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Unsteady MHD Radiative, Chemically Reactive and Rotating Fluid flow Past an Impulsively Started Vertical Plate with Variable Temperature and Mass Diffusion

KEYWORDS: MHD, Rotating fluid, Radiation, Chemical Reaction, Porous medium and impulsively started vertical plate.

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ABSTRACT *This article is a study on the effects of radiation and chemical reaction, on unsteady free convection flow past an impulsively started vertical porous plate with variable massdiffusion, where the fluid and the plate are considered to be rotating in the presence of transversely applied magnetic field. The equations governing the flow are solved by usual Laplace transform technique. The expressions for velocity, temperature and concentration are obtained. With the aid of the above expressions the quantities for skin friction, rate of heat transfer and rate of mass transfer are also derived. The effects of various physical parameters on the above quantities are studied through graphs and the results are discussed.*

1. Introduction:

Magnetohydrodynamic convective flow with heat and mass transfer has been attracting the attention of many researchers due to its numerous applications in science and engineering. Some of the examples include liquid metal cooling in nuclear reactors, magnetic suppression of molten semi conducting materials, MHD couples and bearings and magnetic control of molten iron flow in steel industry etc. The effects of oscillating plate temperature on the flow past an infinite vertical porous plate was first studied by Soundalgekar [1]. Raptis et al. [2] considered hydromagnetic free convection flow through a porous medium between two parallel plates Gribben [3] has investigated boundary layer flow over a semi infinite plate with an aligned magnetic field in the presence of a pressure gradient. Approximate solution for the two dimensional flow of an incompressible, viscous fluid past an infinite porous vertical plate with constant suction velocity was studied by Soundalgekar [4], in which the difference between the temperature of the plate and the free stream is considered to be large that causes the free convection currents. Raptis and Kafousias [5] have considered the influence of a magnetic field upon the study free convection flow through a porous medium bounded by an infinite vertical plate with constant suction velocity and when the plate temperature is also constant. Recently kim [6] investigated an unsteady MHD convective heat transfer pas a semi infinite vertical porous moving plate with variable suction. Later Chamkha [7] extended this problem and studied a unsteady, two dimensional, laminar boundary layer flow of a viscous, incompressible, electrically conducting and heat absorbing fluid along a semi infinite vertical permeable moving plate in the presence of a uniform transverse magnetic field and thermal and concentration buoyancy effects.

In many industrial and environmental processes radiative convective flows are playing vital role. For example, heating and cooling chambers, fossil fuel combustion energy process, evaporation from large open water reservoirs and astrophysical flows etc. The effect of thermal radiation and mass diffusion also occurs if the temperature of the surrounding fluid is rather high. Some of the engineering applications of this phenomenon are Nuclear Power plants, gas turbines and various propulsion device for aircraft missiles, Satellites and space vehicles etc. Cogley et al. [8] studied radiative heat transfer in a non linear equation – grey gas near equilibrium. Radiation and mass transfer effects on a free convection flow through a porous medium bounded by a vertical surface was considered by Raju et al. [9]. Cookey and Sigalo[10] investigated unsteady MHD free convection flow with radiative heat transfer. Sivaiah et al [11] studied the influence of thermal diffusion and radiation on unstduy magnetohydromagnetic free convection flow past an infinite heated vertical plate in a porous medium Rotation and radiation effects on MHD flow past an impulsively started vertical plate with variable temperature is studied by Rajput and Kumar [12] Chamkha [13] considered radiation effects on free convection flow past a semi infinite vertical plate with mass transfer.

Chemical reactions that are classified as homogeneous or heterogeneous. A reaction is said to be homogeneous if the rate of reaction is directly proportional to the concentration itself. In well mixed systems the reaction is homogeneous if it takes place in a solution. In most of the chemical reactions, the rate depends on the concentration of the species. Chambre and Young [14] have analyzed a first order chemical reaction on the flow past an impulsively started infinite vertical plate with uniform heat flux and mass transfer. An exact analysis of rotation effects on unsteady flow of an incompressible and electrically conducting fluid past a uniformly accelerated infinite isothermal vertical plate under the influence of transverse magnetic field has been presented by Muthu Kumaraswamy et al [15]. Sandeep et al. [16] considered magneto hydrodynamic, radiation and chemical reaction effects on unsteady flow, heat and mass transfer characteristics in a viscous, incompressible and electrically conducting fluid over a semi infinite vertical porous plate in porous medium. Pal and Talukdar [17] investigated the interaction of convection and thermal radiation on unsteady hydromagnetic heat and mass transfer for a viscous fluid past a semi infinite vertical moving plate embedded in a porous media in the presence of heat absorption and first order chemical reaction of the species.

