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RADIATION EFFECT ON SLIP FLOW REGIME TRANSIENT MHD FLUID FLOW IN THE PRESENCE OF CHEMICAL REACTION AND SORET EFFECT

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Abstract: **The main concern of the present article is to study transient magnetohydrodynamics flow, heat and mass transfer past a permeable using 2-term perturbation scheme. The flow of liquid films are taken under the impact of thermal radiation. Effects of flow physical parameters including thermoporesis parameter(So), Schmidt number(Sc), Radiation parameter(R), Prandtl number(Pr), permeability parameter(K), slip parameter(h), chemical reaction parameter(Kc), Grashof number(Gr), modified Grashof Number(Gc) and perturbation parameter(E) on the fluid velocity, temperature and concentration distributions are scrutinized and discussed in detail. In this paper we studied two cases on velocity profiles, flow of cooled plate Gr > 0 and flow of heated plate Gr < 0.**

Keywords: **Soret Effect, Heat and Mass Transfer, Transient, Radiation.**

I. INTRODUCTION

Natural or “Buoyant” or “Free” convection is a very important mechanism that is operative in a variety of environments from cooling electronic circuit boards in computers to causing large scale circulation in the atmosphere as well as in lakes and oceans that influences the weather. It is caused by the action of density gradients in conjunction with a gravitational field. This is a brief introduction that will help you understand the qualitative features of a variety of situations you might encounter.

In the classical MHD flow control, the boundary layer flow of an electrically conducting fluid can be controlled by the application of an external magnetic field subjected to the condition that the electric conductivity of fluid should be high (e.g., liquid form of semiconductors, plasma, electrolytes and liquid metals). Due to the high electric conductivity of the fluid, the influence of applied external magnetic field is significant even in presence of moderate strength of the magnetic field (~1 Tesla). In addition, the application of an external electric field is not required in order to achieve an efficient flow control. In case of weakly conducting fluids (e.g., sea water) the electric current induced by the external magnetic field is too small and external electric field must be applied to control the flow separation. The Lorentz force parallel to the wall has the ability to stabilize the motion inside the boundary layer by slowing down its growth. The effects of chemical reaction and magnetic field on electrically conducting second-grade fluid flow discussed by Midya [1]. Numerous works have been reported on the combined effects of heat and mass transfer in presence of MHD and chemical reaction (see for instance Seddeek et al. [2]; Salem and Abd El-Aziz [3]; Mohamed [4]; Ibrahim et al [5]). Natural convection flow over vertical plate immersed in porous media has paramount importance because of its potential applications in soil physics, geohydrology, and filtration of solids from liquids, chemical engineering and biological

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systems. Convection flows in permeable media has picked up significant consideration as of late in light of their significance in building applications, for example, geothermal frameworks, strong network heat exchangers, warm protections, oil extraction and store of atomic waste materials. These can likewise be connected to underground coal gasification, ground water hydrology, divider cooled synergist reactors, vitality efficient drying procedures and regular convection in earth's outside layer. Nitty gritty surveys of flow through and past permeable media can be found in (Nield and Benjan [6]). Hiremath and Patil [7] concentrated on the impact on free convection streams on the oscillatory move through a permeable medium, which is limited by vertical plane surface of consistent temperature. Fluctuating warmth and mass exchange through permeable medium with variable porous ness has been talked about by Sharma et al. [8]. A comprehensive account of the available information in this field is provided in books by Pop and Ingham [9], Ingham and Pop [10], Vafai [11], Vadasz [12], etc. When technological processes take place at higher temperatures thermal radiation heat transfer has become very important and its effects cannot be neglected (Siegel and Howel [13]). The effect of radiation on MHD flow, heat and mass transfer become more important industrially. Many processes in engineering areas occur at high temperature and knowledge of radiation heat transfer becomes a very important for the design of the pertinent equipment. The quality of the final product depends to a great extent on the heat controlling factors, and the knowledge of radiative heat transfer in the system can lead to a desired product with sought qualities. Olanrewaju et al. [14] analyzed that the three dimensional unsteady MHD flow and mass transfer in a porous space in the presence of thermal radiation. Different researches have been forwarded to analyze the effects of thermal radiation on different flows (Cortell [15]; Bataller [16]; Ibrahim et al. [17]; Shateyi [18]; Shateyi and Motsa [19]; Aliakbar et al. [20]; Hayat [21]; Cortell [22]; among other researchers).

In spite of all these studies, the Chemical reaction and Soret effects on unsteady MHD free convective heat and mass transfer past an infinite vertical plate embedded in a porous medium in presence of thermal radiation has received little attention. Hence, the main object of the present investigation is to study the effects thermal radiation, chemical reaction and Soret effects on the unsteady MHD free convection fluid flow past a vertical porous plate. The governing equations are transformed by using 2-term perturbation scheme. The effects of various governing parameters on the velocity, temperature, and concentration profiles are presented graphically.

II. MATHEMATICAL FORMULATION

An unsteady two-dimensional flow of an incompressible and electrically conducting viscous fluid, along an infinite vertical permeable plate embedded in a porous is considered.

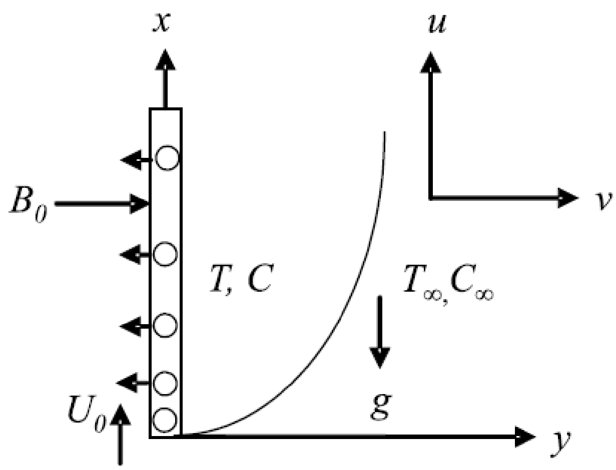

Fig.I. Flow configuration and coordinate system

❖ The x- axis is taken on the infinite plate, and parallel to the free-steam velocity which is vertical and the y– axis is taken normal to the plate.

❖ A magnetic field B_0 of uniform strength is applied transversely to the direction of the flow. Initially the plate and the fluid are at same temperature T_∞ in a stationary condition with concentration level C_∞ at all points.

❖ For $t>0$, the plate starts moving impulsively in its own plane with a velocity U_0, its temperature is raised to T_w and the concentration level at the plate is raised to C_w.

❖ The fluid is assumed to have constant properties except that the influence of the density variations with temperature and concentration, which are considered only the body force term.

❖ For small velocity, the viscous dissipation and Darcy's dissipation are neglected.

