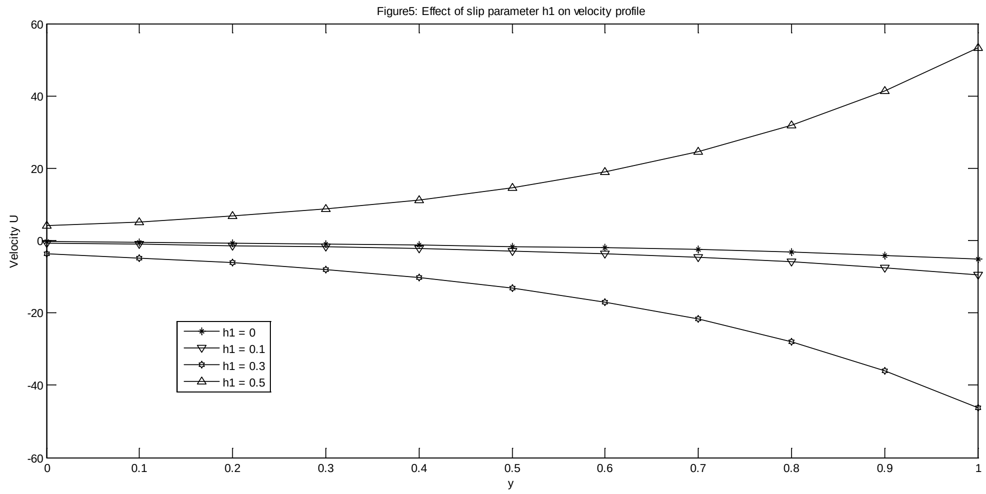

Figure 5: velocity profiles against y for different values of h_1 =? with $P_r = 0.71, w = 0.1, t = 0.1, \varepsilon = 0.02, G_c = 2,\ K_c = 0.1, M = 0.5, q\ 1, G_r = 2\ , S_c = 0.6, K_p = 1, F = 0.1, A = 0.5, B = 0.5, , h_2 = 0.1, \propto_1 = 0.1$ and $\propto_2 = 0.2$

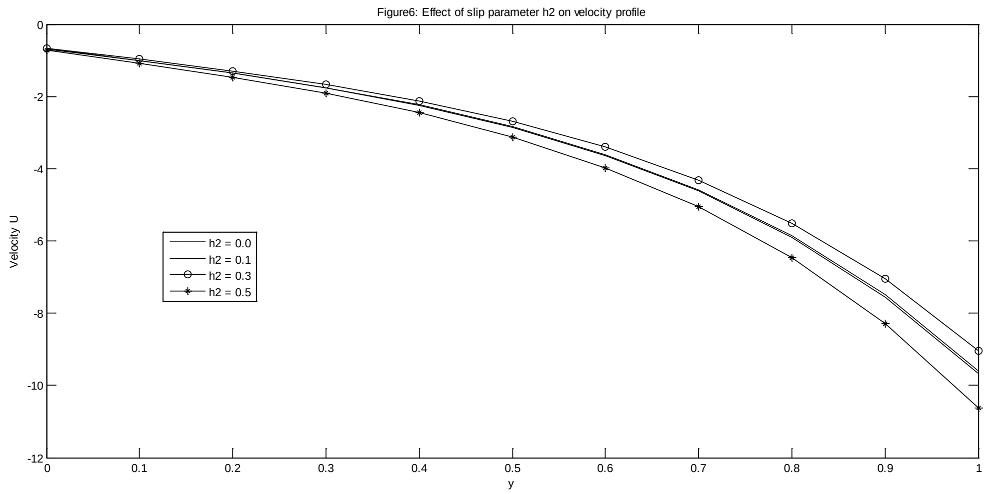

Figure 6: velocity profiles against y for different values of h_2 =? with $P_r = 0.71, w = 0.1, t = 0.1, \varepsilon = 0.02, G_c = 2,\ K_c = 0.1, M = 0.5, q\ 1, G_r = 2\ , S_c = 0.6, K_p = 1, F = 0.1, A = 0.5, B = 0.5, , h_1 = 0.1, \propto_1 = 0.1$ and $\propto_2 = 0.2$