In this paper we have considered the combined effects of rotation, thermal radiation and homogeneous chemical reaction on MHD flow of a viscous incompressible fluid past an impulsively started vertical plate with variable temperature and variable mass diffusion, which is an extension to the work of Rajuput and Kumar [12]. The equations governing the flow are studied by the Laplace transform technique.

2. Formulation of the problem:

We have considered the unsteady MHD flow of an electri-

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cally conducting, radiative and chemically reactive and viscous incompressible fluid past an impulsively started vertical porous plate with fluctuating temperature and variable mass diffusion. The fluid and the plate are assumed to rotate as a rigid body with a uniform angular velocity Ω^* about y^*-axis, in the presence of an imposed uniform magnetic field B_0 normal to the plate. Initially, the temperature and concentrations of the fluid near the plate are assumed to be T_0 and C_0 respectively. At time t^* > 0, the plate starts moving with a velocity $u^* = u_0$ in its own plane and then the temperature and concentration from the plate are raised to T_w^* and C_w^* respectively. Since the plate occupying the plane y^* = 0 is of infinite extent, all the physical quantities are the functions of y^* and t^* only. It is assumed that the induced magnetic field is negligible as the transversely applied magnetic field and magnetic Reynolds number are assumed to be very small. The fluid considered is a gray, absorbing emitting radiation but a non scattering medium and there is a first order chemical reaction between the diffusing species of the fluid. Under the above assumptions, the flow is governed by the following set of equations:

$$\frac{\partial u^*}{\partial t^*} - 2\Omega^* v^* = g\beta_c^*(c^* - c_\alpha^*) + g\beta_T^*(T^* - T_\infty^*) + \upsilon\frac{\partial^2 u^*}{\partial y^{*2}} - \frac{\sigma\beta_0^2 u^*}{\rho} - \frac{\upsilon}{k^*}u^* \quad (1)$$

$$\frac{\partial v^*}{\partial t^*} + 2\Omega^* u^* = \upsilon\frac{\partial^2 v^*}{\partial y^{*2}} - \frac{\sigma\beta_0^2 v^*}{\rho} - \frac{\upsilon}{k^*}v^* \quad (2)$$

$$\frac{\partial T^*}{\partial c^*} = \frac{k}{\rho c_p}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{1}{\rho c_p}\frac{\partial q^*}{\partial y^*} \quad (3)$$

$$\frac{\partial C^*}{\partial t^{*1}} = D\frac{\partial^2 C^*}{\partial y^{*2}} - k_c^*(C^* - C_0^*) \quad (4)$$

The corresponding boundary conditions are defined by

$$\begin{aligned} &t^* \le 0,\ u^* = 0,\ C^* = C_\infty^* \ \ for\ all\ y^* \\ &t^* > 0,\ u^* = u_0,\ C^* = C_\infty^* + (C_w^* - C_\infty^*)At^*,\ T^* = T_\infty^* + (T_w^* - T_\infty^*)A \cdot t^* \ \ at\ y^* = 0 \\ &\quad u^* \to 0, T^* \to T_\infty^*, C^* \to C_\infty^* \ \ as\ y^* \to \infty \end{aligned} \quad (5)$$

