Radiation and Chemical Reaction Effects on Unsteady MHD Free Convective Periodic Heat Transport Modeling In a Saturated Porous Medium for Arotating System

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***Abstract**:* A rotating model is extended for a two-dimensional, unsteady, incompressible electrically conducting, laminar immediate convection boundary layer flow of light and mass communicate in a saturated porous crystal ball gazer, among an overall vertical porous surface in the perseverance of radiation and vicious circle effects was considered. The fundamental equations governing the flow are in the art an element of partial differential equations and have been reduced to a inhere of non-linear ordinary differential equations by applying suitable similarity transformations. The problem is tackled analytically using classical two term perturbation technique. Pertinent results with respect to embedded parameters are displayed through graphically for the velocity, Temperature, concentration, skin friction, Sherwood number, Nusselt number are discussed qualitatively.

***Keywords**: Magnetic field, Porous medium, chemical reaction, heat transfer, mass transfer and Skin- friction.*

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1. INTRODUCTION

Magneto hydrodynamic free convective flows along mutually the chattels personal of heat and mass transfer have enormous applications in geophysics, metallurgy and engineering and science a well known as MHD pumps, MHD generators, magnetic restriction of more abated semi conducting materials, MHD couples and bearings and magnetic control of more abated iron flow in steel industry etc. One such study is familiar to the effects of MHD free convection flow, which plays a sharps and flat role in agriculture, engineering and oil industries. The problem of free convection under the promote of magnetic field has attracted the interest of profuse researchers in view of its investigation in geophysics and astrophysics. In view of these applications, Eckert and Drake [1] have done pioneering work on heat and mass transfer. Elbashbeshy [2] studied heat and mass transfer along a vertical plate under the combined buoyancy effects of thermal and species diffusion, in the presence of the magnetic field. An exact solution of flow past an exponentially accelerated infinite vertical plate and temperature with variable mass diffusion was found by Asogwa et al [3].Helmy [4] have presented the effects of magnetic field for an unsteady free convective flow past a vertical porous plate. Soundalgekar [5] analysed the problem of free convection effects on flow past a vertical uniformly accelerated vertical plate under the action of transversely applied magnetic field with mass transfer. Kim [6] investigated unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction by assuming that the free stream velocity follows the exponentially increasing small perturb action law. The analytical solution of heat and mass transfer on the free convective flow of a viscous incompressible fluid pastan infinite vertical porous plate in presence of transverse sinusoidal suction velocity and a constant free stream velocity was presented by Ahmed [7]. Also, Ahmed and Liu [8] were analysed the effects of mixed convection and mass transfer of three-dimensional oscillatory flow of a viscous incompressible fluid past an infinite vertical porous plate in presence of transverse sinusoidal suction velocity oscillating with time and a constant free stream velocity by use of classical perturbation technique. Convective heat and mass tran sfer flow in a saturated porous medium has gained growing interest. This fact has been motivated by its importance in many engineering applications such as building thermal insulation, geothermal systems, food processing and grain storage, solar power collect rs, contaminant transport in groundwater, casting in manufacturing processes, drying processes, nuclear waste, just to name a few. A theoretical and experimental work on this subject can be found in the recent monographs by Ingham and Pop [9] and Nield and Bejan [10]. Suction/blowing on convective heat transfer over a vertical permeable surface embedded in a porous medium was analysed by Cheng [11]. In that, work an application to warm water discharge along the well or fissure to an aquifer of infinite extent is discussed. Kim and Vafai [12] have analysed the buoyancy driven flow about a vertical plate for constant wall temperature and heat flux. Raptis and Singh [13] studied flow past an impulsively started vertical plate in a porous medium by a finite difference method.