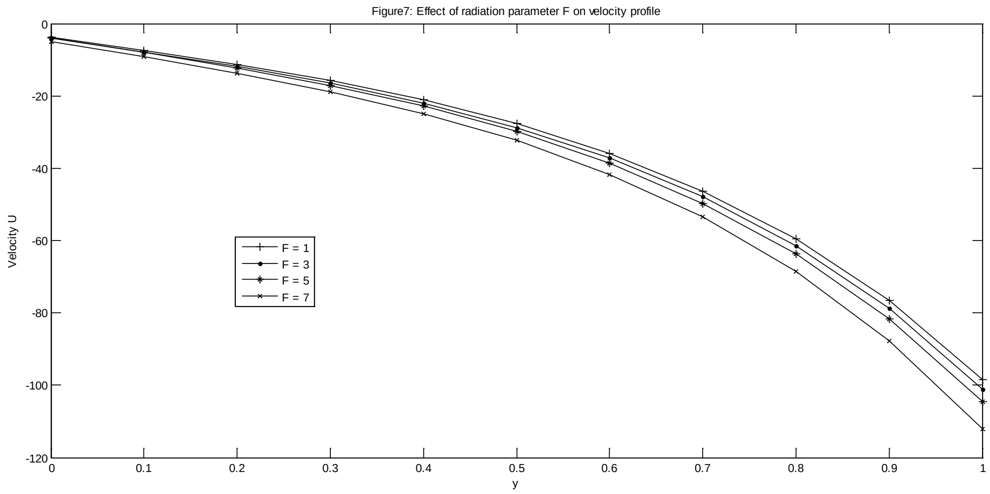

Figure 7: velocity profiles against y for different values of F =? with $P_r = 0.71, w = 0.1, t = 0.1, \varepsilon = 0.02, G_c = 2, K_c = 0.1, M = 0.5, q\ 1, G_r = 2, S_c = 0.6, K_p = 1, A = 0.5, B = 0.5, h_1 = 0.1, h_2 = 0.1, \propto_1 = 0.1$ and $\propto_2 = 0.2$

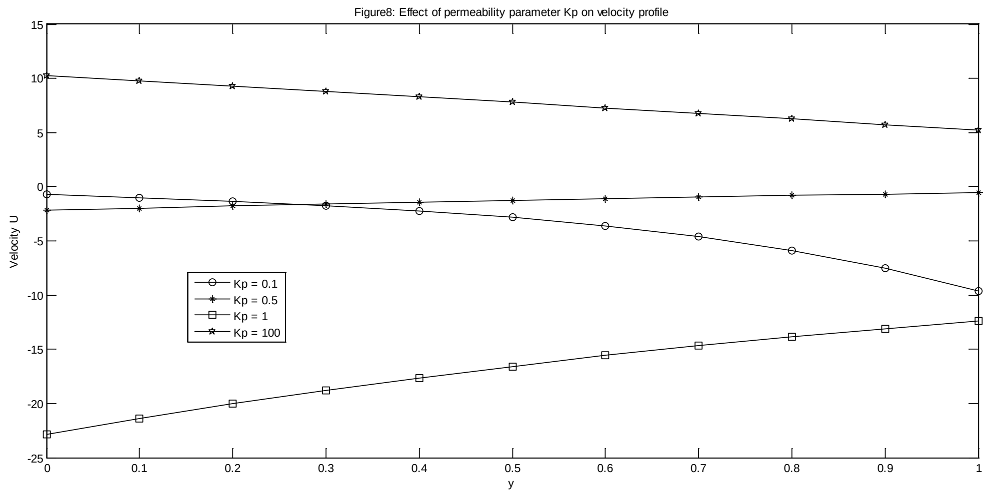

Figure 8**:** velocity profiles against y for different values of K_p =? with $P_r = 0.71, w = 0.1, t = 0.1, \varepsilon = 0.02, G_c = 2, K_c = 0.1, M = 0.5, q\ 1, G_r = 2, S_c = 0.6, F = 0.1, A = 0.5, B = 0.5, h_1 = 0.1, h_2 = 0.1, \propto_1 = 0.1$ and $\propto_2 = 0.2$