❖ The flow in the medium is entirely due to the buoyancy force caused by a temperature difference between the porous plate and the fluid.

The flow configuration and coordinate system are shown in Fig.I. Under the above assumption, the physical variables are functions of y and t only and the governing the conservation of mass (continuity), momentum, energy and concentration can be written as follows:

$$\frac{\partial \tilde{v}}{\partial \tilde{y}}=0 \tag{1}$$

$$\frac{\partial \tilde{u}}{\partial \tilde{t}}+\tilde{v}\frac{\partial \tilde{u}}{\partial \tilde{y}}=g\beta_T\left[\tilde{T}-\tilde{T}_\infty\right]+g\beta_C\left[\tilde{C}-\tilde{C}_\infty\right]+\upsilon\frac{\partial^2\tilde{u}}{\partial \tilde{y}^2}-\frac{\upsilon}{\tilde{k}}\tilde{u}-\frac{\sigma B_0^2}{\rho}\tilde{u} \tag{2}$$

$$\frac{\partial \tilde{T}}{\partial \tilde{t}}+\tilde{v}\frac{\partial \tilde{T}}{\partial \tilde{y}}=\frac{K_T}{\rho Cp}\frac{\partial^2\tilde{T}}{\partial \tilde{y}^2}-\frac{1}{\rho Cp}\frac{\partial q_r}{\partial \tilde{y}} \tag{3}$$

$$\frac{\partial \tilde{C}}{\partial \tilde{t}}+\tilde{v}\frac{\partial \tilde{C}}{\partial \tilde{y}}=D\frac{\partial^2\tilde{C}}{\partial \tilde{y}^2}+D_1\frac{\partial^2\tilde{T}}{\partial \tilde{y}^2}-\tilde{K}_C\left[\tilde{C}-\tilde{C}_\infty\right] \tag{4}$$

The relevant boundary conditions are

$$\tilde{u}=L_1\left(\frac{\partial \tilde{u}}{\partial \tilde{y}}\right),\quad \tilde{T}=\tilde{T}_w,\quad \tilde{C}=\tilde{C}_w\quad at\quad \tilde{y}=0 \tag{5}$$

$$\tilde{u}\to 0,\quad \tilde{T}\to\tilde{T}_\infty,\quad \tilde{C}\to\tilde{C}_\infty\quad as\quad \tilde{y}\to\infty \tag{6}$$

The equation of continuity(1) yields that, $\tilde{v}$ is either a constant or some function of time and radiative heat flux is assumed from Sparrow and Cess [23]. Where *x. y* are the dimensional distance along and perpendicular to the plate, respectively. *u* and *v* are the velocity components in the x, y directions respectively, *g* is the gravitational acceleration, β_T and β_C are the thermal and concentration expansion coefficients respectively, *K* is the permeability parameter, B_0 is the magnetic induction, *T* is the thermal temperature inside the thermal boundary layer and *C* is the corresponding concentration, σ is the electric conductivity, Cp is the specific heat at constant pressure, k_T is the thermal diffusion ratio D is the diffusion coefficient, *t* is the time, q_r is the heat flux, ρ is the fluid density.

The non-dimensional quantities are

$$U=\frac{\tilde{u}}{\xi_0},y=\frac{\tilde{y}\xi_0}{\upsilon},n=\frac{4\upsilon\tilde{n}}{\xi_0^2},L_1=\frac{2-M_x}{M_x},h=\frac{L_1\xi_0}{\upsilon},Kc=\frac{\tilde{K}_c\upsilon}{\xi_0^2},S_0=\frac{D_1\left[\tilde{T}_w-\tilde{T}_\infty\right]}{\upsilon\left[\tilde{C}_w-\tilde{C}_\infty\right]},$$

$$R=\frac{4\upsilon\tilde{I}}{\rho Cp\xi_0^2},M=\frac{\sigma B_0^2\upsilon}{\rho\xi_0^2},Gc=\frac{g\beta_C\upsilon\left[\tilde{C}_w-\tilde{C}_\infty\right]}{\xi_0^3},Gr=\frac{g\beta_T\upsilon\left[\tilde{T}_w-\tilde{T}_\infty\right]}{\xi_0^3}, \tag{7}$$

$$K=\frac{\tilde{K}_0\xi_0^2}{\upsilon^2},t=\frac{\xi_0^2\tilde{t}}{4\upsilon},M_1=-\left(M-\left(\frac{n}{4}\right)\right)$$

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Using above quantities in equations (1)-(6), we can obtain

$$\frac{1}{4}\frac{\partial U}{\partial t}-\left(1+Ee^{-nt}\right)\frac{\partial U}{\partial y}-GrT-GcC-\frac{\partial^2 U}{\partial y^2}+M_1U=0 \tag{8}$$

$$\frac{1}{4}\frac{\partial T}{\partial t}-\left(1+Ee^{-nt}\right)\frac{\partial T}{\partial y}-\frac{1}{\Pr}\frac{\partial^2 T}{\partial y^2}+RT=0 \tag{9}$$

$$\frac{1}{4}\frac{\partial C}{\partial t}-\left(1+Ee^{-nt}\right)\frac{\partial C}{\partial y}-\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}+KcC-S_0\frac{\partial^2 T}{\partial y^2}=0 \tag{10}$$

And

$$U=h\left(\frac{\partial U}{\partial y}\right),\quad T=1,\quad C=1\quad at\quad y=0 \tag{11}$$

$$U\to 0,\quad T\to 0,\quad C\to 0\quad as\quad y\to\infty \tag{12}$$

III. SOLUTION OF THE PROBLEM

The set of partial differential equations (8) – (10) cannot be solved in closed form. However, they can be solved analytically after reducing them into a set of ordinary differential equations by taking the expressions for velocity U(y), temperature T(y) and concentration C(y) in dimensionless form as follows:

$$U(y,t)=f_0+Ee^{-nt}f_1 \tag{13}$$

$$T(y,t)=g_0+Ee^{-nt}g_1 \tag{14}$$

$$C(y,t)=h_0+Ee^{-nt}h_1 \tag{15}$$

Substituting (13) – (15) in (8) – (10) and equating the coefficients of zeroth order and equating the coefficients of the first order, neglecting the higher order of and simplifying we obtain the following set of equations:

$$f_0''+f_0'-Mf_0+Gch_0+Grg_0=0 \tag{16}$$

$$f_1''+f_1'-M_1f_1+f_0'+Grg_1+Gch_1=0 \tag{17}$$

$$g_0''+\Pr g_0'-R\Pr g_0=0 \tag{18}$$

$$g_1''+\Pr g_1'+\left[\left(\frac{n}{4}\right)-R\right]\Pr g_1+g_0'\Pr=0 \tag{19}$$

$$h_0''+Sch_0'-KcSch_0+ScS_0g_0''=0 \tag{20}$$

$$h_1''+Sch_1'+\left[\left(\frac{n}{4}\right)-Kc\right]Sch_1+Sch_0'+ScS_0g_1''=0 \tag{21}$$

