MHD Convection Flow of Kuvshinski Fluid past an Infinite Vertical Porous Plate with Radiation and Chemical Reaction Effects

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Abstract: An unsteady MHD free convective flow of a viscous incompressible visco-elastic fluid through a porous medium in the presence of radiation and chemical reaction effects are considered. The governing non-linear partial differential equations of the flow, heat and mass transfer are transformed into ordinary differential equations by using similarity transformations and then solved by two term perturbation technique. The effects of various flow parameters on velocity, temperature and concentration profiles as well as the skin-friction, Nusselt number and Shear wood number are discussed qualitatively and discussed graphically.

Keywords: *MHD, Radiation, Kuvshinski Fluid, Skin-friction, Nusselt number.*

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I. INTRODUCTION

The process of heat and mass transfer is encountered in aeronautics, fluid fuel nuclear reactor, chemical process industries and many engineering applications in which the fluid is a working medium. The wide range of technological and industrial applications has stimulated considerable amount of interest in the study of heat and mass transfer in convective flows. The convection problem in a porous medium has important applications in geothermal reservoirs and geothermal extractions. The phenomenon of free convection arises in the fluid when temperature changes cause density variation leading to buoyancy forces acting on the fluid elements. This can be seen in our everyday life in the atmospheric flow, which is driven by temperature differences.

Free convective flow past a vertical plate has been studied extensively by Ostrach [1]. Siegel [2] investigated the transient free convection from a vertical flat plate. Chambre et al. [3] were investigated the diffusion of a chemically reactive species in a laminar boundary layer flow. Takhar et al. [4] studied the radiation effects on MHD free convective flow for nongray-gas past a semi-infinite vertical plate. Hossain and Begum [5] were analyzed an unsteady free convective mass transfer flow past a vertical porous plate. Shvets and Vishevskiy [6] discussed the effect of dissipation on convective heat transfer in the flow of non-Newtonian fluids. Kinyanjui et al. [7] considered magneto hydrodynamic free convective heat and mass transfer of a heat generating fluid past an impulsively saturated infinite vertical porous plate with Hall current and radiation absorption. Cookey et al. [8] have investigated the influence of viscous dissipation and radiation on steady MHD free convective flow past an infinite heated vertical plate in a porous medium with time dependent suction. Combined effects of magnetic field and viscous dissipation on a power law fluid over a plate with variable surface heat flux embedded in a porous medium were discussed by Amin [9]. Unsteady effect on MHD free convective and mass transfer flow through porous medium with constant suction and constant heat flux in rotating system was studied by Sharma [10]. Salam [11] have examined a coupled heat and mass transfer flow in Darcy-Forchheimer mixed convection from a vertical flat plate embedded in fluid saturated porous medium under the influence of radiation and viscous dissipation. Effect of mass transfer on radiation and free convective flow of Kuvshinski fluid through a porous medium was studied by Harish Kumar et al. [12]. Ibrahim et al. [13] analyzed the effects of the chemical reaction and radiation absorption on the unsteady MHD free convective flow past a semi infinite vertical permeable moving plate with source and suction. Reddy et al. [14]were investigated the radiation and mass transfer effects on an unsteady MHD free convective flow past a semi-infinite vertical permeable moving plate with viscous dissipation. Many practical diffusive operations involve the molecular diffusion of a species in the presence of chemical reaction within or at the boundary. Kumar [15] investigated the radiative heat transfer with the viscous dissipation effect in the presence of transverse magnetic field. Many processes in engineering areas occur at high temperatures and knowledge of radiation heat transfer becomes very important for the design of the pertinent equipment. Nuclear power plants, gas turbines and various propulsion devices for aircrafts, missiles, satellites and space vehicles are examples of such engineering areas. Gireesh Kumar et. al. [16] have discussed the effects of chemical reaction and mass transfer on radiation and MHD free convection flow of Kuvshiski fluid through a porous medium. Rajesh [17] examined the chemical reaction and radiation effects on the transient MHD free convective flow of dissipative fluid past an infinite vertical porous plate with ramped wall temperature. Agrawal et al. [18] has been discussed the effect of stratified viscous Kuvshinski fluid on MHD free convective flow with heat and mass transfer past a vertical porous plate. Aravind Kumar Sharma et.al [19] have studied the effect of Kuvshinski fluid on double-diffusive unsteady convective heat and mass transfer flow past a porous vertical moving plate with heat source and Soret effect. Sudershan Reddy et al.[20] have discussed the chemical reaction and radiation absorption effects on MHD convective heat and mass transfer flow past a semi-infinite vertical moving porous plate with time dependent suction. Sharma and Varshney **[**21**]** were investigated the effect of stratified Kuvshinski fluid on MHD free convective flow past a vertical porous plate with heat and mass transfer neglecting induced magnetic field in comparison to applied magnetic field. Manjulatha et.al. [22] were discussed the effects of radiation absorption and mass transfer on the steady free convective flow of a viscous, incompressible and electrically conducting fluid past an infinite vertical flat plate through a porous medium with an aligned magnetic field. Devasena et al. [23] have analyzed the combined effects of chemical reaction, thermo diffusion and thermal radiation and dissipation on connective heat and mass transfer flow of a Kuvenski fluid past a vertical plate embedded in a porous medium. Manjulatha et al. [24] investigated the radiation and chemical reaction effects on the unsteady MHD oscillatory flow in a channel filled with saturated porous medium in an aligned magnetic field. Unsteady magneto hydrodynamic (MHD) free convective flow of a viscous, incompressible and electrically conducting, well known non-Newtonian fluid named as Kuvshinski fluid past an infinite vertical porous plate in the presence of homogeneous chemical reaction, radiation absorption and heat source/sink was studied analytically by Reddy et al. [25]. An unsteady MHD two dimensional free convective flow of a viscous, incompressible, radiating, chemically reacting and radiation absorbing Kuvshinski fluid through a porous medium past a semi-infinite vertical plate was investigated by Vidya Sagar et al. [26].