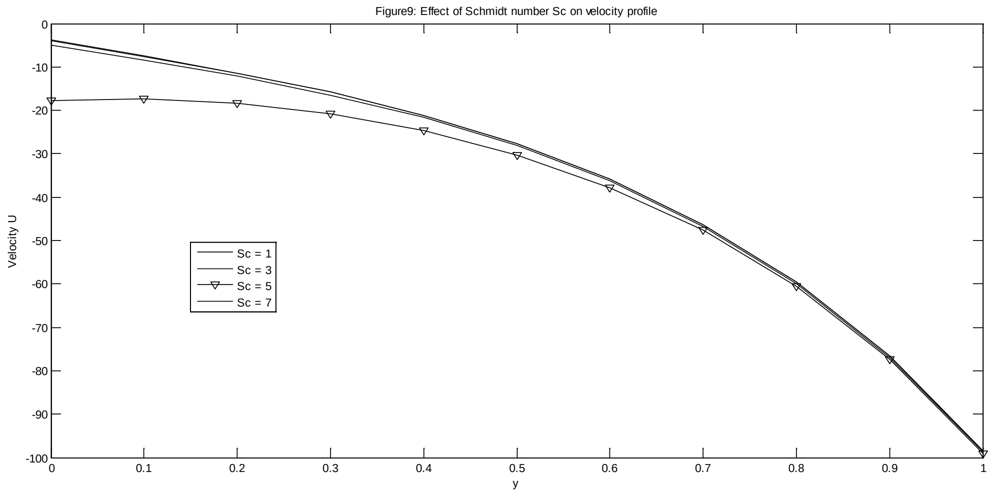

Figure 9**:** velocity profiles against y for different values of $S_c =?$ with $P_r = 0.71, w = 0.1, t = 0.1, \varepsilon = 0.02, G_c = 2,\ G_r = 2\ , K_p = 1, F = 0.1, K_c = 0.1, M = 0.5, q\ 1,\ A = 0.5, B = 0.5, h_1 = 0.1, h_2 = 0.1, \propto_1 = 0.1$ and $\propto_2 = 0.2$