The final solutions of velocity, temperature and concentration are

$$\begin{aligned}U(y,t)&=f_0+Ee^{-nt}f_1\\&=\left[H_9e^{-m_5y}-H_7e^{-m_1y}-H_8e^{-m_3y}\right]+\\&\quad Ee^{-nt}\left[H_{15}e^{-m_6y}-H_{10}e^{-m_1y}-H_{11}e^{-m_2y}-H_{12}e^{-m_3y}-H_{13}e^{-m_4y}+H_{14}e^{-m_5y}\right]\end{aligned} \tag{22}$$

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$$T(y,t) = g_0 + Ee^{-nt} g_1 = \left[e^{-m_1 y}\right] + Ee^{-nt}\left[H_1\left(e^{-m_1 y} - e^{-m_2 y}\right)\right] \quad (23)$$

$$C(y,t) = h_0 + Ee^{-nt} h_1 = \left[(1+H_2)e^{-m_3 y} - H_2 e^{-m_1 y}\right] + Ee^{-nt}\left[H_6 e^{-m_4 y} - H_3 e^{-m_1 y} + H_4 e^{-m_2 y} + H_5 e^{-m_3 y}\right] \quad (24)$$

Where

$$m_1 = \frac{\Pr + \sqrt{(\Pr)^2 + 4R\Pr}}{2} \; ; \; m_2 = \frac{\Pr + \sqrt{(\Pr)^2 - 4\Pr\left[\left(\frac{n}{4}\right) - R\right]}}{2} \; ; \; H_1 = \frac{\Pr m_1}{m_1^2 - \Pr m_1 + \Pr\left[\left(\frac{n}{4}\right) - R\right]} \; ;$$

$$m_3 = \frac{Sc + \sqrt{(Sc)^2 + 4ScKc}}{2} \; ; \; H_2 = \frac{ScS_0 m_1^2}{m_1^2 - Scm_1 - scKc} \; ; \; m_4 = \frac{Sc + \sqrt{(Sc)^2 - 4Sc\left[\left(\frac{n}{4}\right) - Kc\right]}}{2} \; ;$$

$$H_3 = \frac{\left[ScH_2 m_1 + ScS_0 H_1 m_1^2\right]}{m_1^2 - Scm_1 + \left[\left(\frac{n}{4}\right) - Kc\right]Sc} \; ; \quad H_4 = \frac{ScS_0 H_1 m_2^2}{m_2^2 - Scm_2 + \left[\left(\frac{n}{4}\right) - Kc\right]Sc} \; ;$$

$$H_5 = \frac{Sc(1+H_2)m_3}{m_3^2 - Scm_3 + \left[\left(\frac{n}{4}\right) - Kc\right]Sc} \; ; \; H_6 = H_3 - H_4 - H_5 \; ; \; m_5 = \frac{1+\sqrt{1+4M}}{2} \; ; \; H_7 = \frac{(Gr + H_2)}{m_1^2 - m_1 - M} \; ;$$

$$H_8 = \frac{Gc(1+H_2)}{m_3^2 - m_3 - M} \; ; \quad H_9 = \frac{(hm_1+1)H_7 + (hm_3+1)H_8}{(hm_5+1)} \; ; \quad m_6 = \frac{1+\sqrt{1-4M_1}}{2} \; ;$$

$$H_{10} = \frac{m_1 H_7 + GrH_1 - GcH_3}{m_1^2 - m_1 - M_1} \; ; \; H_{11} = \frac{GrH_1 - GcH_4}{m_2^2 - m_2 - M_1} \; ; \; H_{12} = \frac{m_3 H_8 + GcH_5}{m_3^2 - m_3 + M_1} \; ; \; H_{13} = \frac{GcH_6}{m_4^2 - m_4 + M_1} \; ;$$

$$H_{14} = \frac{m_5 H_9}{m_5^2 - m_5 + M_1} \; ;$$

$$H_{15} = \frac{(hm_1+1)H_{10} - (hm_2+1)H_{11} + (hm_3+1)H_{12} + (hm_4+1)H_{13} - (hm_5+1)H_{14}}{(hm_6+1)} \; ;$$

IV. RESULTS AND DISCUSSION

The governing partial differential equations of flow and heat transfer are transformed into a system of non-linear ordinary differential equations by using the 2-term perturbation technique. To draw graphs we used these values: h=1, K=1, Gc=5, Gr=5, M=2, S_0=1, Kc=1, Pr=0.71. In this paper we studied two cases on velocity profiles, flow of cooled plate Gr > 0 and flow of heated plate Gr < 0. Figs. 1-18 are sketched to see the variations of Soret parameter(So), Schmidt number(Sc), radiation parameter(R), Prandtl number(Pr), permeability parameter(K), slip parameter(h), chemical reaction parameter(Kc), Grashof number(Gr), modified Grashof Number(Gc) and perturbation parameter(E) on concentration, temperature and velocity distributions respectively. Figure 1 depicts the effect of magnetic field parameter on the fluid velocity and we observed that an increase in magnetic field parameter the velocity decreases in case of cooled of the plate, it is due to the presence of magnetic field normal to the flow in an electrically conducting fluid introduces a Lorentz force which acts against to the flow while it increases in case of heated plate. Figure 2 shows the effect of soret parameter on velocity. The velocity increases as So increases, as the plate is cooling. In the case of heating of the plate, it is observed that So decreases the velocity. It is observed that an increase in R leads to an increase in the velocity when Gr > 0 and leads to an decrease in the velocity when Gr < 0 from Figure 3. Figure 4 reveals the influence of chemical reaction parameter Kc on the velocity profile. It is observed that the increase in chemical reaction parameter leads to fall in velocity with increasing values of chemical reaction parameter Kc in the case of cooling of the plate but increases in the case of heating of the plate. Figure 5 reveals the influence of thermal Grashof number Gr on the velocity distribution. It is observed that the increase in thermal Grashof number leads to fall in velocity in the both cases of cooled and heated plates. It is observed that an increase in Gc leads to an increase in the velocity when Gr > 0 and leads to an decrease in the velocity when Gr < 0 from Figure 6. The velocity profiles for different values of permeability parameter K are shown in Figure 7. From this it is seen that the velocity increases with decreasing values of permeability parameter in the case of cooled plate but increases in the case of heated plate. From the figure 8, we seen that an increase h leads to a rise in the velocity with Gr > 0 and leads to decrease in the velocity with Gr < 0. Further, it is observed that the velocity increases near the plate. It is observed that an increase in E leads to an increase in the velocity when Gr > 0 and leads to an decrease in the velocity when Gr < 0 from Figure 9. The velocity profiles for different values of Sc is shown in Figure 10. From this it is seen that the velocity increases with decreasing values of Sc in the case of cooled plate but increases in the case of heated plate.The velocity profiles for different values of Pr is shown in Figure 11. From this it is seen that the velocity increases with decreasing values of Pr in the case of cooled plate but increases in the case of heated plate. Physically, Prandtl number is the ratio of kinematic viscidness to thermal diffusivity and is a dimensionless quantity. The Pr is increased when the value of momentum diffusivity is greater than the thermal diffusivity. Thus, heat transmission at the surface grows with the increase in Pr values while mass transmission is concentrated as the Prandtl number grows. The impact of Pr is given in the Figure 12. It clearly shows that temperature reduces with large Pr number. The logic behind this is that, with the large value of Pr, thermal layer of the boundary reduces. The consequence is more noticeable for slight Prandtl quantity as the width of the thermal boundary layer is relatively greater. Impacts of thermal radiation parameter R on temperature are presented in Figure 13. It is found that as the values of R increases, T(y) decreases. This means that significant part of the fluid inside the boundary layer has low temperature and consequently the thermal diffusivity becomes low with the thin thermal boundary layer. Figure 14 shows concentration distribution profiles for different values of Kc. It can be noted from the figure that the concentration of the fluid decreases as the parameter increase. The non-dimensional concentration profile reduces with dissimilar measures of parameter Sc shown in Figure 15. It is obvious that a flow part increases in the horizontal direction by giving rise in the Schmidt number. It is trivial that, with a rise in the Schmidt number, the flow part increases in the x-direction. The logic behind is that the Schmidt parameter is the ratio of momentum and concentration diffusivities. Fig. 16 illustrates the effect of radiation parameter on concentration profiles. The profiles increases as the parameter increases. Concentration profile exhibits the inverse relation with Pr number shown in Figure 17. It means that thinning of the thermal boundary layer progresses the flow in the x-direction, which is reflected in the graph. The thermophoresis parameter So rises, in contrast with concentration profile. This phenomenon is described by Figure 18.