Now Introducing the following non-dimensional quantities

$$u = \frac{u^*}{u_0},\quad V = \frac{V^*}{u_0^*},\quad t = \frac{t^* u_0^2}{\upsilon},\quad y = \frac{y^* u_0}{\upsilon},\quad G_m = \frac{g\beta_c^* v(C_w^* - C_\infty^*)}{u_0^3} \quad (6)$$

$$G_r = \frac{g\beta_T^* v(T_w^* - T_\infty^*)}{u_0^3},\quad \Omega = \frac{\Omega^* \upsilon}{u_0^2},\quad T = \frac{T^* - T_\infty^*}{T_w^* - T_\infty^*},\quad C = \frac{C^* - C_\infty^*}{C_w^* - C_\infty^*},\quad A = \frac{u_0^2}{\upsilon}$$

$$M = \frac{\sigma\beta_0^2 v}{\rho u_0^2},\quad R = \frac{16a^* v^2 \sigma T_\infty^3}{k\, u_0^2},\quad S_c = \frac{v}{D},\quad P_r = \frac{\mu C_p}{k}$$

$$\frac{\partial u}{\partial t} - 2\Omega V = G_r\theta + G_m c + \frac{\partial^2 u}{\partial y^2} - M_1 u \quad (7)$$

$$\frac{\partial v}{\partial t} + 2\Omega u = \frac{\partial^2 V}{\partial y^2} - M_1 v \quad (8)$$

$$\frac{\partial c}{\partial t} = \frac{1}{S_c}\frac{\partial^2 c}{\partial y^2} - k_c C \quad (9)$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial y^2} - \frac{R}{P_r}\theta \quad (10)$$

Substuting equ(6) into set of equs(1) to (4), we get the governing equations in non-dimensional form, as given below

$$\begin{aligned} &t \le 0,\ \ u = 0,\ \ T = 0, C = 0\ \ \forall y \\ &t > 0,\ \ u = 1,\ \ T = t, C = t\ at\ y = 0 \\ &\quad u \to 0, T \to 0, C \to 0\ \ as\ y \to \infty \end{aligned} \quad (11)$$

Where the symbols are, B_0-external magnetic field , C^* - Species concentration in the field, C_w^*- Concentration of the fluid , C_∞^*- Concentration in the fluid far away from the plate, D-Chemical molecular diffusivity, g- Acceleration due to gravity , t^*-Time, u^*- Primary velocity of the fluid , v^*-Secondary velocity of the fluid , u_0 - Velocity of the fluid , Z^*-Coordinate axis normal to the plate, β^*-Volumetric coefficient of expansion with concentration, σ- Stefan-Boltzman constant, ρ - Density, ν-Kinematic viscocity and Ω^*-Rotation parameter, M- Magnetic parameter , t-Dimensionless time, Ω-dimensionless rotation parameter, C-dimensionless concentration, G_m - mass Grashof number, Sc-Schmidt number, u -dimensionless velocity along x-axis, v-dimensionless velocity along y- axis and Z-dimensionless coordinate axis normal to the plate, T- dimensionless temperature, T^*-temperature fluid near the plate, F- radiation parameter, P_r- Prandtl number, k_c - chemical reaction parameter.

Let us assume q = u + i v, From equation (7) and (8), we get

$$\frac{\partial q}{\partial t} = G_m C + G_r\theta + \frac{\partial^2 q}{\partial y^2} - M1q \quad (11)$$

where $M1 = M + 2i\Omega$

Also, the non dimensional from boundary conditions (10) are reduced to

$$\begin{aligned} &t \le 0,\ \ a(q,0) = 0, T(y,0) = 0,\ c(y,0) = 0\ \ for\ all\ values\ of\ y \\ &t > 0,\ \ q(0,t) = 1, T(0,t) = T\ \ at\ y = 0 \\ &a(y,t) \to 0, T(y,t) \to 0,\ C(y,t) \to 0\ \ as\ y \to \infty \end{aligned} \quad (12)$$

3. Solution of the problem:
The equations (9), (10) and (12) subject to the boundary conditions (13) are solved by the Laplace-Transform technique and the solutions derived are as follows

$$c(y,t) = \left[\frac{t}{2} + \frac{y}{4}\sqrt{\frac{s_c}{k_c}}\right]\left[e^{yc\sqrt{s_c k_c}}\mathrm{erfc}\left(\eta\sqrt{s_c} + \sqrt{k_c t}\right)\right] + \left[\frac{t}{2} - \frac{y}{4}\sqrt{\frac{s_c}{k_c}}\right]\left[e^{-y\sqrt{s_c k_c}}\mathrm{erfc}\left(\eta\sqrt{s_c} - \sqrt{k_c t}\right)\right] \quad (14)$$