Ahmed [14] studied the effect of transverse periodic permeability oscillating with time onthe free convective heat transfer flow of a viscous incompressible fluid through a highly porous medium bounded by an infinite vertical porous plate subjected to a periodic suction velocity. Rotating flow of electrically conducting viscous incompressible fluids has gained considerable attention because of its numerous applications in physics and engineering which are directly governed by the action of Coriolis and magnetic forces. In geophysics, it is applied to measure and study the positions and velocities with respect to a fixed frame of reference on the surface of earth which rotate with respect to an inertial frame in the presence of its

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magnetic field. Recently, Ahmed and Joaquin [15] investigated the effects of Hall current, magnetic field, rotation of the channel and suction-injection on the oscillatory free convective MHD flow in a rotating vertical porous channel when the entire system rotates about an axis normal to the channel plates and a strong magnetic field of uniform strength is applied along the axis of rotation. Yaqing et al. [16] were analysed the MHD flow and heat transfer of generalized Burges fluid due an exponential accelerating plate with the effect of radiation. Ravi et al [17] have studied the transient free convective flow of a micro polar fluid between two vertical walls. Shahin Ahmed [18] have analyzed an unsteady free convective periodic heat transport modeling in a saturated porous medium for rotating system. In the present paper, an attempt has been made to study the radiation and chemical reaction effects on MHD free convective of the rotation system of the heat and mass transfer flow through a highly porous medium when the temperature of the surface varies with time about a non-zero constant mean and the temperature at the free stream inconstant. The entire system rotates about an axis perpendicular to the planes of the plates. Such flows are very important in geophysical and astrophysical problems.

2. MATHEMATICAL FORMULATION

An unsteady flow model of a viscous incompressible fluid over a porous medium occupying a semi-infinite region of the space bounded by a vertical infinite porous surface in a rotating system under the action of a related magnetic field applied balanced to the direction of flow has been analysed. The temperature of the surface varies by the whole of time about a non-zero constant mean and the temperature at the free stream is constant. The porous medium is, in fact, a non-homogenous medium, which may be returned by a homogenous fluid having dynamical properties equal to those of a non-homogenous continuum. Also, we suggest that the fluid properties are not concerned by the temperature and concentration differences except by the density in the body force term; the influence of the density variations in the momentum and energy equations is negligible. The vertical infinite porous plate rotates in unison mutually a viscous fluid occupying the porous region with the constant angular velocity approaching an axis which is perpendicular to the vertical plane surface. The Cartesian coordinate system is chosen such that x', y' -axes respectively are in the vertical upward and perpendicular directions on the plane of the vertical porous surface $z=0$ while $z'-$axis is normal to it.The above frame of reference and assumptions, the physical variables, except the pressure p, are functions of z and time t only. Consequently, the equations expressing the conservation of mass, momentum and energy and the equation of mass transfer, neglecting the heat due to viscous dissipation, which is valid for small velocities, are given by

$$\frac{\partial w'}{\partial z'}=0 \tag{1}$$

$$\frac{\partial u'}{\partial t'}+w'\frac{\partial u'}{\partial z'}-2\Omega' v'=g\beta\left(T'-T'_\infty\right)+g\beta'\left(C'-C'_\infty\right)+\nu\frac{\partial^2 u'}{\partial z'^2}-\frac{\nu}{K'}u'-\frac{\sigma B^2{}_0 u'}{\rho} \tag{2}$$

$$\frac{\partial v'}{\partial t'}+w'\frac{\partial v'}{\partial z'}2\Omega' u'=\nu\frac{\partial^2 v'}{\partial z'^2}-\frac{\nu}{K'}v'-\frac{\sigma B_0{}^2 v'}{\rho} \tag{3}$$

$$0=-\frac{1}{\rho}\frac{\partial p'}{\partial z'}-\frac{\nu}{K'}w' \tag{4}$$

$$\frac{\partial T'}{\partial t'}+w'\frac{\partial T'}{\partial z'}=\frac{k}{\rho C_P}\frac{\partial^2 T'}{\partial z'^2}-\frac{1}{\rho C_P}\frac{\partial q_r}{\partial y} \tag{5}$$

$$\frac{\partial C'}{\partial t'}+w'\frac{\partial C'}{\partial z'}=D\frac{\partial^2 C'}{\partial z'^2}-kr\left(C-C_\infty\right) \tag{6}$$

with the boundary conditions

$$\begin{aligned}&u'=0, v'=0, T'=T'_w+\varepsilon\left(T'_w-T'_\infty\right)e^{i\omega t}, C'=C'_w+\varepsilon\left(C_w-C_\infty\right)e^{i\omega t} at \;\; z'=0\\&u', v'\to 0, T'\to T'_\infty, C'\to C'_\infty \; as \;\; z'\to\infty\end{aligned} \tag{7}$$

Where all the symbols are defined in the Nomenclature section.