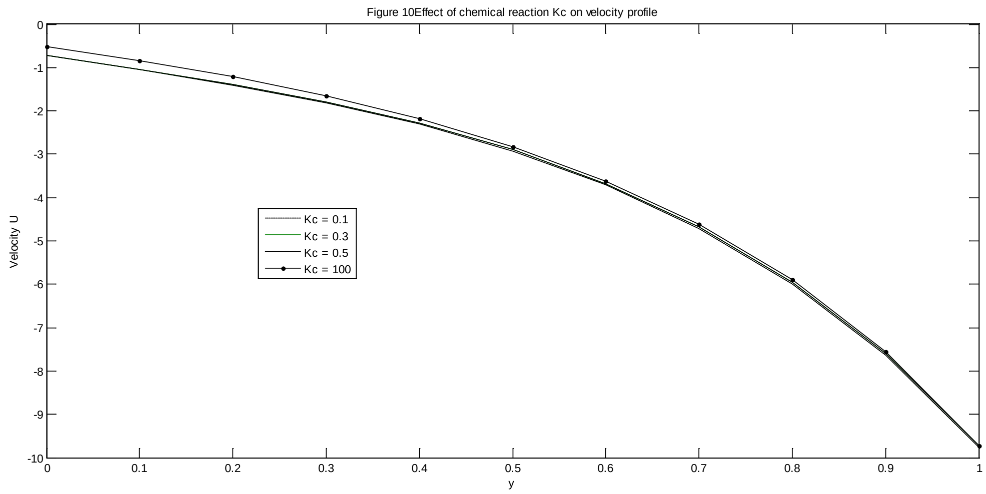

Figure 10: velocity profiles against y for different values of $K_c =?$ with $P_r = 0.71, w = 0.1, t = 0.1, \varepsilon = 0.02, G_c = 2,\ G_r = 2\ , K_p = 1, F = 0.1, S_c = 0.6, M = 0.5, q\ 1,\ A = 0.5, B = 0.5, h_1 = 0.1, h_2 = 0.1, \propto_1 = 0.1$ and $\propto_2 = 0.2$

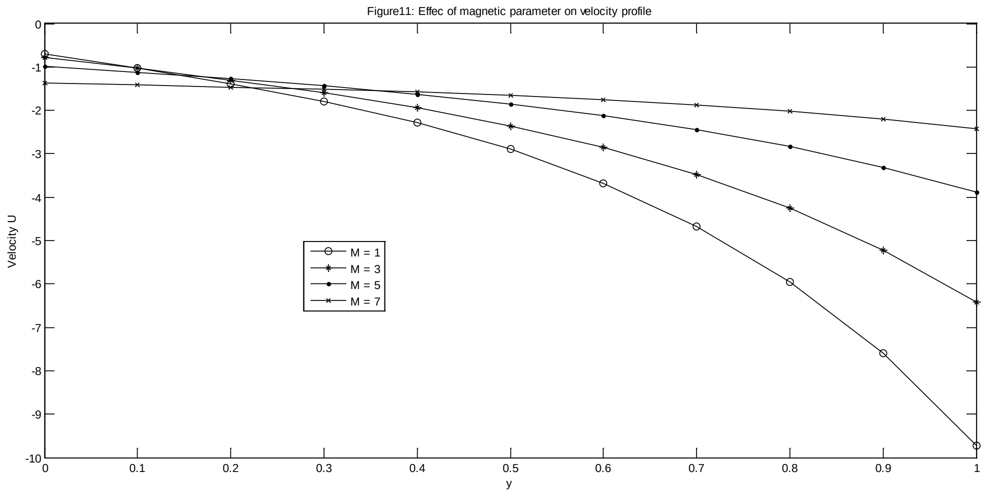

Figure 11: velocity profiles against y for different values of $M =?$ with $P_r = 0.71, w = 0.1, t = 0.1, \varepsilon = 0.02, G_c = 2,\ S_c = 0.6, G_r = 2\ , K_p = 1, F = 0.1, K_c = 0.1, q = 1,\ A = 0.5, B = 0.5, h_1 = 0.1, h_2 = 0.1, \propto_1 = 0.1$ and $\propto_2 = 0.2$

Figure 1 and 2 shows the effect of suction parameters α_1 and α_2 on the velocity profile, it is observed that increasing in suction parameters by the curves accelerate the velocity of the flow field at all points. Figure 3 and 4 shows the effect of Grashof number G_r , G_c on velocity profile, it is noticed that increase of the Grashof numbers decreases the velocity of the flow field at all points. Figure 5 and 6 shows the effect of slip parameters h_1, h_2 on the velocity profile which enhance the velocity of the flow field and tend to diverges the flow field at all points. Figure 7 show the effect of radiation parameter on velocity profile, it is observed that the increase of radiation parameter F is to retard the velocity of the flow field at all points. Figure 8 show the effect of permeability parameter K_p on velocity profile. An increase in permeability parameter tends to converge the velocity of the flow field at all points. Figure 9 show the effect of growing Schmidt number S_c on velocity profile. It is observed that increase in Schmidt number tend to converge the velocity of the flow field at all points. Figure 10 show the effect of chemical reaction on velocity profile. It is noticed that the increasing in chemical reactionK_c, is to accelerate the velocity of the flow field at all points. Figure 11 show the effect of magnetic parameter on velocity profile. It is found that the velocity of the flow field decreases with increase in magnetic parameter$M$ at all points