$$\theta(y,t) = \left[\frac{t}{2} + \frac{y}{4}\frac{P_r}{4\sqrt{R}}\right]\left[e^{y\sqrt{R}}erfc\left(\eta\sqrt{P_r} + \sqrt{\frac{R}{P_r}t}\right)\right] + \left[\frac{t}{2} - \frac{yP_r}{4\sqrt{R}}\right]\left[e^{-y\sqrt{R}}erfc\left(\eta\sqrt{P_r} - \sqrt{\frac{R}{P_r}t}\right)\right] \quad (15)$$

$$\begin{aligned} q(y,t) = {} & \frac{A_1}{2}\left[e^{-y\sqrt{m}}erfc(\eta - \sqrt{mt}) + e^{y\sqrt{m}}erfc(\eta + \sqrt{mt})\right] - \\ & B_1\left[\left(\frac{t}{2} - \frac{y}{4\sqrt{m}}\right)\left[e^{-y\sqrt{m}}erfc(\eta - \sqrt{mt})\right] + \left(\frac{t}{2} + \frac{y}{4\sqrt{m}}\right)\left[e^{y\sqrt{m}}erfc(\eta + \sqrt{mt})\right]\right] - \\ & \frac{C_1 e^{-B_1 t}}{2}\left[e^{-y\sqrt{m-B_1}}erfc\left(\eta - \sqrt{(m-B_1)t}\right) + e^{y\sqrt{m-B_1}}erfc\left(\eta + \sqrt{(m-B_1)t}\right)\right] - \\ & \frac{C_2 e^{-B_2 t}}{2}\left[e^{-y\sqrt{m-B_2}}erfc\left(\eta - \sqrt{(m-B_2)t}\right) + e^{y\sqrt{m-B_2}}erfc\left(\eta + \sqrt{(m-B_2)t}\right)\right] - \\ & \frac{C_1}{2}\left[e^{-y\sqrt{R}}erfc\left(\eta\sqrt{P_r} - \sqrt{\frac{R}{P_r}t}\right) + e^{y\sqrt{R}}erfc\left(\eta\sqrt{P_r} + \sqrt{\frac{R}{P_r}t}\right)\right] \\ & D_1\left[\left(\frac{t}{2} - \frac{yP_r}{4\sqrt{R}}\right)\left[e^{-y\sqrt{R}}erfc\left(\eta\sqrt{P_r} - \sqrt{\frac{R}{P_r}t}\right)\right] + \left(\frac{t}{2} + \frac{yP_r}{4\sqrt{R}}\right)\left[e^{y\sqrt{R}}erfc\left(\eta\sqrt{P_r} + \sqrt{\frac{R}{P_r}t}\right)\right]\right] + \\ & \frac{C_1 e^{-B_1 t}}{2}\left[e^{-y\sqrt{R-B_1P_r}}erfc\left(\eta\sqrt{P_r} - \sqrt{\left(\frac{R}{P_r} - B_1\right)t}\right) + e^{y\sqrt{R-B_1P_r}}erfc\left(\eta\sqrt{P_r} + \sqrt{\left(\frac{R}{P_r} - B_1\right)t}\right)\right] - \\ & \frac{C_2}{2}\left[e^{-y\sqrt{S_ck_c}}erfc(\eta\sqrt{S_c} - \sqrt{k_c t}) + e^{y\sqrt{S_ck_c}}erfc(\eta\sqrt{S_c} + \sqrt{k_c t})\right] - \\ & (D_2\left[\left(\frac{t}{2} - \frac{y}{4}\sqrt{\frac{S_c}{k_c}}\right)\left[e^{-y\sqrt{S_ck_c}}erfc(\eta\sqrt{S_c} - \sqrt{k_c t})\right] + \left(\frac{t}{2} + \frac{y}{4}\sqrt{\frac{S_c}{k_c}}\right)\left[e^{y\sqrt{S_ck_c}}erfc(\eta\sqrt{S_c} + \sqrt{k_c t})\right]\right] - \\ & \frac{e^{-B_2 t}}{2}\left[e^{-y\sqrt{S_ck_c - B_2S_c}}erfc\left(\eta\sqrt{S_c} - \sqrt{(k_c - B_2)t}\right) + e^{y\sqrt{S_ck_c - B_2S_c}}erfc\left(\eta\sqrt{S_c} + \sqrt{(k_c - B_2)t}\right)\right] \end{aligned} \quad (16)$$