In a physically realistic situation, we cannot ensure perfect insulation in any experimental setup. There will always be some fluctuations in the temperature. The plate temperature is assumed to vary harmonically with time. It varies from

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$T'_w \pm \varepsilon\left(T'_w - T'_\infty\right)$ as t varies from 0 to $\dfrac{2\pi}{\omega}$. Since ε is small, the plate temperature varies only slightly from the mean value $T'_{w.}$

For constant suction, we have from Eq. (1) in view of (7)

$$w = -w_0 \tag{8}$$

By using the Rosseland diffusion approximation and following among other researchers, the radiative heat flux, q_r is given by

$$q_r = -\frac{4\sigma^*}{3K_s}\frac{\partial T'^4}{\partial y'} \tag{9}$$

where σ^* and K_s are the Stefan- Boltzmann constant and the Roseland mean absorption coefficient, respectively. We assume that the temperature differences within the flow are sufficiently small such that T^4 may be expressed as a linear function of temperature.

$$T^4 \approx 4T_\infty^3 T - 3T_\infty^4 \tag{10}$$

Using (8) and (9) in theof Equation (5) we obtain

$$\frac{\partial T'}{\partial t'} + w'\frac{\partial T'}{\partial z'} = \frac{k}{\rho C_P}\frac{\partial^2 T'}{\partial z'^2} + \frac{16\sigma^* T_\infty^3}{3\rho C_p K_s}\frac{\partial^2 T'}{\partial y'^2} \tag{11}$$

Considering $u' + iv' = F$ and taking into Eq. (8), then Eqs. (2) and (3) can bewritten as

$$\frac{\partial F}{\partial t'} - w_0\frac{\partial F}{\partial z'} + 2\Omega' iF = g\beta\left(T' - T'_\infty\right) + g\beta'\left(C' - C'_\infty\right) + v\frac{\partial^2 F}{\partial z'^2} - \frac{v}{K'}F \tag{12}$$

Let us introduce the following non- dimensional quantities:

$$z = \frac{w_0 z'}{v}, F = \frac{F'}{w_0}, t = \frac{tw_0^{2'}}{v}, \omega = \frac{v\omega'}{w_0^2}, \theta = \frac{T' - T'_\infty}{T'_{w-}T'_\infty}, \varphi = \frac{C' - C'_\infty}{C'_w - C'_\infty}, Sc = \frac{v}{D}, R = \frac{4I}{\rho C p w_0}$$
$$\Pr = \frac{\rho v C_p}{k}, K = \frac{w_0^2 K'}{v^2}, Gr = \frac{vg\beta\left(T'_w - T'_\infty\right)}{w_0^3}, Gm = \frac{vg\beta\left(C'_w - C'_\infty\right)}{w_0^3}, \Omega = \frac{\Omega' v}{w_0^2}$$

In view of the above non-dimensional quantities, Eqs. (12), (11) and (6) reduce, respectively, to

$$\frac{\partial F}{\partial t} - \frac{\partial F}{\partial z} + 2i\Omega F = Gr\theta + Gm\varphi + \frac{\partial^2 F}{\partial z^2} - (K^{-1} + M^2)F \tag{13}$$

$$\frac{\partial \theta}{\partial t} - \frac{\partial \theta}{\partial z} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial z^2} - R\theta \tag{14}$$

$$\frac{\partial \varphi}{\partial t} - \frac{\partial \varphi}{\partial z} = \frac{1}{Sc}\frac{\partial^2 \varphi}{\partial z^2} - Kr\varphi \tag{15}$$

the corresponding boundary conditions (7) becomes

$$\begin{aligned} &F = 0,\ \theta = 1 + \varepsilon e^{i\omega t}, \varphi = 1 + \varepsilon e^{i\omega t} \quad \text{at} \quad z = 0 \\ &F \to 0,\ \ \theta \to 0,\ \ \varphi \to 0, \text{ as } z \to \infty \end{aligned} \tag{16}$$