The objective of the present problem is to study an unsteady MHD free convection flow of Kuvshinski fluid flow past an infinite vertical porous plate with the radiation and chemical reaction effects. The governing non-linear partial differential equations of the flow, heat and mass transfer are transformed into ordinary differential equations by using similarity transformations and then solved by two term perturbation technique. The effects of various flow parameters on velocity, temperature and concentration profiles as well as the skin-friction, Nusselt number and Shear wood number are discussed qualitatively and graphically.

II. MATHEMATICAL FORMULATION:

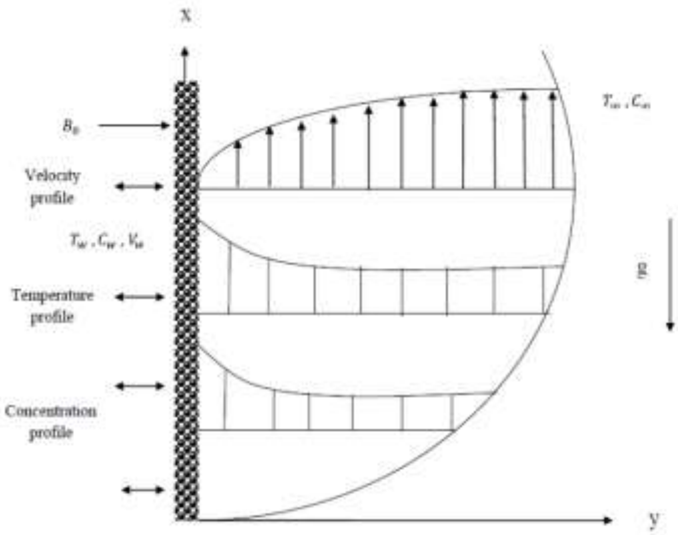

Fig. Physical model

We consider an unsteady two dimensional flow of a laminar, viscous, incompressible eclectically conducting, radiating and chemically reacting Kuvshinski fluid through porous medium past a semi-infinite vertical moving plate. According to the coordinate system $x'-$axis is taken along the vertical porous plate in the up word direction and $y'-$axis normal to it. The fluid is assumed to be gray, absorbing-emitting but non-scattering medium. The radiative heat flux in the x-direction is considered negligible in comparison with in the y' direction. A uniform magnetic field is applied perpendicular to the fluid flow direction and assumed that an induced magnetic field is neglected. Viscous and Darcy resistance terms are taken into account. The fluid properties are assumed to be constant except that the influence of density variation with temperature and concentration has been considered in the body-force term. The level of foreign mass is assumed to be low, So that the Dufour effect is neglected. Also