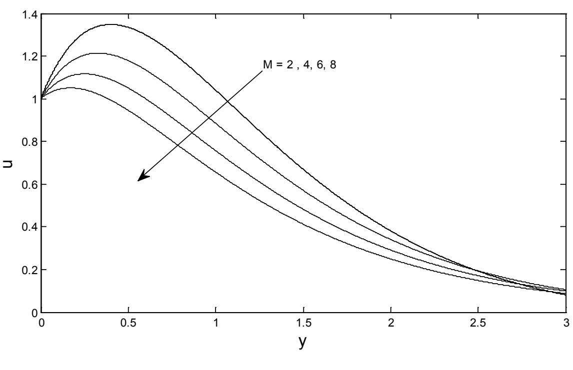

Figure .1. Primary Velocity profiles in variation of M when $S_c = 0.22, k = 1, G_r = 5, G_m = 5, P_r = 0.71, K_C = 1, \Omega = 0.5, F = 0.5, t = 0.2.$

4. Results and Discussion:
Numerical evaluation of the analytical results reported in the

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previous section was performed and a representative set of results is reported graphically through figures 1-15. These results are obtained to illustrate the influence of the various physical parameters like Magnetic parameter M, Schmidt number Sc and rotation parameter Ω etc on primary and secondary velocity distributions, temperature and concentration.

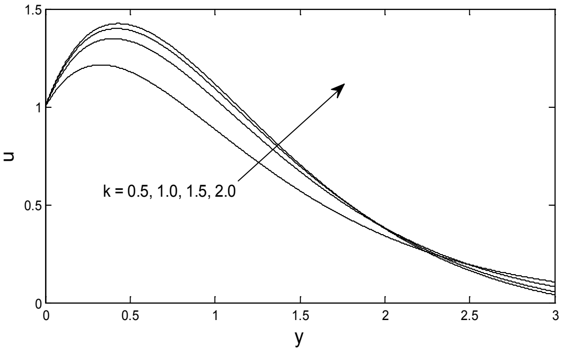

Figure .2. Primary Velocity profiles in variation of k when $S_c = 0.22, M = 2, G_r = 5, G_m = 5, P_r = 0.71, K_C = 1, \Omega = 0.5, F = 0.5, t = 0.2.$

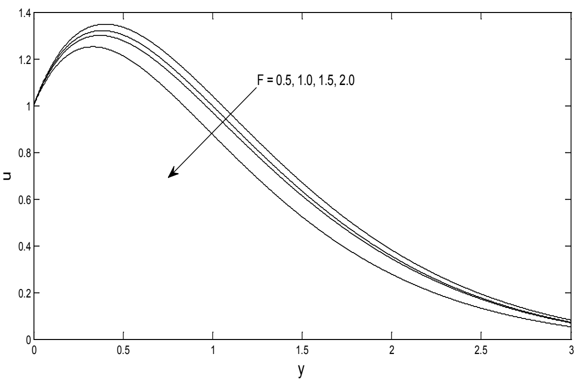

Figure.3. Velocity profiles, in variation of F when $S_c = 0.22, k = 1, G_r = 5, G_m = 5, P_r = 0.71, M = 2, K_C = 1, \Omega = 0.5, H = 1, t = 0.2.$

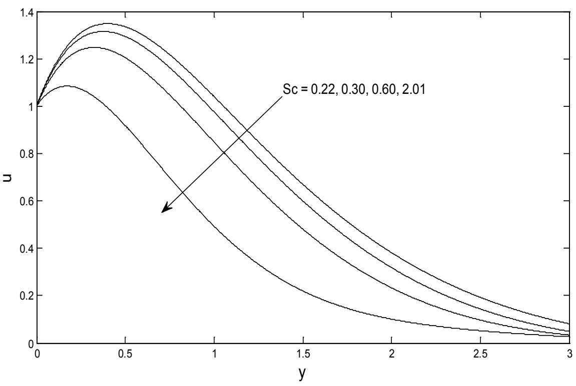

Figure.4. Primary velocity profiles in variation of S_c when $K_c = 1, k = 1, G_r = 5, G_m = 5, P_r = 0.71, M = 2, F = 0.5, \Omega = 0.5, t = 0.2.$