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3. METHOD OF SOLUTION:

In order to reduce the system of partial differential equations (13)−(15) under their boundary conditions (16), to a system of ordinary differential equations in the non-dimensional form, we assume the following for velocity, temperature and concentration of the flow field as the amplitude ε(<< 1) of the permeability variations is very small.

$$\begin{aligned} F(z,t) &= F_0(z) + \varepsilon e^{i\omega t} F_1(z); \\ \theta(z,t) &= \theta_0(z) + \varepsilon e^{i\omega t}\theta_1(z); \\ \varphi(z,t) &= \varphi_0(z) + \varepsilon e^{i\omega t}\varphi_1(z) \end{aligned} \tag{17}$$

Substituting (17) into the system (13)−(15) and equating harmonic and non-harmonic terms we get

$$\begin{aligned} & F_0'' + F_0' - (2iR + K^{-1} + M)F_0 = -(Gr\theta_0 + Gm\varphi_0), \\ & F_1'' + F_1' - \left[K^{-1} + M + i(\omega + 2R)\right]F_1 = -(Gr\theta_1 + Gm\varphi_1), \\ & \theta_0'' + \Pr\theta_0' = 0, \\ & \theta_1'' + \Pr\theta_1' - i\omega\Pr\theta_1 = 0, \\ & \varphi_0'' + Sc\varphi_0' = 0, \\ & \varphi_1'' + Sc\varphi_1' - i\omega Sc\varphi_1 = 0. \end{aligned} \tag{18}$$

The appropriate boundary conditions reduce to

$$\begin{aligned} & F_0(0) = 0, \theta_0(0) = 1, \varphi_0(0) = 1, F_1(0) = 0, \theta_1(0) = 0, \varphi_1(0) = 0 \\ & F_0(\infty) \to 0, \theta_0(\infty) \to 0, \varphi_0(\infty) \to 0, F_1(\infty) \to 0, \theta_1(\infty) \to 0, \varphi_1(\infty) \to 0 \end{aligned} \tag{19}$$

Solving the group of Equations (18) under the boundary condition using equation (19), we obtain the velocity, temperature and concentration distribution in the boundary layer as

$$\begin{aligned} F(z,t) &= k_4 e^{-m_5 z} + k_2 e^{-m_3 z} + k_3 e^{-m_1 z} + \varepsilon e^{i\omega t}(k_8 e^{-m_6 z} + k_6 e^{-m_4 z} + k_7 e^{-m_2 z}) \\ \theta(z,t) &= e^{-m_3 z} + \varepsilon e^{i\omega t} e^{-m_4 z} \\ \varphi(z,t) &= e^{-m_1 z} + \varepsilon e^{i\omega t} e^{-m_2 z} \end{aligned}$$

The skin-friction, Nusselt number and Sherwood number are important physical parameters for this type of boundary layer flow.

Skin friction

Knowing the velocity field, the skin – friction at the plate can be obtained, which in non –dimensional form is given by

$$C_f = -\left(\frac{\partial F}{\partial z}\right)_{z=0} = -\left(\frac{\partial F_0}{\partial z} + \varepsilon e^{i\omega t}\frac{\partial F_1}{\partial z}\right)_{z=0}$$

$$C_f = k_4 m_5 + k_2 m_3 + k_3 m_1 + \varepsilon e^{i\omega t}\left(k_8 m_6 + k_6 m_4 + k_7 m_2\right)$$

Nusselt number

Knowing the temperature field, the rate of heat transfer coefficient can be obtained, which in non –dimensional form is given, in terms of the Nusselt number, is given by