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5.2 TEMPERATURE FIELD

A thermal boundary layer develops when a fluid at specific temperature flows over a surface which is at different temperature. The flow parameters affected temperature field due to variation of prandtl number P_r, radiation parameter F, Eckert number E_c . The effects of these parameters on the temperature field will be seen by the following graphs.

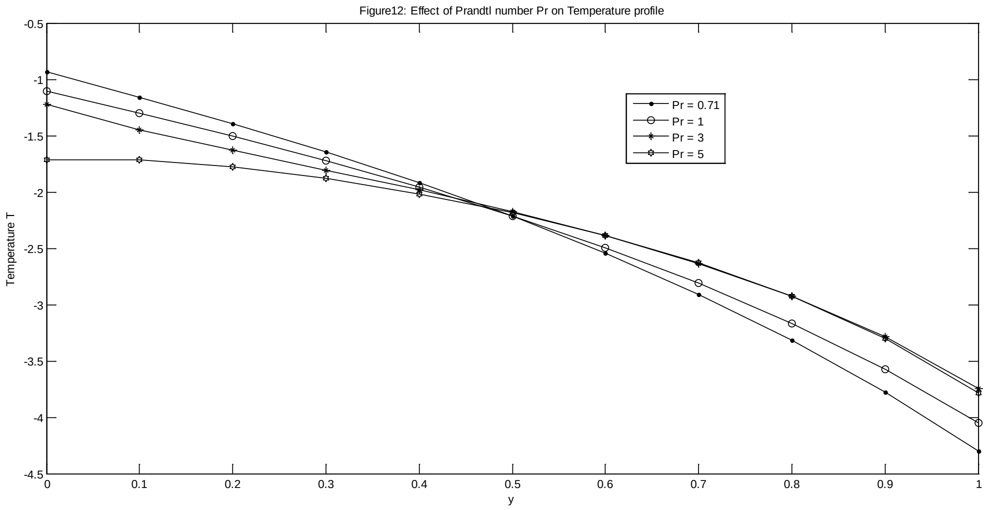

Figure 12: Temperature profiles against y for different values of P_r =? with $S_c = 0.6, w = 0.1, t = 0.1, \varepsilon = 0.02, G_c = 2, G_r = 2, K_p = 1, F = 0.1, K_c = 0.1, M = 0.5, q\ 1, A = 0.5, B = 0.5, h_1 = 0.1, h_2 = 0.1, \propto_1 = 0.1$ and $\propto_2 = 0.2$