Primary velocity profiles are displayed from figures 1-6. Figure 1 depicts the effects of Magnetic parameter M on velocity while keeping the other parameters as constant. From this figure it is noticed that the velocity distribution attains a distinctive maximum value in the vicinity of the plate surface and then decreases properly to approach the free stream value zero. It is found that an increase in the value of M results a decrease in primary velocity. This is true as the magnetic force retards the flow the velocity decreases

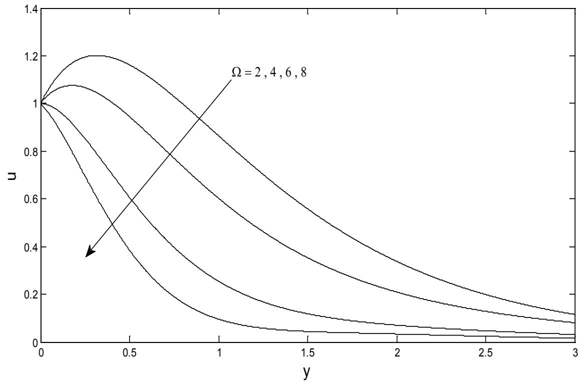

Figure.5. Primary velocity profiles in variation of Ω when $K_c = 1, k = 1, G_r = 5, G_m = 5, S_c = 0.22, M = 2, F = 0.5, t = 0.2.$

The effect of porosity parameter, radiation parameter, Schmidt number, rotation parameter and chemical reaction parameter on primary velocity is presented through 2 to 6. From these figures it is observed that velocity increases with an increase in these respective parameters where as it shows reverse effect for the case of Schmidt number, chemical reaction parameter, rotation parameter and Prandtl number.

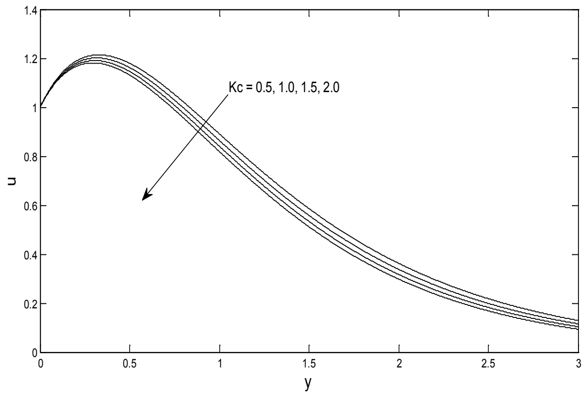

Figure.6. Primary velocity profiles in variation of K_c when $\Omega = 1, k = 1, G_r = 5, G_m = 5, S_c = 0.22, M = 2, F = 0.5, \Omega = 0.5, t = 0.2.$

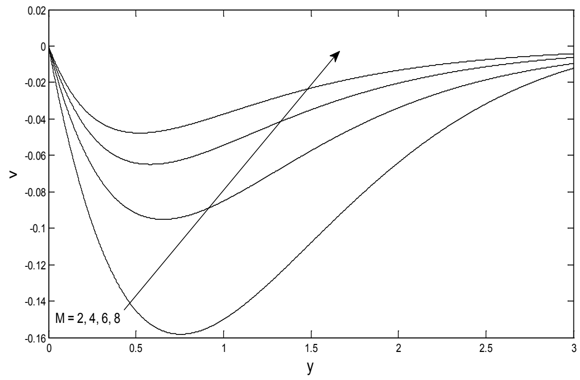

Figure .7. Secondary velocity profiles in variation of M when $S_c = 0.22, k = 1, G_r = 5, G_m = 5, P_r = 0.71, K_C = 1, F = 0.5, \Omega = 0.5, t = 0.2.$

Secondary velocity profiles are displayed in figures 7 to 12. From these figures it is noticed that secondary velocity increases with an increase in the respective parameters like radiation parameter, Schmidt number and chemical reaction parameter, where as it shows different phenomenon in the case of other parameters like magnetic parameter, porosity parameter and rotation parameter.