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$$N_u = -\left(\frac{\partial\theta}{\partial z}\right)_{z=0} = \left(\frac{\partial\theta_0}{\partial z} + \varepsilon e^{i\omega t}\frac{\partial\theta_1}{\partial z}\right)_{z=0} = m_3 + \varepsilon e^{i\omega t} m_4$$

Sherwood number

Knowing the concentration field, the rate of mass transfer coefficient can be obtained, which in non –dimensional form, in terms of the Sherwood number, is given by

$$S_h = -\left(\frac{\partial\varphi}{\partial z}\right)_{z=0} = \left(\frac{\partial\varphi_0}{\partial z} + \varepsilon e^{i\omega t}\frac{\partial\varphi_1}{\partial z}\right)_{z=0} = m_1 + \varepsilon e^{i\omega t} m_2$$

Appendix:

$$k_1 = M + \frac{1}{K} + i\omega; k_2 = \frac{-Gr}{m_3^{\ 2} - m_3 - k_1}; k_3 = \frac{-Gm}{m_1^{\ 2} - m_1 - k_1};$$

$$k_4 = -k_2 - k_3; k_5 = M + \frac{1}{k} + 2i\Omega; k_6 = \frac{-Gr}{m_4^{\ 2} - m_4 - k_5};$$

$$k_7 = \frac{-Gm}{m_2^{\ 2} - m_2 - k_5}; k_8 = -k_6 - k_7$$

$$m_1 = \frac{Sc + \sqrt{Sc^2 + 4KrSc}}{2}; m_2 = \frac{Sc + \sqrt{Sc^2 + 4(Kr + i\omega)Sc}}{2}; m_3 = \frac{\Pr + \sqrt{\Pr^2 + 4\Pr R}}{2};$$

$$m_4 = \frac{\Pr + \sqrt{\Pr^2 + 4\Pr(R + i\omega)}}{2}; m_5 = \frac{1 + \sqrt{1 + 4k_1}}{2}; m_6 = \frac{1 + \sqrt{1 + 4k_5}}{2}$$

4. RESULT AND DISCUSSION

The problem of unsteady MHD free convective flow with radiation and chemical reaction effects in a rotating porous medium has been considered. The solutions for velocity, temperature field and concentration profiles are obtained using thetwo-term perturbation technique. The effects of flow parameters such as the magnetic parameter (M), permeability parameter (K), Grashof number (Gr), modified Grashof number (Gm), Prandtl number (Pr), radiation parameter (R), Schmidt number (Sc) and the rotation parameter Ω on the velocity, temperature and concentration profiles have been studied analytically and presented graphically.

The effect of magnetic field parameter M on the velocity profile is shown in Fig. 1. The velocity decreases with an increasing in the magnetic parameter. Because that the application of transverse magnetic field will result a resistive type force (Lorentz force) like drag force which tends to resist the fluid flow and thus reducing its velocity. Also, the boundary layer thickness decreases with an increase in the magnetic parameter.The effect of the permeability parameter K on the velocity field is shown in Fig. 2. An increase in K will therefore increase the resistance of the porous medium (as the permeability physically becomes less with increasing K) which will tend to decelerate the flow and reduce the velocity.

The velocity profiles for different values of Grashof number is shown in Fig. 3. The thermal Grashof number signifies the relative effect of the thermal buoyancy force to the viscous hydrodynamic force. The flow is accelerated due to the enhancement in buoyancy force corresponding to an increase in the thermal Grashof number i.e., free convection effects. The positive values of Gr correspond to cooling of the plate by natural convection. Heat is therefore conducted away from the vertical plate into the fluid which increases the temperature and thereby enhances the buoyancy force. In addition, it is seen that the peak values of the velocity increase rapidly near the plate as thermal Grashof number increases and then decays smoothly to the free stream velocity.
Fig. 4 presents typical velocity profiles in the boundary layer for various values of the modified Grashof numberGm. The modified Grashof number Gmdefines the ratio of the species buoyancy force to the viscous hydrodynamicforce. It is noticed that the velocity increases with increasing values of the solutal Grashof number.