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assume that the Dissipation effects are neglected. Under the above assumptions and invoking the Boussinesq approximation, the boundary layer equations governing the flow and mass transfer of a visco-elastic fluid can be written as

$$\frac{\partial v'}{\partial y'}=0 \quad (1)$$

$$\left(1+\lambda'\frac{\partial}{\partial t'}\right)\frac{\partial u'}{\partial t'}+v'\frac{\partial u'}{\partial y'}=\nu\frac{\partial^2 u'}{\partial y'^2}+g\beta\left(T'-T'_\infty\right)+g\beta^*\left(C'-C'_\infty\right)-\left(1+\lambda'\frac{\partial}{\partial t'}\right)\left(\frac{\sigma B_0}{\rho}+\frac{\nu}{K'}\right)u' \quad (2)$$

$$\frac{\partial T'}{\partial t'}+v'\frac{\partial T'}{\partial y'}=\frac{k}{\rho c_p}\frac{\partial^2 T'}{\partial y'^2}+\frac{1}{\rho c_p}Q_0\left(T'-T'_\infty\right)-\frac{1}{\rho c_p}\frac{\partial q_r}{\partial y'} \quad (3)$$

$$\frac{\partial C'}{\partial t'}+v'\frac{\partial C'}{\partial y'}=D\frac{\partial^2 C'}{\partial y'^2}+D_1\frac{\partial^2 T'}{\partial y'^2}-Kr\left(C'-C'_\infty\right) \quad (4)$$

The boundary conditions for the velocity, temperature and concentration fields are

$$t'\le 0:\quad u'=0,\quad T'=T'_\infty\quad C'=C'_\infty \text{ for all } y'$$
$$t'>0:\begin{cases} u'=u_p & T'=T'_\infty+\varepsilon\left(T'_w-T'_\infty\right)e^{n't'},\ C'=C'_\infty+\varepsilon\left(C'_w-C'_\infty\right)e^{n't'} \text{ at } y'=0 \\ u'=0, & T'\to T'_\infty,\quad C'\to C'_\infty, \text{ as } y'\to\infty \end{cases} \quad (5)$$

where u' and v' are the velocity components in the x', y' directions respectively, g is the gravitational acceleration, ν-is the kinematic viscosity, σ-is the electrical conductivity, $\lambda^*$is the Kuvshinski fluid, ρ is the density, $k-$ is the thermal conductivity, β and β^* are the thermal and concentration expansion coefficients respectively, K' is the Darcy permeability, B_0 is the magnetic induction, T' is the fluid temperature, C' is the fluid concentration, T'_w and C'_w- are the temperature and concentration of the fluid at the wall, C_p is the specific heat at constant pressure, D is the diffusion coefficient, q_r is the radiative heat flux, Q_0 is the dimensional heat absorption coefficient, D_1 is the Coefficient of thermal diffusivity, Kr chemical reaction parameter and u'_p- is the direction of the fluid flow. In addition it is assumed that the temperature and concentration at the wall are exponentially varying with time.

Assume that the suction velocity normal to the plate is constant. So, eqn (1) gives

$$v'=-v_0 \quad (6)$$

The local radiant for the case of an optically thin gray gas is expressed by

$$\frac{\partial q_r}{\partial y'}=-4a^*\sigma T'^3_\infty\left(T'^4_\infty-T'^4\right) \quad (7)$$

where a^* is the absorption constant and σ is the Stefan- Boltzmann constant respectively. It is assumed that the temperature differences within the flow are sufficiently small and that T'^4 may be expressed as a linear function of the temperature. This is obtained by expanding T'^4 in a Taylor series about T'_∞ and neglecting the higher order terms, thus we get

$$T'^4\cong 4T'^3_\infty T'-3T'^4_\infty \quad (8)$$

From equations (7) and (8), equation (3) reduces to

$$\frac{\partial T'}{\partial t'}+v'\frac{\partial T'}{\partial y'}=\frac{k}{\rho c_p}\frac{\partial^2 T'}{\partial y'^2}+\frac{1}{\rho c_p}Q_0\left(T'-T'_\infty\right)-\frac{16a^*\sigma T^*_\infty}{\rho c_p}\left(T'-T'_\infty\right) \quad (9)$$

On introducing the following non-dimensional quantities:

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$$y=\frac{v_0 y'}{\nu},u=\frac{u'}{v_0},t=\frac{t'v_0^2}{\nu},\theta=\frac{T'-T'_\infty}{T'_w-T'_\infty},C=\frac{C'-C'_\infty}{C'_w-C'_\infty},K=\frac{K'v_0^2}{\nu^2},\lambda=\frac{\lambda^* v_0^2}{\nu}$$
$$Gr=\frac{g\beta\nu(T'_w-T'_\infty)}{v_0^3},\Pr=\frac{\mu\rho C_p}{k},N=\frac{\beta^*\nu(C'_w-C'_\infty)}{\beta(T'_w-T'_\infty)},Sc=\frac{\nu}{D}, \tag{10}$$
$$\mathrm{R}=\frac{16a^*\nu^2\sigma T'^3_\infty}{kv_0^2},M=\frac{\sigma B_0^2\nu}{\rho v_0^2},So=\frac{D_1(T'_w-T'_\infty)}{\nu(C'_w-C'_\infty)},Q=\frac{Q'\nu^2}{\kappa u_0^2},Kr=\frac{K'r\nu}{u_0{}^2}$$