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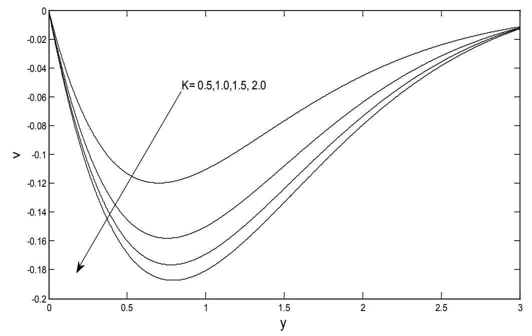

Figure .8. Secondary velocity profiles in variation of k when $S_c = 0.22, M = 2, G_r = 5, G_m = 5, P_r = 0.71, K_C = 1, F = 0.5, \Omega = 0.5, t = 0.2.$

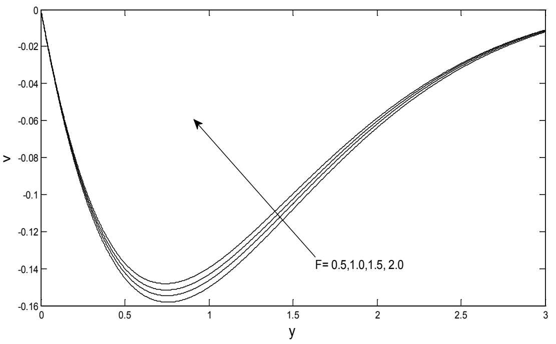

Figure.9. Secondary velocity profiles, in variation of F when $S_c = 0.22, k = 1, G_r = 5, G_m = 5, P_r = 0.71, M = 2, K_C = 1, H = 1, \Omega = 0.5, t = 0.2.$

Radiation parameter effect on temperature is shown in figure 13. From this figure it is evident that temperature decreases with an increase in radiation parameter. Finally concentration profiles are shown through figures 14 and 15. From these figures it is noticed that concentration decreases with an increase in chemical reaction parameter and Schmidt number

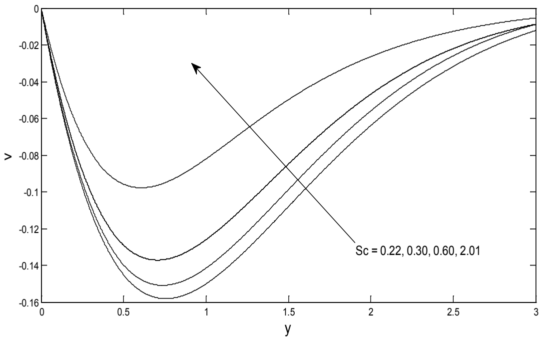

Figure.10. Secondary velocity profiles in variation of S_c when $K_c = 1, k = 1, G_r = 5, G_m = 5, P_r = 0.71, M = 2, \Omega = 0.5, F = 0.5, t = 0.2.$

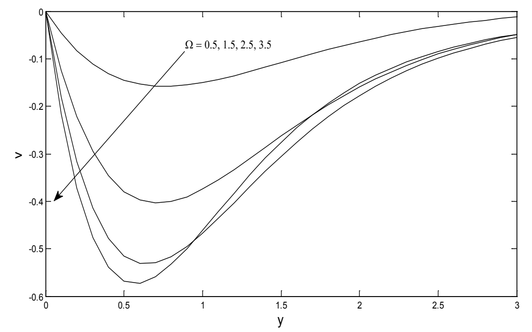

Figure.11. Secondary velocity profiles in variation of Ω when $K_c = 1, k = 1, G_r = 5, G_m = 5, S_c = 0.22, M = 2, F = 0.5, t = 0.2.$

5. Conclusions:

In this paper we have studied an unsteady MHD radiative, chemically reactive and rotating fluid flow past an impulsively started vertical plate with variable temperature and mass diffusion in the closed form by using the Laplace transform technique. In this study the following conclusions are made.