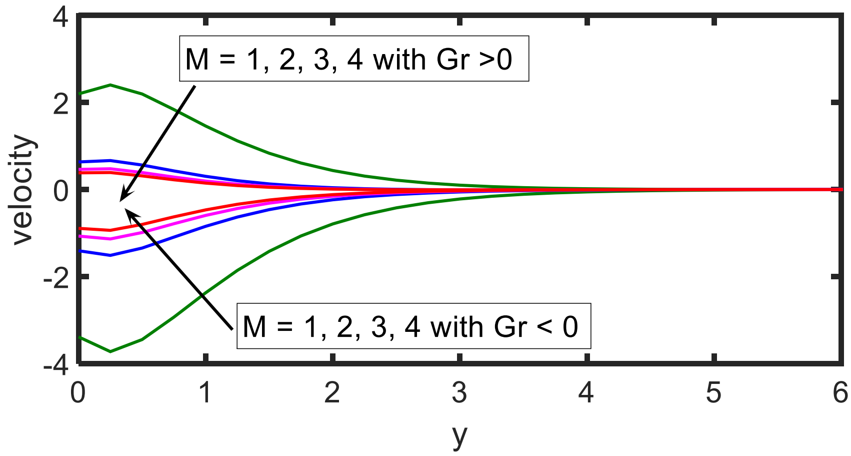

Fig. 1. Behavior of M on U(y)

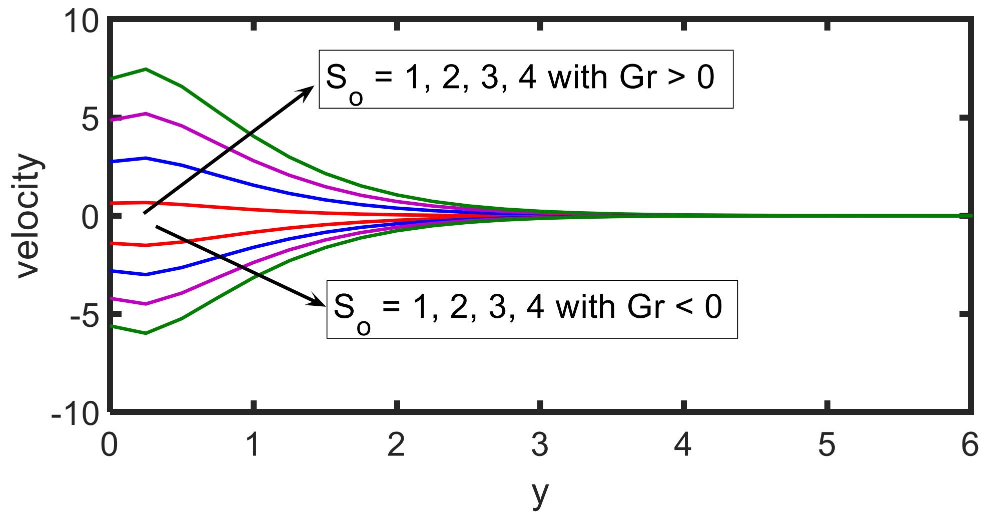

Fig. 2. Behavior of So on U(y)

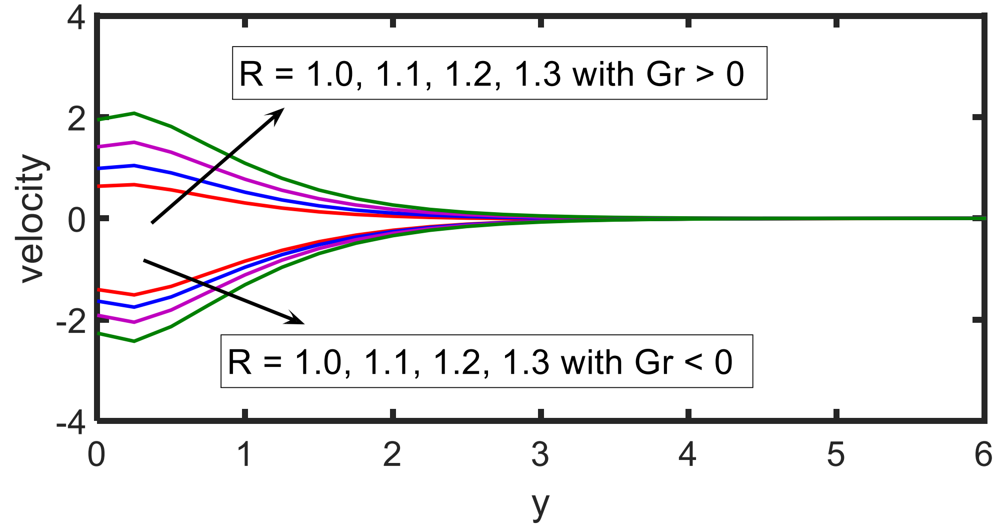

Fig. 3. Behavior of R on U(y)