The governing equations for the momentum, the energy, and the concentration in a dimensionless form are

$$\left(1+\lambda\frac{\partial}{\partial t}\right)\frac{\partial u}{\partial t}-\frac{\partial u}{\partial y}=Gr\left(\theta+NC\right)+\frac{\partial^2 u}{\partial y^2}-\left(1+\lambda\frac{\partial}{\partial t}\right)\left(M+\frac{1}{K}\right)u \tag{11}$$

$$\frac{\partial\theta}{\partial t}-\frac{\partial\theta}{\partial y}=\frac{1}{\Pr}\frac{\partial^2\theta}{\partial y^2}-R\theta+Q\theta \tag{12}$$

$$\frac{\partial C}{\partial t}-\frac{\partial C}{\partial y}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}+So\frac{\partial^2\theta}{\partial y^2}-KrC \tag{13}$$

where $Gr,\mathrm{M},\mathrm{K},\Pr,R,Q,\mathrm{Sc},So,Kr,\lambda,N$ are the Grashof number, modified Grashof number, magnetic parameter, permeability parameter, Prandtl number, radiation parameter, heat source parameter, Schmidt number, Soret number, chemical reaction parameter, N is the Buoyancy ratio and λ is the viaco-elastic parameter respectively.

The relevant corresponding boundary conditions for $t>0$ are transformed to:

$$\begin{aligned} &u=u_p, \quad \theta=1+\varepsilon e^{nt}, \quad C=1+\varepsilon e^{nt} \quad \text{at} \quad y=0\\ &u\to 0,\ \ \theta\to 0,\ \ C\to 0 \quad \text{as} \quad \mathrm{y}\to\infty \end{aligned} \tag{14}$$

III. SOLUTION OF THE PROBLEM

In order to reduce the system of partial differential equations (11)−(13) under their boundary conditions (14), 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.

$$\begin{aligned} &u\left(y,t\right)=u_0\left(y\right)+\varepsilon u_1\left(y\right)e^{i\omega t}\\ &\theta\left(y,t\right)=\theta_0\left(y\right)+\varepsilon\theta_1\left(y\right)e^{i\omega t}\\ &C\left(y,t\right)=C_0\left(y\right)+\varepsilon C_1\left(y\right)e^{i\omega t} \end{aligned} \tag{15}$$

Substituting (15) into the system (11) − (13) and equating harmonic and non-harmonic terms we get

$$u_0''+u_0'-\left(M+1/K\right)u_0=-Gr\theta_0-GrNC_0 \tag{16}$$
$$u_1''+u_1'-M_2u_1=-Gr\theta_1-GrNC_1 \tag{17}$$
$$\theta_0''+\Pr\theta_0'-k_1\theta_0=0 \tag{18}$$
$$\theta_1''+\Pr\theta_1'-k_2\theta_1=0 \tag{19}$$

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$$C_0'' + ScC_0' + KrScC_0 = -ScSo\theta_0'' \tag{20}$$

$$C_1'' + ScC_1' + k_3C_1 = -ScSo\theta_1'' \tag{21}$$

The corresponding boundary conditions can be written as

$$\begin{aligned} &u_0 = u_p,\ u_1 = 0,\ \theta_0 = 1, \theta_1 = 1, C_0 = 1, C_1 = 1 \quad \text{at} \quad y = 0 \\ &u_0 \to 0,\ u_1 \to 0,\ \theta_0 \to 0,\ \theta_1 \to 0,\ C_0 \to 0, C_1 \to 0 \quad \text{as} \quad y \to \infty \end{aligned} \tag{22}$$

Solving equations (16) – (21) under the boundary conditions (22), we obtain the velocity, temperature and concentration distribution in the boundary layer as:

$$u(y,t) = C_4 e^{-m_6 y} + B_1 e^{-m_1 y} - B_3 e^{-m_3 y} + \varepsilon e^{nt}\left(C_5 e^{-m_5 y} + B_2 e^{-m_2 y} + B_4 e^{-m_4 y}\right)$$

$$\theta(y,t) = e^{-m_1 y} + \varepsilon e^{nt} e^{-m_2 y}$$

$$C(y,t)=) = (1 + A_3)e^{-m_3 y} - A_3 e^{-m_1 y} + \varepsilon e^{nt}\left[A_4\left(e^{-m_4 y} - e^{-m_2 y}\right)\right]$$

Here constant are not given due to shake of brevity.