Fig. 5 and Fig.6 illustrate the velocity and temperature profiles for different values of Prandtl number Pr. The numerical results show that the effect of increasing values of Prandtl number results in a decreasing velocity. From Fig. 6, it is observed that an increase in the Prandtl number results a decrease of the thermal boundary layer thickness and in general lower average temperature within the boundary

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layer. The reason is that smaller values of Pr are equivalent to increasing the thermal conductivities, and therefore heat can diffuse away from the heated surface more rapidly than for higher values of Pr. Hence in the case of smaller Prandtl numbers as the boundary layer is thicker and the rate of heat transfer is reduced.

The influence of the thermal radiation parameter R on the velocity and temperature are shown in Fig. 7 and Fig.8 respectively. The radiation parameter R defines the relative contribution of conduction heat transfer to thermal radiation transfer. It is obvious that an increase in the radiation parameter results in decreasing velocity and temperature within the boundary layer.

For different values of the Schmidt number Sc the velocity and concentration profiles are plotted in Fig. 9 and Fig.10 respectively. The Schmidt number Sc embodies the ratio of the momentum diffusivity to the mass diffusivity. It physically relates the relative thickness of the hydrodynamic boundary layer and mass transfer boundary layer. As the Schmidt number increases the concentration decreases. This causes the concentration buoyancy effects to decrease yielding a reduction in the fluid velocity. The reductions in the velocity and concentration profiles are accompanied by simultaneous reductions in the velocity and concentration boundary layers, which is evident from Fig. 9 and Fig. 10.

Fig. 11 and Fig. 12 display the effects of the chemical reaction parameter (Kr) on the velocity and concentration profiles, respectively. As expected, the presence of the chemical reaction significantly affects the concentration profiles as well as the velocity profiles. It should be mentioned that the studied case is for a destructive chemical reaction (Kr). In fact, as chemical reaction increases, the considerable reduction in the velocity profiles is predicted, and the presence of the peak indicates that the maximum value of the velocity occurs in the body of the fluid close to the surface but not at the surface. Also, with an increase in the chemical reaction parameter, the concentration decreases. It is evident that the increase in the chemical reaction significantly alters the concentration boundary layer thickness but does not alter the momentum boundary layers.

5. CONCLUSIONS

- The present theoretical analysis brings out the following results of physical interest on the velocity, temperature, concentration, skin friction and Nusselt number and Sherwood number of the flow field for a rotating system in a saturated porous medium
- It is noticed that all the velocity profiles increase steadily near the plate and thereafter they showa constant decrease and reach the value zero at the free stream.
- The magnetic parameter, Prandtl number, radiation parameter, Schmidt number and Chemical reaction are found to decelerate the velocity and temperature of the flow field.
- The porosity parameter, Grashof number and modified Grashof number are found to be increases of the velocity flow field.
- The Prandtl number and the frequency parameter have the effect of increasing the heat transfercoefficient**.**

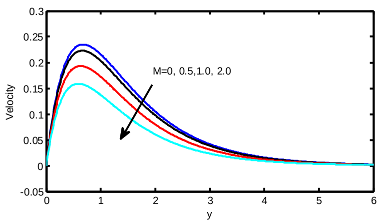

Fig.1.Velocity profiles for different values of magnetic parameter (M)

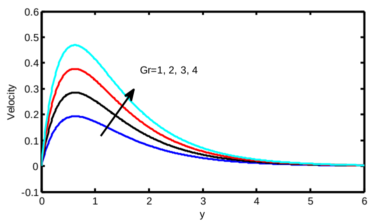

Fig.3.Velocity profiles for different values of Grashof number (Gr)

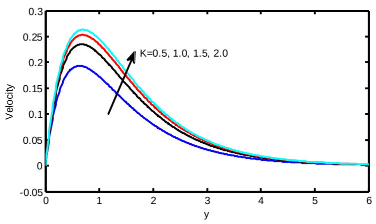

Fig.2.Velocity profiles for different values of permeability parameter (K)

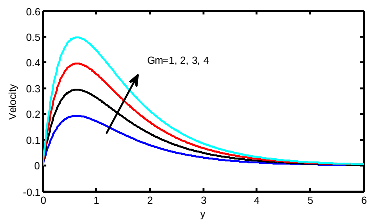

Fig.4.Velocity profiles for different values of modified Grashof number (Gm).