1. Primary velocity distribution increases with an increase in the values of Gr, Gm, k, and t where as it decreases with the increasing values of M, F, Kc, Sc , Ω and Pr.
2. Secondary velocity distribution decreases with an increase in the values of Gr, Gm, k, Ω and t where as it increases with the increasing values of M, F, Kc, Sc, and Pr.
3. Temperature distribution decreases with an increase in the values of F. Also concentration distribution decreases with an increase in both the values of Kc and Sc.

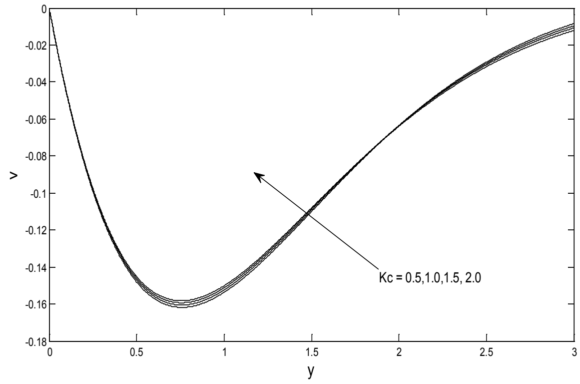

Figure.12. Secondary velocity profiles in variation of K_c when $\Omega = 1, k = 1, G_r = 5, G_m = 5, S_c = 0.22, M = 2, F = 0.5, \Omega = 0.5, t = 0.2.$

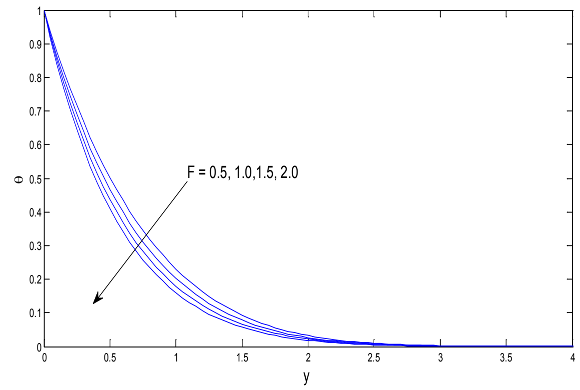

Figure.13. Temperature profiles in variation of F when t = 1

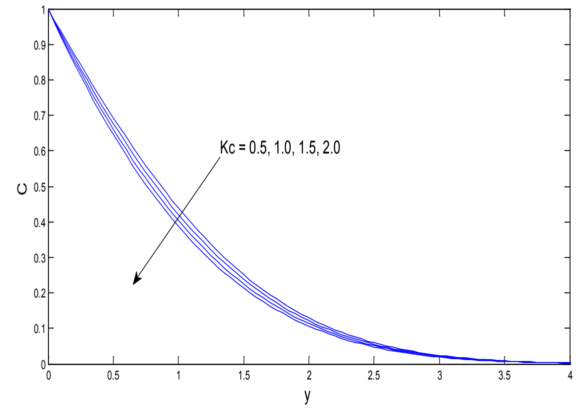

Figure.14. Concentration profiles in variation of Kc when Sc = 0.22, t = 1

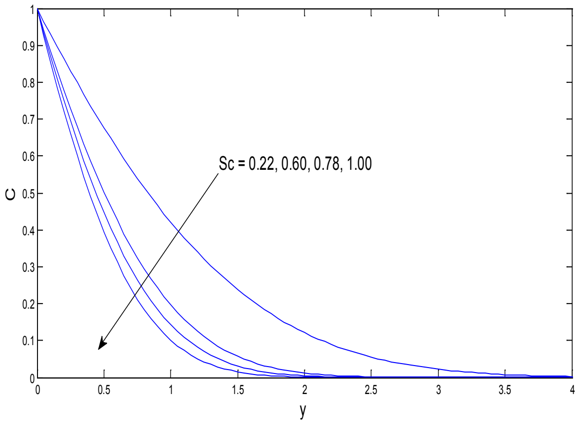

Figure.15. Concentration profiles in variation of S_c when K_c = 0.22, t =1

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