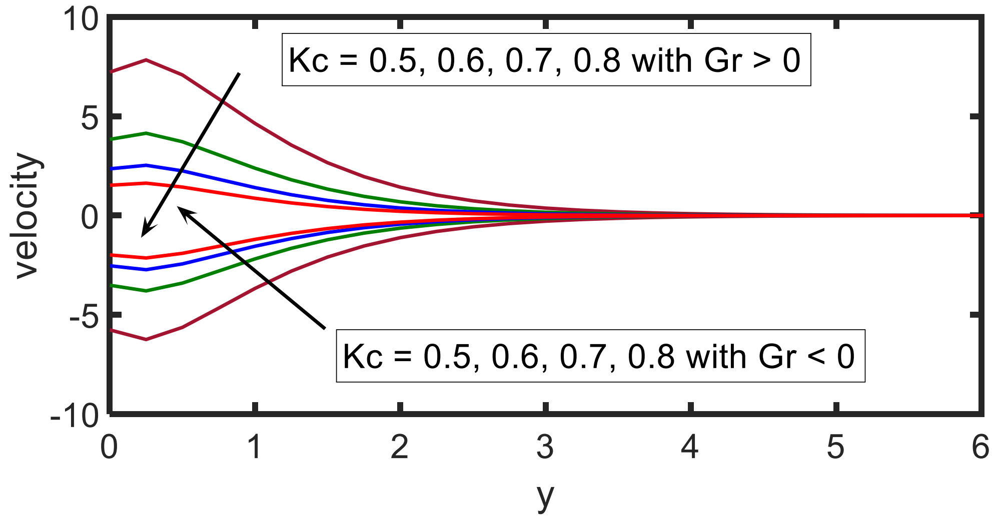

Fig. 4. Behavior of Kc on U(y)

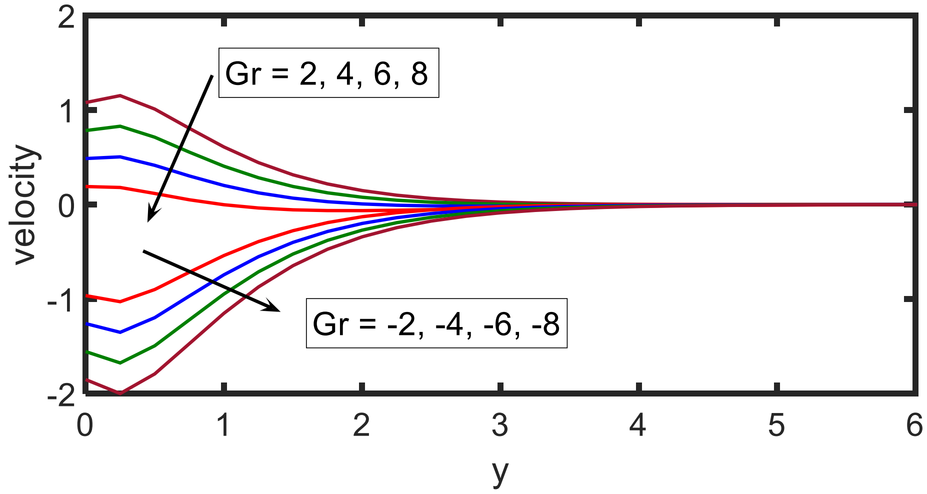

Fig. 5. Behavior of Gr on U(y)

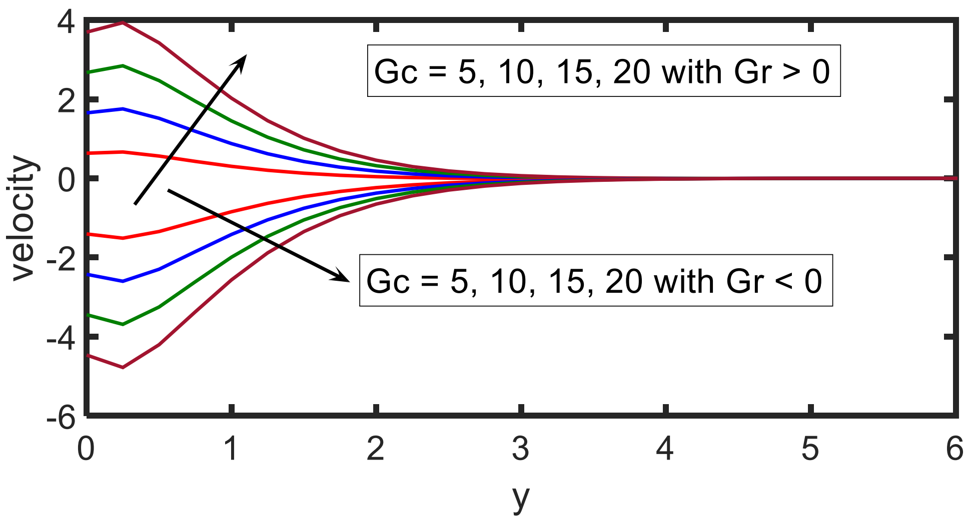

Fig. 6. Behavior of Gc on U(y)

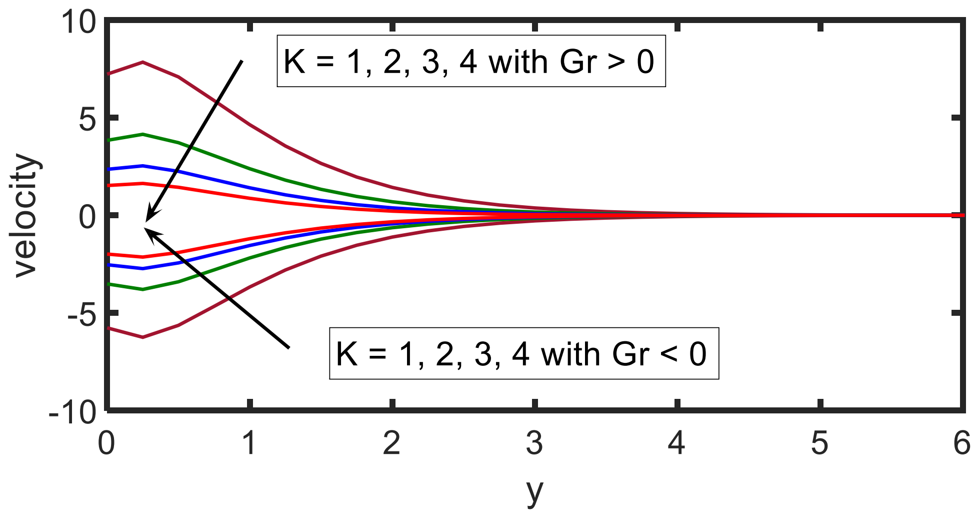

Fig. 7. Behavior of K on U(y)