SKIN-FRICTION

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

$$c_f = -\left(\frac{\partial u}{\partial y}\right)_{y=0} = m_6 C_4 + B_1 m_1 - B_3 m_3 + \varepsilon e^{nt}\left(C_5 m_5 + B_2 m_2 + B_4 m_4\right)$$

NUSSELT NUMBER

From temperature field, now we study Nusselt number (rate of change of heat transfer) which is given in non dimensional form as

$$Nu = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = m_1 + \varepsilon e^{nt} m_2$$

SHERWOOD NUMBER

From concentration field, now we study Sherwood number (rate of change of mass transfer) which is given in non dimensional form as

$$Sh = -\left(\frac{\partial C}{\partial y}\right)_{y=0} = m_3(1 + A_3) - A_3 m_1 + \varepsilon e^{nt}\left[A_4\left(m_4 - m_2\right)\right]$$

IV. RESULTS AND DISCUSSION

In order to get the physical insight into the problem, we have plotted velocity, temperature, concentration, skin friction, the rate of heat transfer and the rate of mass transfer for different values of the physical parameters like Radiation parameter (R), Magnetic parameter (M), Heat source parameter (Q), Soret number (Sr), Schmidt number (Sc), Grashof number (Gr), buoyancy ratio parameter (N), Prandtl number (Pr), chemical reaction parameter (Kr), Kuvshinski parameter (λ) in figures 1 to 15.

The effect of Magnetic field parameter *M* for both Newtonian and Visco-elastic fluids on velocity profiles are shown in Fig.1. It is clear that the fluid velocity decreases with an increasing value of *M* for both cases. Because the transverse magnetic field retards the fluid flow, which is known as Lorentz force. It is also observed that the velocity reaches the maximum peak value at the surface. Fig.2 illustrates the influence of Radiation parameter *R* on velocity distribution for Newtonian and Visco-elastic fluids. It is noticed from the figure that the fluid velocity increases with an increase in the Radiation parameter *R* in both cases, because of the fluid considered here which is gray emitting and absorbing radiation but non-scattering medium. Fig.3 demonstrates the effect of the Soret number *Sr* on the fluid velocity for both Newtonian and Visco-elastic fluids. Comparing the curves of the said figure it is observed that a growing Soret number *Sr* increases the fluid velocity and momentum boundary layer thickness. Also it is observed that the boundary layer thickness is thinner for Visco-elastic fluid with the comparison of Newtonian fluid.

In Figures 4 and 5, effects of thermal Grashof number and ratio buoyancy on the velocity are presented, in which it is noticed that the velocity increases in both the cases as both the parameters namely Grashof number and buoyancy increases. It is also noticed that the momentum boundary layer thickness for increases significantly with an increase in Grashof number and buoyancy parameter. Effect of porosity parameter on velocity is shown in Figure 6, from this figure it is seen that velocity increases with the increasing values of porosity parameter. Effect of Prandtl number on velocity is presented in Figure 7. The numerical results show that the effect of increasing values of Prandtl number results a decrease in velocity. From Figure 8 it is observed that an increases in the heat source parameter with an increasing the velocity field. Fig. 9 shows the effect of visco-elastic parameter on the velocity profiles. It is observed that the velocity increases as visco – elastic parameter increases. Fig.10 illustrated that the effect of Prandtl number (Pr) on temperature profiles. It is observed that the Prandtl number increases, the temperature filed decreases. Fig. 11 shows the effect of radiation parameter on the temperature profiles. It is observed that the temperature decreases with an increasing radiation parameter. Fig. 12 shows the effect of heat source parameter on the temperature profiles. It is observed that the temperature increases as heat source parameter increases. Fig. 13 displays the effect of chemical reaction parameter on concentration profiles. It is observed that the concentration decreases with an increasing the chemical reaction parameter (*Kr*). Fig. 14 displays the effect of Soret number on concentration profiles. It is noticed that the concentration increases with an increasing the Soret number (Sr). The effect of Schmidt number (Sc) on the concentration profiles is shown in Fig. 15. It is observed that the species concentration decreases as the Schmidt number (Sc) increases.