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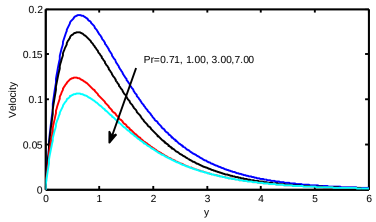

Fig.5.Velocity profiles for different values of Prandtl number (Pr).

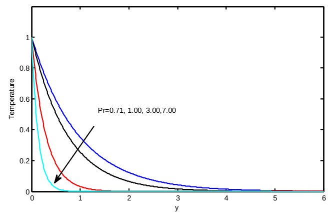

Fig.6.Temperature profiles for different values of Prandtl number (Pr).

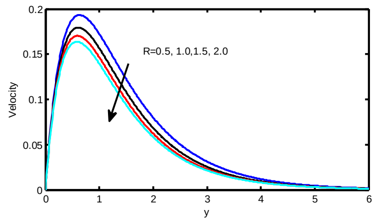

Fig.7.Velocity profiles for different values of radiation parameter (R).

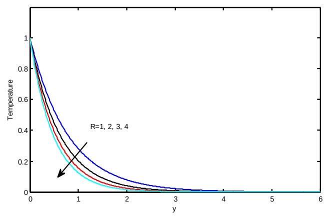

Fig.8.Temperature profiles for different values of radiation parameter (R).

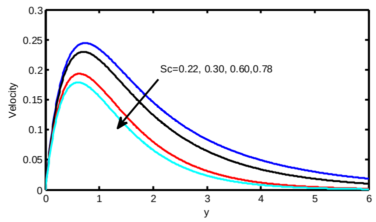

Fig.9.Velocity profiles for different values of Schmidt number (Sc).

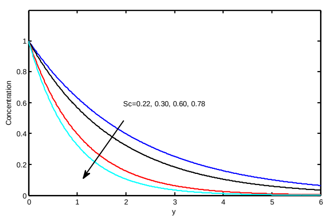

Fig.10.Concentration profiles for different values of Schmidt number (Sc).

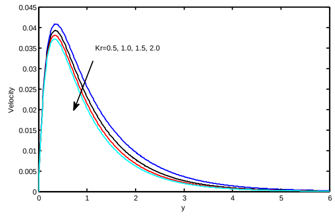

Fig.11.Velocity profiles for different values of chemical reaction parameter (Kr).

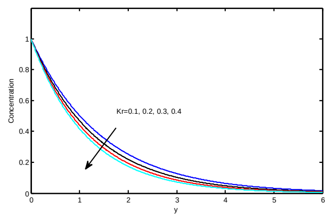

Fig.12.Concentration profiles for different values of chemical reaction parameter (Kr).

Nomenclature

u, v, w Velocity components in x, y *and* z directions respectively

$w_0(>0)$ Constant suction velocity of liquid through the porous plane surfaces

z Normal direction of vertical porous plane surface

z' Dimensional normal distance

C' Dimensional species concentration

Cp specific heat at constant pressure

D Chemical molecular diffusivity

g Acceleration due to gravity

Gm Modified Grashof number

Gm Grashof number

M Hartmann number (magnetic parameter)

K Permeability of the porous medium

K' Permeability parameter

Pr Prandlt number

p Pressure

Ω Rotation parameter

Sc Schmidt number

t Time

t' Dimensional time

F' Dimensional velocity

T Temperature

T' Dimensional temperature

Greek symbols

β Volumetric co-eff. of thermal expansion

β' Volumetric co-eff. of expansion with concentration

ε (0 < ε < 1) a constant
ν Kinematic viscosity
ρ Density
ω Frequency of oscillation of the plate temperature,
ω' Dimensionless frequency
Ω' Angular velocity of the rotating frame of reference,

Superscript

F' Derivative of U with respect to z

Subscripts

w Conditions on the porous plane surface
∞ conditions away from the porous plane surface

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