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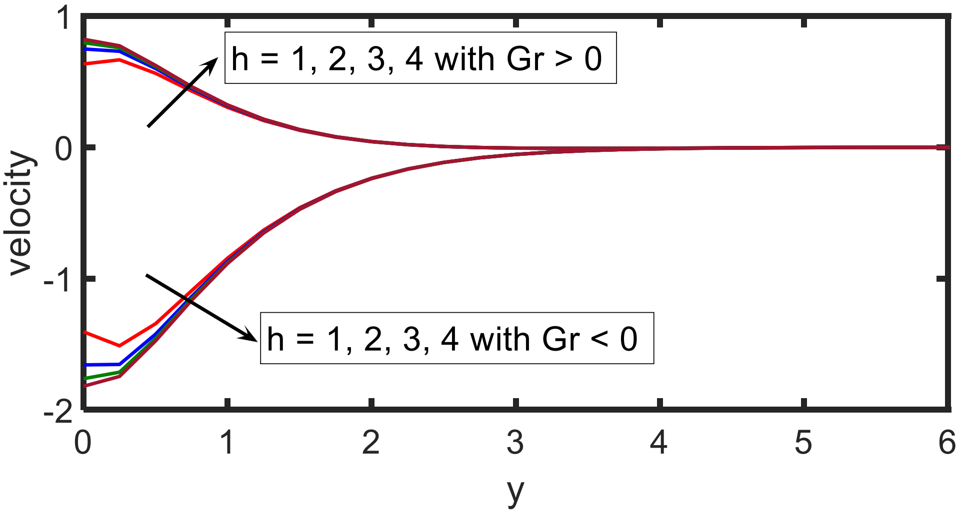

Fig. 8. Behavior of h on U(y)

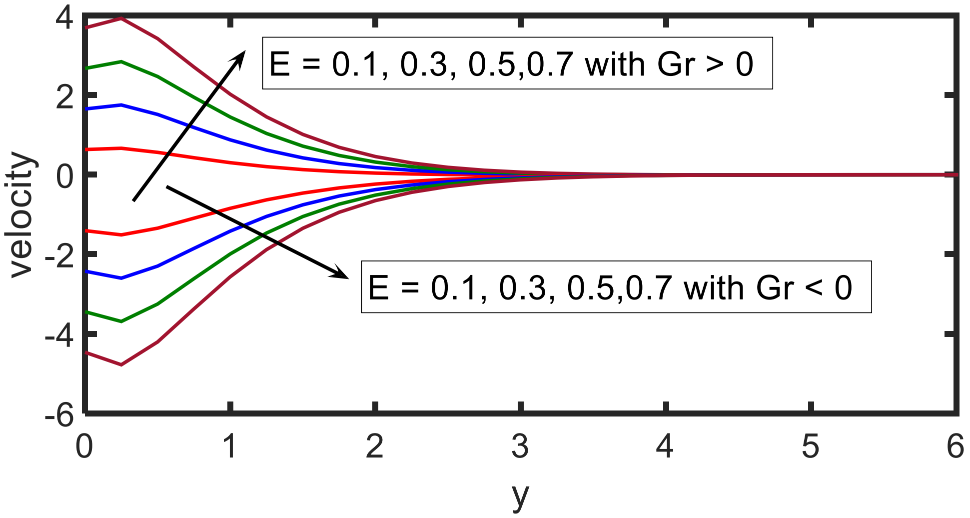

Fig. 9. Behavior of E on U(y)

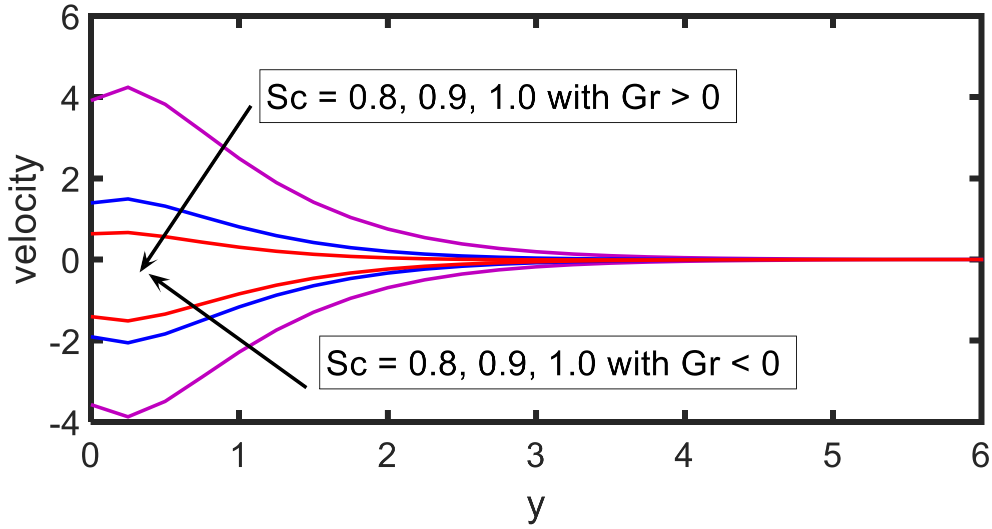

Fig. 10. Behavior of Sc on U(y)

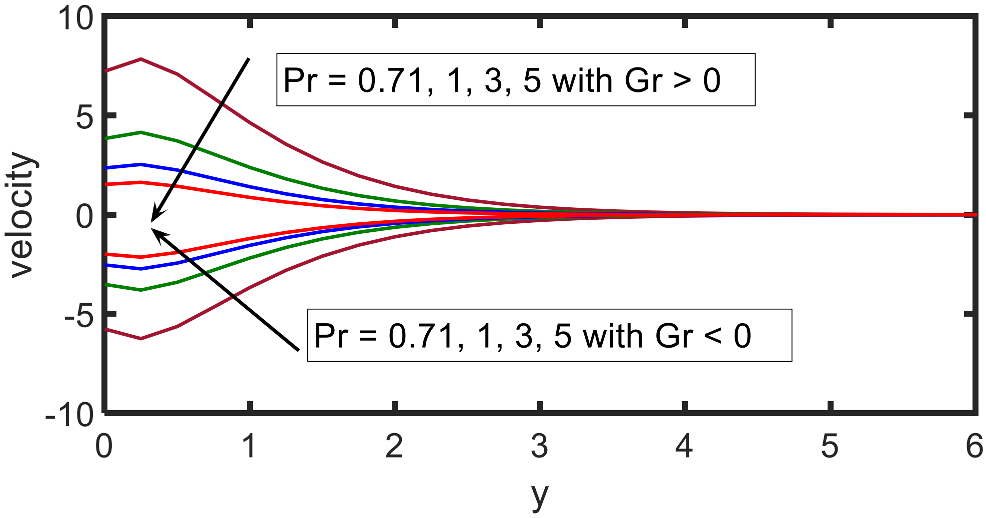

Fig. 11. Behavior of Pr on U(y)