V. CONCLUSIONS

Based on the results and discussions above, the following conclusions have been made:

- The velocity increases for increasing values of radiation parameter, Soret number, Grashof number, modified Grashof number, permeability parameter, Hall parameter and visco-elastic parameter where as a reverse trend is noticed in the case of magnetic parameter and Prandtl number.
- The temperature increases with an increase in heat source parameter where as a reverse trend is noticed in the case of radiation parameter and Prandtl number.
- The concentration increases with Soret number where as a reverse trend is noticed in the case of Schmidt number and chemical reaction parameter.

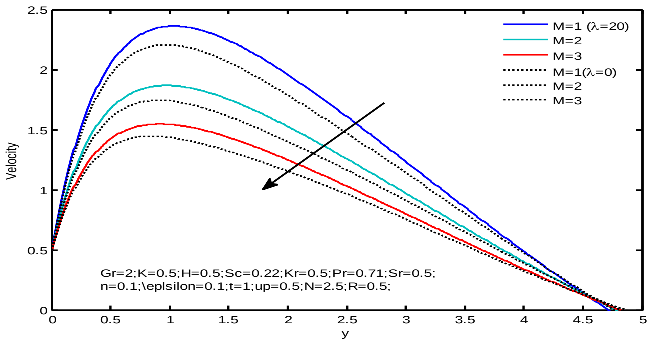

Fig.1. Velocity profiles for different values of magnetic parameter (M).

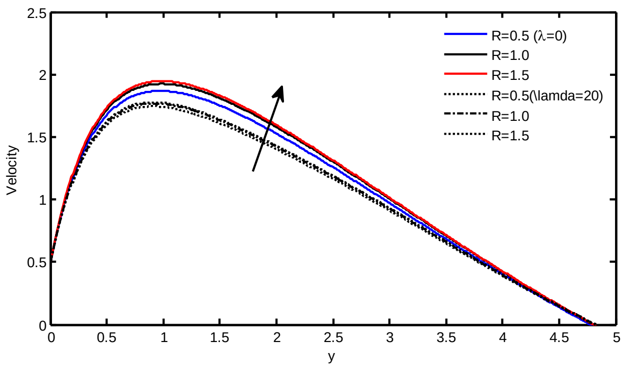

Fig.2. Velocity profiles for different values of radiation parameter(R).

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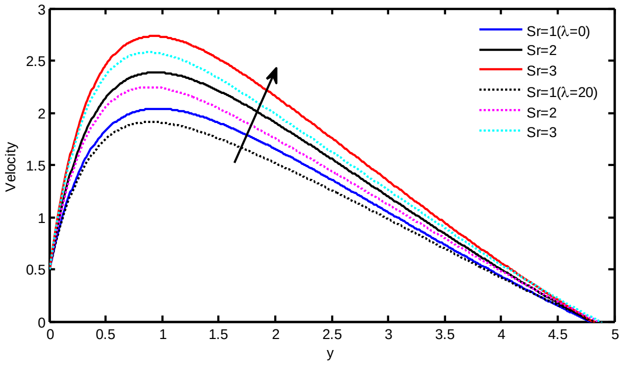

Fig.3. Velocity profiles for different values of Soret number (Sr).

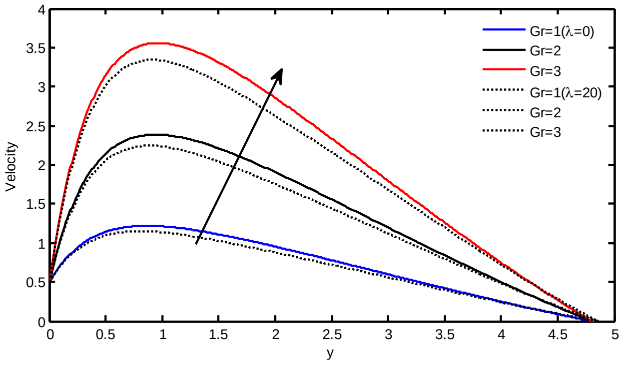

Fig.4. Velocity profiles for different values of Grashof number (Gr).

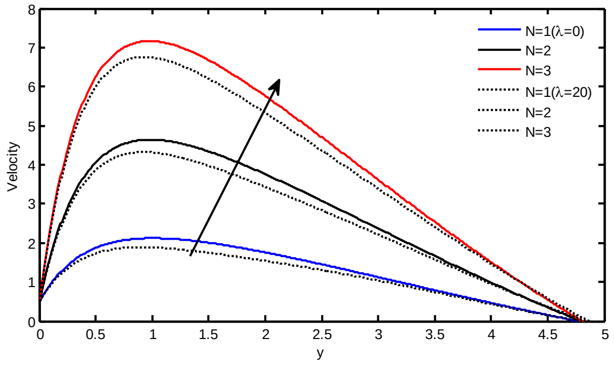

Fig.5. Velocity profiles for different values of buoyancy parameter (N).