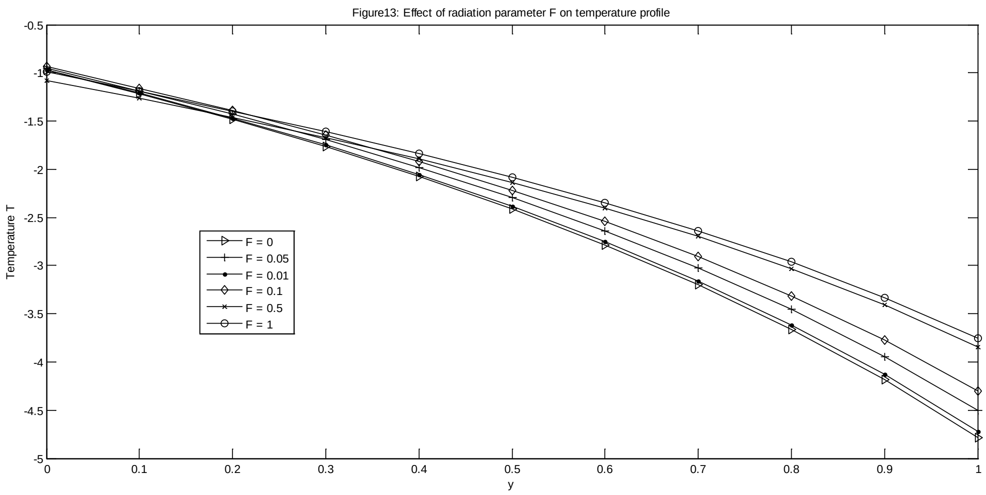

Figure 13: Temperature profiles against y for different values of F =? with $P_r = 0.71, w = 0.1, t = 0.1, \varepsilon = 0.02, G_c = 2,\ K_c = 0.1, M = 0.5, q\ 1, G_r = 2\ , S_c = 0.6, K_p = 1, A = 0.5, B = 0.5, h_1 = 0.1, h_2 = 0.1, \propto_1 = 0.1$ and $\propto_2 = 0.2$

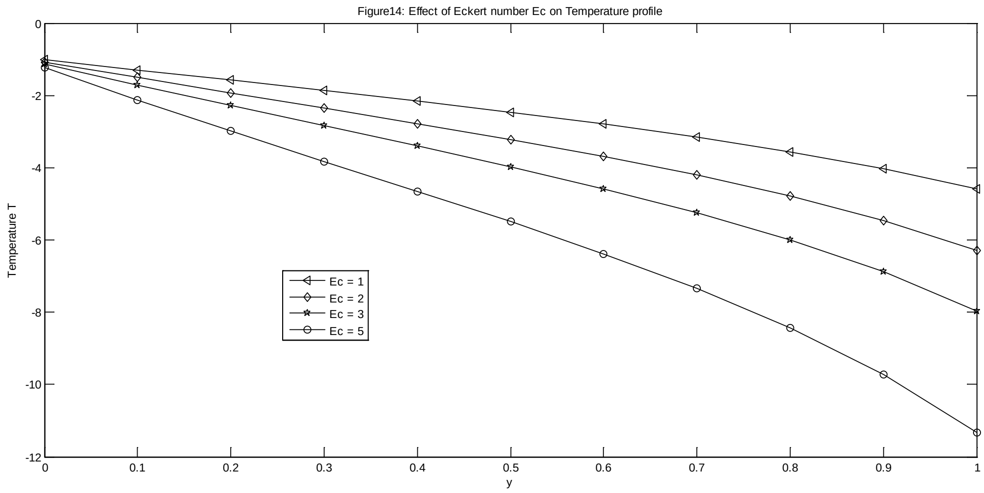

Figure 14: Temperature profiles against y for different values of E_c =? with $P_r = 0.71, w = 0.1, t = 0.1, \varepsilon = 0.02, G_c = 2,\ F = 1, K_c = 0.1, M = 0.5, q\ 1, G_r = 2\ , S_c = 0.6, K_p = 1, A = 0.5, B = 0.5, h_1 = 0.1, h_2 = 0.1, \propto_1 = 0.1$ and $\propto_2 = 0.2$

Figure 12 show the effect of Prandti number on temperature profile. It is found that an increase in prandtl number P_r cause about decrease in temperature of the flow field at all points. Figure 13 show the effect of radiation parameter on temperature profile. The temperature of the flow field is found to diverge with the increase in radiation parameter F at all points. Figure 14 show the effect of Eckert number on temperature profile. We observed that an increase in Eckert number E_c, decreases the temperature of the flow field at all points.

5.3 CONCENTRATION DISTRIBUTION

The present of foreign mass in the flow field greatly affect the concentration boundary layer thickness of the flow field at all points. The factors responsible for these variations are Schmidt numberS_c, chemical reaction parameterK_c and are shown below.