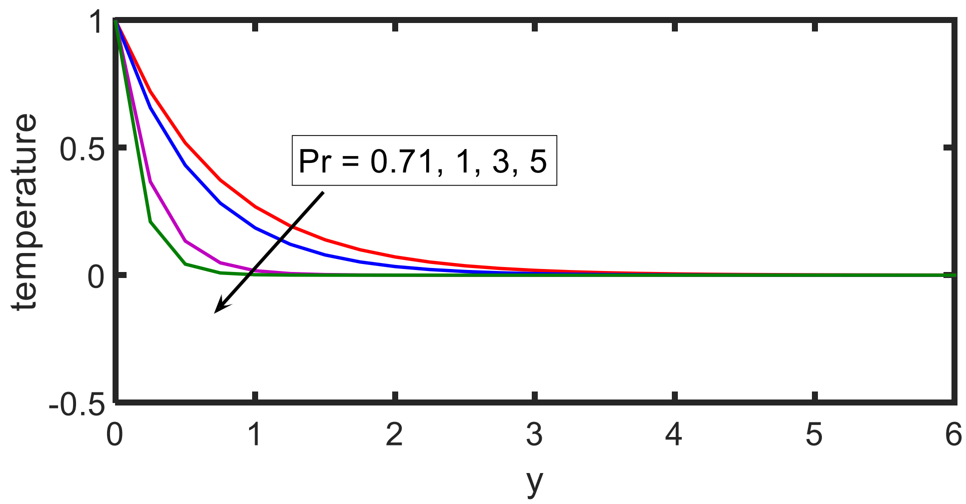

Fig. 12. Behavior of Pr on T(y)

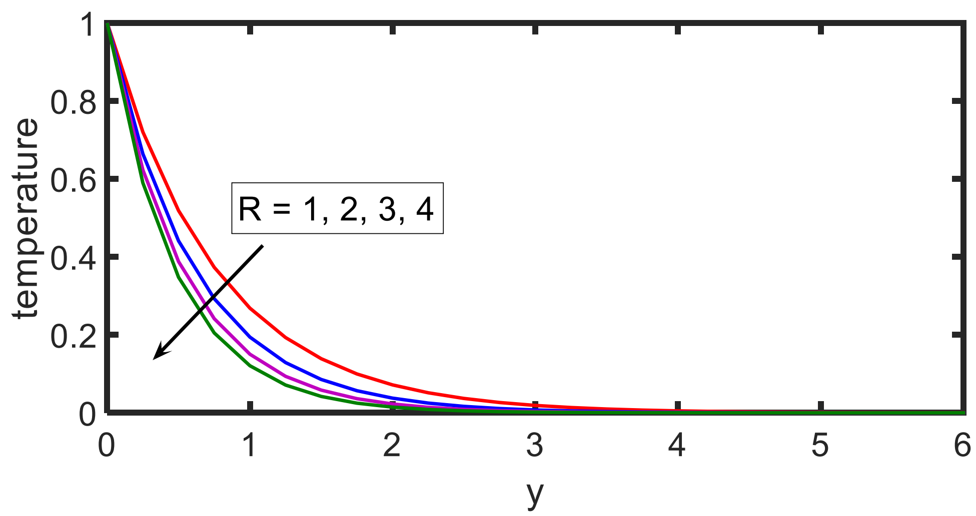

Fig. 13. Behavior of R on T(y)

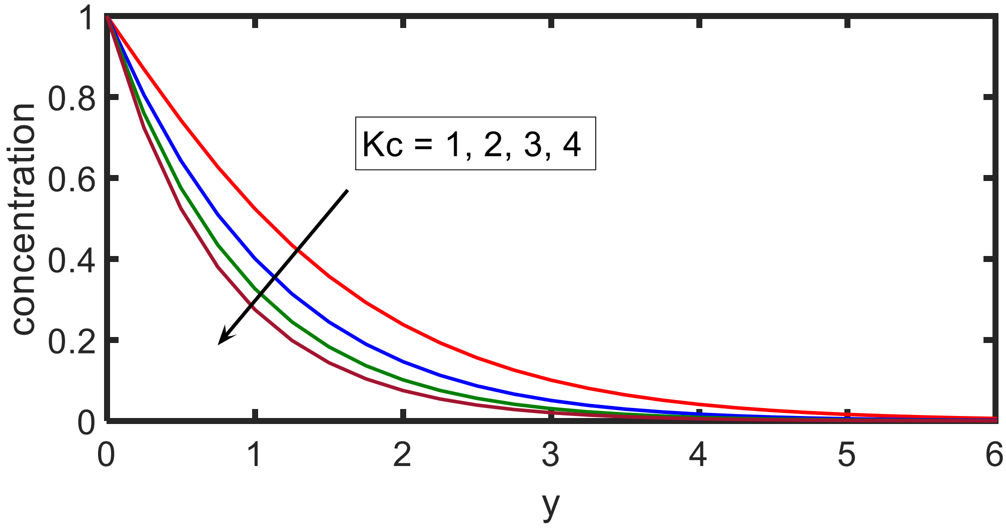

Fig. 14. Behavior of Kc on C(y)

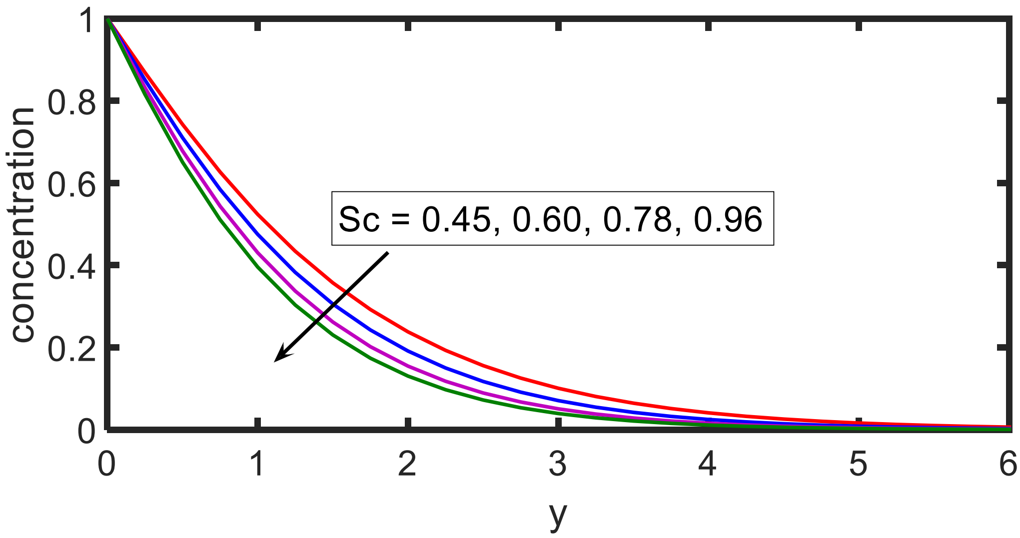

Fig. 15. Behavior of Sc on C(y)