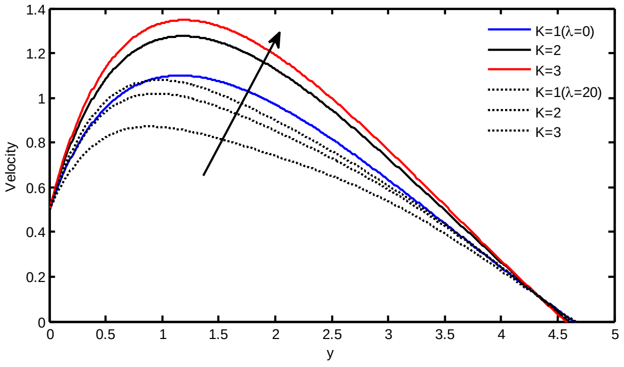

Fig.6. Velocity profiles for different values of permeability parameter (K).

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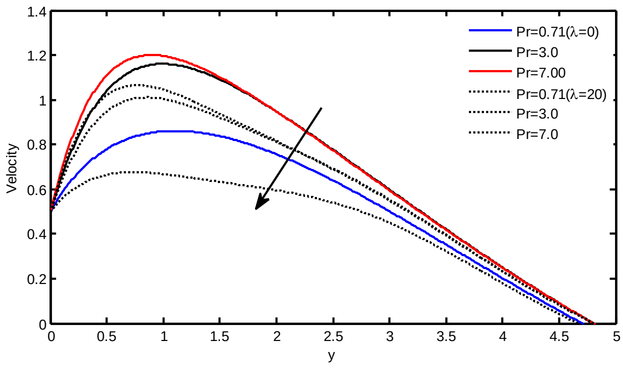

Fig.7. Velocity profiles for different values of Prandtl number (Pr).

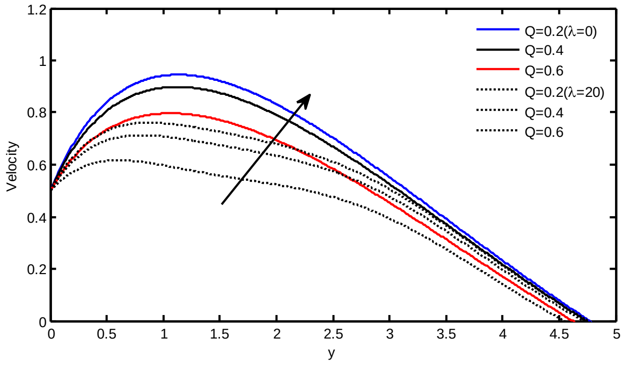

Fig.8. Velocity profiles for different values of heat source parameter (Q).

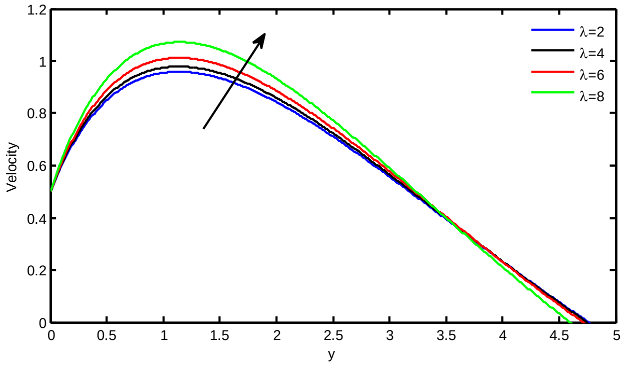

Fig.9. Velocity profiles for different values of visco-elastic parameter (λ).

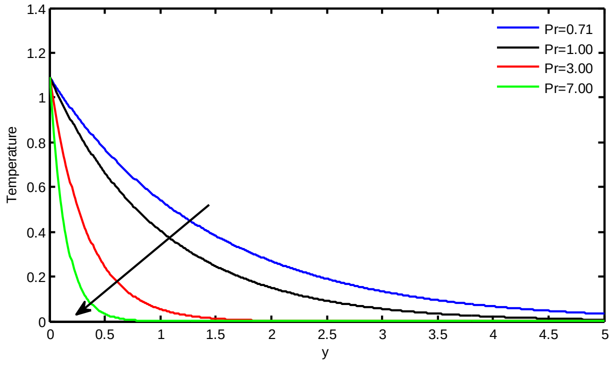

Fig.10. Temperature profiles for different values of Prandtl number (Pr).