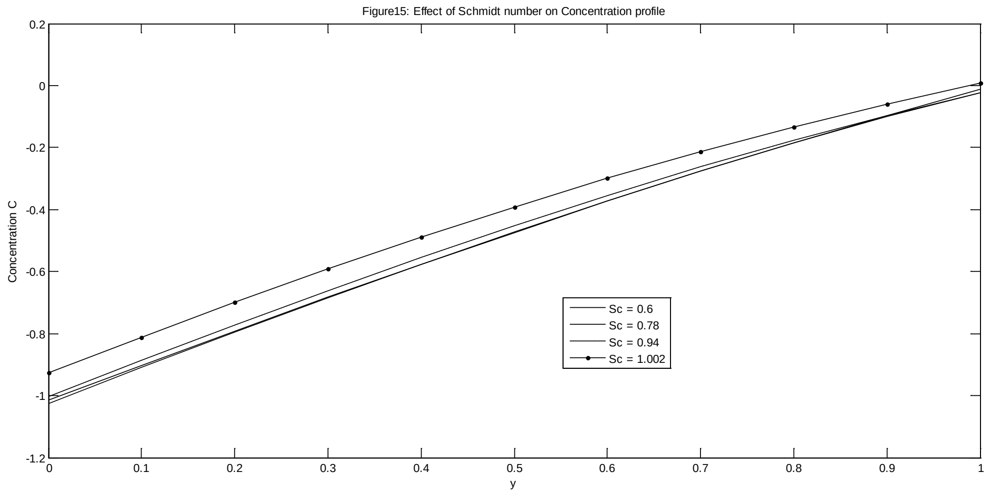

Figure 15: concentration profiles against y for different values of S_c =? with $P_r = 0.71, w = 0.1, t = 0.1, \varepsilon = 0.02, G_c = 2, G_r = 2, K_p = 1, q = 1, E_c = 1$ $F = 0.1, K_c = 0.1, M = 0.5,$ $A = 0.5, B = 0.5, h_1 = 0.1, h_2 = 0.1, \propto_1 = 0.1$ and $\propto_2 = 0.2$

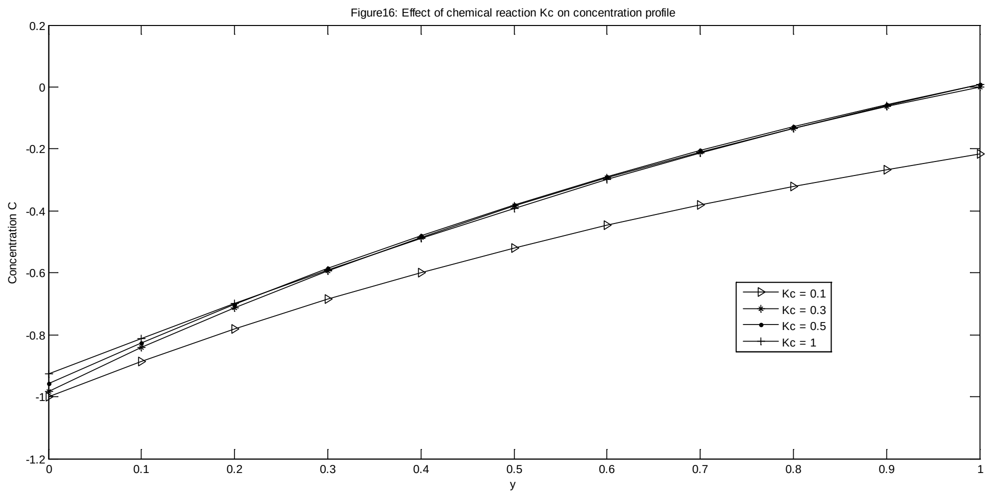

Figure 16: concentration profiles against y for different values of K_c =? with $P_r = 0.71, w = 0.1, t = 0.1, \varepsilon = 0.02, G_c = 2, G_r = 2, K_p = 1, q = 1, E_c = 1$ $F = 0.1, S_c = 0.6, M = 0.5,$ $A = 0.5, B = 0.5, h_1 = 0.1, h_2 = 0.1, \propto_1 = 0.1$ and $\propto_2 = 0.2$

Figure 15 show the effect of Schmidt number on concentration profile. The concentration of the flow field is observed to be converging at all points with increase in Schmidt number S_c. Figure 16 show the effect of chemical reaction on concentration profile. It is clearly observed that concentration of the flow field increases with increase in chemical reaction K_c at all points.