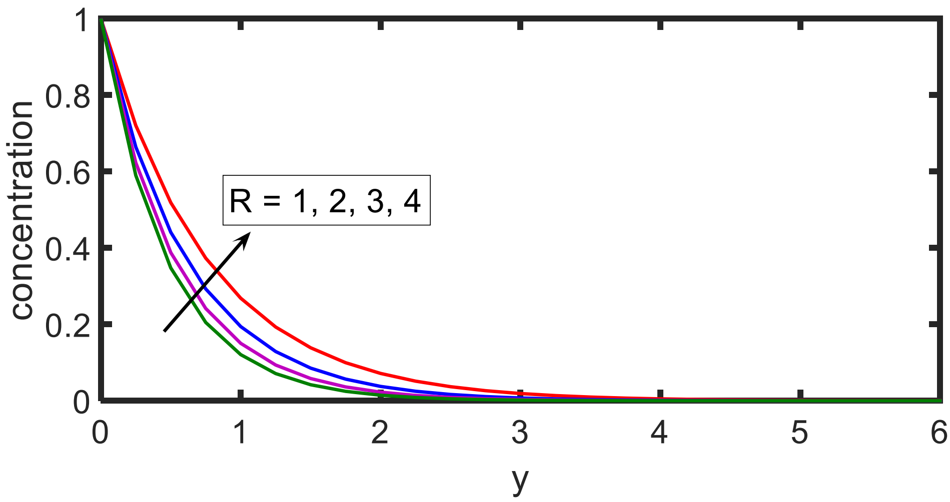

Fig. 16. Behavior of R on C(y)

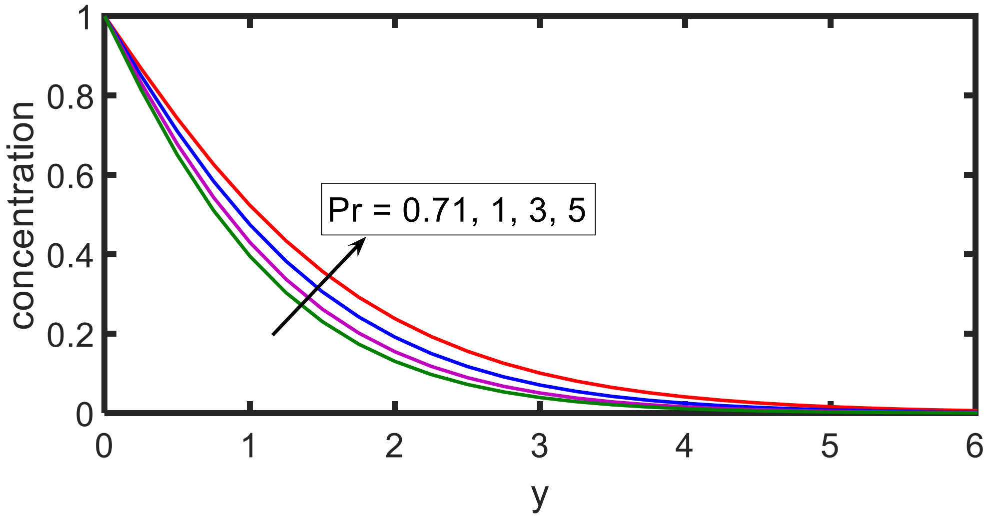

Fig. 17. Behavior of Pr on C(y)

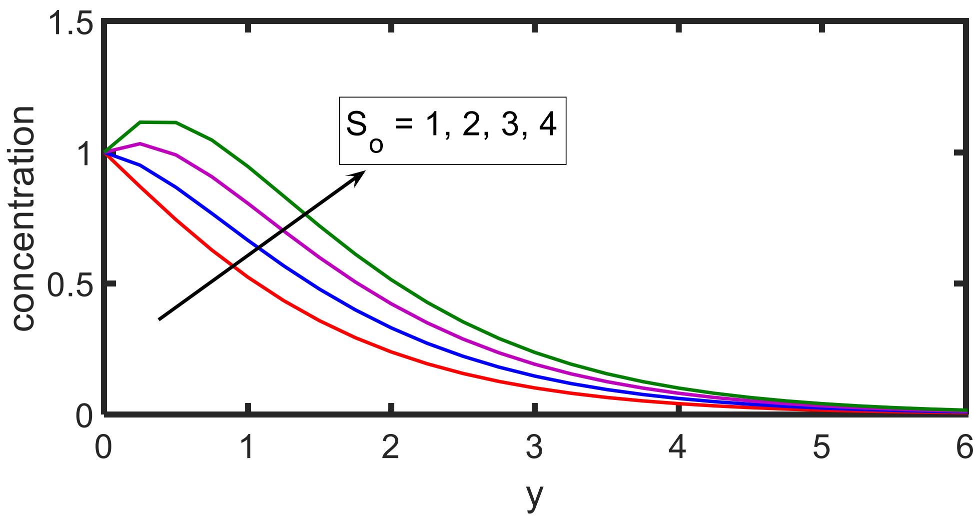

Fig. 18. Behavior of So on C(y)

V. CONCLUSIONS

In this paper a mathematical model has been presented for the influence of radiation and Thermophoresis on MHD free convective flow past a vertical porous plate in a porous medium under the influence of Chemical reaction effects. Suing the similarity transformation a set of ordinary differential equations has been derived for the conservation of mass, momentum and species diffusion in the boundary layer. These nonlinear, coupled differential equations solved under valid boundary conditions using perturbation technique. The conclusions of the study are as follows:

1. An increase in magnetic field parameter the velocity decreases in case of cooled plate, while it increases in case of heated plate.

2. It is seen that the velocity increases with decreasing values of permeability parameter in the case of cooled plate but increases in the case of heated plate.

3. Temperature reduces with large Pr number.

4. It is found that as the values of R increases, T(y) decreases.

5. It can be noted from the figure that the concentration of the fluid decreases as the parameter increase.

6. It is obvious that a flow part increases in the horizontal direction by giving rise in the Schmidt number.

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