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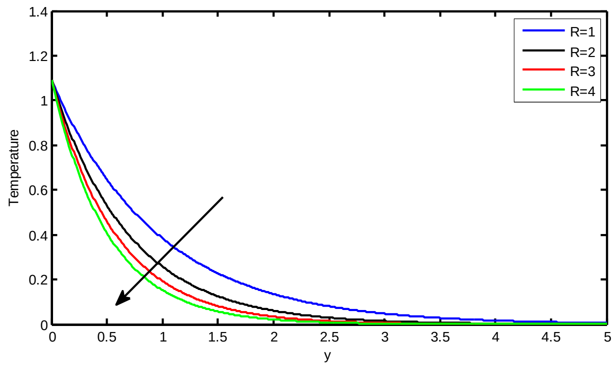

Fig.11. Temperature profiles for different values of radiation parameter (R).

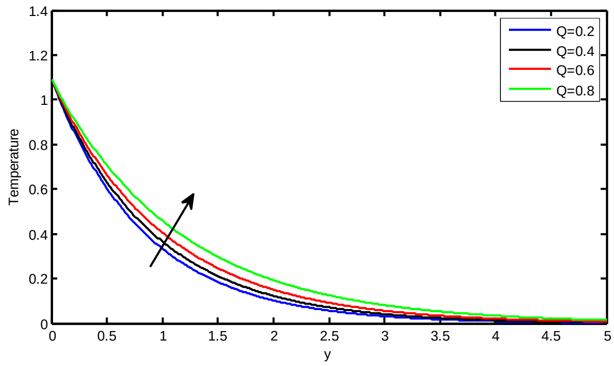

Fig.12. Temperature profiles for different values of heat source parameter (Q).

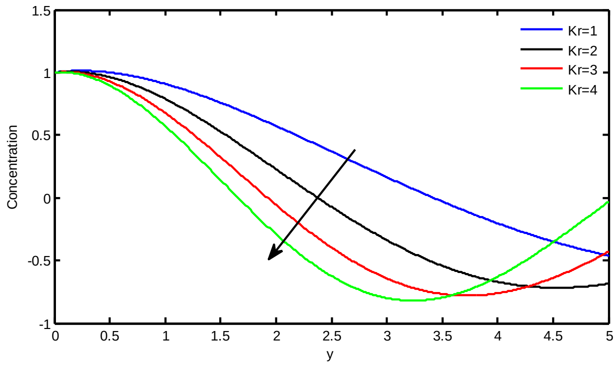

Fig.13. Concentration profiles for different values of chemical reaction parameter (Kr).

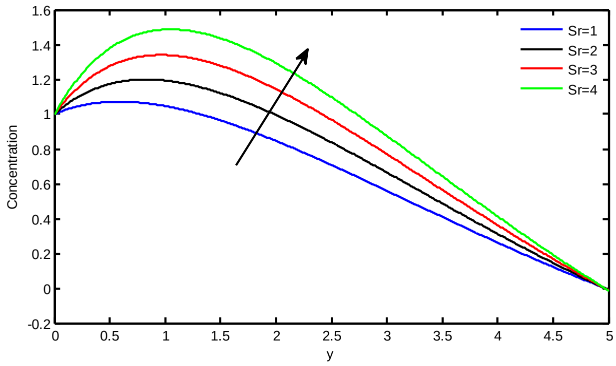

Fig.14. Concentration profiles for different values of Soret number (Sr).

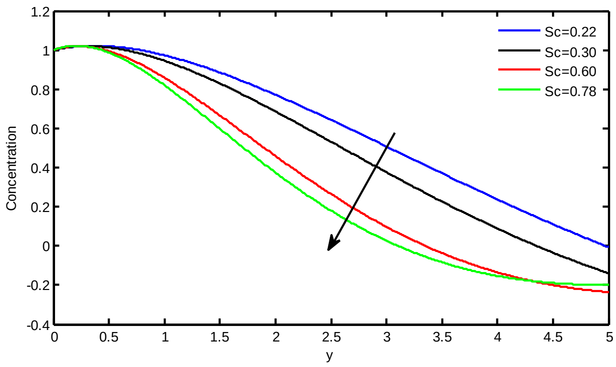

Fig.15. Concentration profiles for different values of Schmidt number (Sc).

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