4.4 SKIN FRICTION, NUSSELT NUMBER AND SHERWOOD NUMBER DISTRIBUTION

Table1: variation of skin friction τ_1,τ_2, Nusselt number N_{u_1} ,N_{u_2} and Sherwood number Sh_1 ,Sh_2

t	τ_1	τ_2	N_{u_1}	N_{u_2}	Sh_1	Sh_2
0.0	45.7394	20.2722	-6.7439	-1.8770	0.3022	-0.2776
0.1	45.7559	20.2879	-6.7439	-1.8765	0.3016	-0.2780
0.2	45.7722	20.3034	-6.7439	-1.8761	0.3010	-0.2785
0.3	45.7881	20.3187	-6.7439	-1.8756	0.3004	-0.2789
0.4	45.8038	20.3338	-6.7439	-1.8751	0.2998	-0.2793
0.5	45.8192	20.3487	-6.7438	-1.8746	0.2992	-0.2798
0.6	45.8344	20.3634	-6.7437	-1.8741	0.2986	-0.2802
0.7	45.8493	20.3779	-6.7437	-1.8735	0.2980	-0.2807
0.8	45.8639	20.3923	-6.7436	-1.8730	0.2974	-0.2811
0.9	45.8782	20.4064	-6.7435	-1.8724	0.2968	-0.2815
1.0	45.8922	20.4204	-6.7434	-1.8718	0.2962	-0.2820

6. Summary and Conclusions

The effect of heat and mass transfer on free convective couette dissipative fluid flow through a porous medium with chemical reaction and slip conditions. The governing equations of the flow field are solved for the velocity, temperature, concentration distribution, skin friction and the rate of heat and mass transfer using a perturbation technique.

We present below some of the important features of the flow field due to the variation of the flow parameters.

1. Both the suction parameters α_1 and α_2 on the velocity profile are observed to have an accelerating effect on the velocity of the flow field at all points. The Grashof number G_r , $G_c$for heat and mass transfer are found to retard the velocity of the flow field at all points. Both the slip parameters h_1, h_2 enhance the velocity of the flow field in different manner and are tends to diverge the flow field at all points. It was observed that the increasing radiation parameter F is to retard the velocity of the flow field at all points. The effect of increasing permeability parameter K_p tend to converge the velocity of the flow field at all points. The effect of the growing Schmidt number S_c is to converge the velocity of the flow field at all points. The effect of the increasing chemical reactionK_c is to accelerate the velocity of the flow field at all points. It is found that the velocity of the flow field decreases with the increasing magnetic parameter$M$ at all points.
2. The effect of the increasing prandtl number P_r cause about decrease in temperature of the flow field at all points. The temperature of the flow field diverges at all points with the increase in radiation parameter F. The effect of the increasing Eckert number E_c, tends to decrease in the temperature of the flow field at all points.
3. The concentration of the flow field seems to be converging at all points with increase in Schmidt number S_c. The concentration of the flow filed increases with the increasing chemical reaction K_c at all points.
4. The skin friction increases with increase in time. Nusselt number (the rate of heat transfer) remain constant at the upper boundary and increases across the lower bound with increase in time, the rate of mass transfer decreases at the upper bound and increases across the lower bound with increase in time.

This work has potential role in the field of science and engineering such as designing chemical processing equipment, crop damages due to freezing and environmental pollution.

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