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THERMAL DIFFUSION AND RADIATION EFFECTS ON MHD MIXED CONVECTION FLOW IN A CHANNEL WITH POROUS MEDIUM

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ABSTRACT

The present work analyzes the effects of Soret and thermal radiation on MHD flow through two infinite vertical porous plates with constant heat source or sink. The dimensionless governing equations for this investigation are solved analytically using regular perturbation method. The expressions for velocity, temperature, concentration as well as skin friction, Nusselt number and Sherwood number are solved with appropriate boundary conditions. The effects of different parameters entering in to the problem are discussed analytically and presented graphically. This model finds applications in studying heat-exchanger technology, geothermal energy storage and all those processes which are greatly exaggerated by heat-enhancement concepts.

Key words: *Thermal diffusion; Thermal radiation; Porous medium; MHD; Heat source.*

1. INTRODUCTION

Convective flows in porous medium have received much attention in recent years because of its importance in engineering applications such as geothermal systems, solid matrix heat exchangers, oil extraction and store of nuclear waste materials. Convection in porous media can also be applied to underground coal gasification, ground water hydrology, iron blast furnaces, wall cooled catalytic reactors, solar power collectors, energy efficient drying processes, cooling of nuclear fuel in shipping flasks, cooling of electronic equipments. In view of these applications many research's [1][2][3] studied the effect of porous medium on various geometries. Tripathi [4] introduced the concept of transient peristaltic heat flow through a finite porous channel. Ravikumar *et al.* [5] studied the chemical reaction effects on MHD flow through porous medium bounded by two vertical plates. Effects of chemical reaction on free convective flow of a polar fluid through porous medium in the presence of internal heat generation has examined by Patil and Kulkarni [6]. Hussain *et al.* [7] analyzed the oscillatory flows of second grade fluid in a porous space. The peristaltic transport of a Newtonian/Non -Newtonian fluid in channels with heat transfer and porous medium was investigated by [8][9].

Megnetohydrodynamic convection plays a significant role in various industrial applications. In a border sense, MHD has applications in three different subject areas, such as astrophysical, geophysical and engineering problems. Examples include MHD generators, MHD accelerators, high temperature plasmas, cooling of nuclear reactors, power generator systems and geothermal energy extractions. By the application of magnetic field, hydro magnetic techniques are used for the purification of molten metals from non-metallic inclusions. It is also very much useful to polymer technology and metallurgy. Megnetohydrodynamics plays an important role in agriculture engineering and petroleum industries. The study of MHD flow of an electrically conducting fluid is of considerable interest in modern metallurgical and metal-Working processes. This type of problems is very much useful to polymer technology and metallurgy. Several scholars [10][11][12][13] have shown their interest in MHD flows because of varied applications.

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Study of megnetohydrodynamic (MHD) heat transfer field can be divided into two classes: in the first class, the electromagnetic fields are used to control the heat transfer as in the convection flows and aerodynamic heating; while in the second class, the heating is produced by electromagnetic fields as MHD generators, pumps, etc. Coming under the present problem is the first class. The MHD phenomenon is characterized by a mutual interaction between the fluid velocity field (hydrodynamic boundary layer) and the electromagnetic field. Satisfying the Faraday laws, the fluid motion affects the magnetic field and the magnetic field affects the fluid motion. Hence the study of interaction of geomagnetic field with the fluid in geothermal region is of great interest, thus leading to the study of MHD convection flow through a porous medium. Ibrahim *et al.* [14] are studied the effect of chemical reaction and radiation on unsteady MHD free convection flow past a semi infinite vertical permeable moving plate with heat source and suction.MHD oscillatory flow in an asymmetric wavy channel has analyzed by Muthuraj and Srinivas [15]. Chaudhary and Arpita [16] have studied combined heat and mass transfer effects on MHD free convection flow past an oscillating plate embedded in porous medium.

Considerable interest has recently been shown in radiation interaction with free convection for heat transfer in fluid. This is due to the significant role of thermal radiation in the surface heat transfer when convection heat transfer is small particularly in free convection problems involving absorbing-emitting fluids. In view of these applications several authors [17][18][19][20][21] have studied and reported the significance of thermal radiation. The free convection processes involving the combined mechanism of heat and mass transfer are encountered in many natural processes, in many industrial applications and in many chemical processing systems. In recent years, the study of free convective mass transfer flow has become the object of extensive research as the effects of heat transfer along with the mass transfer effects are dominant features in many engineering applications such as rocket nozzles, cooling of nuclear reactors, aircrafts and their atmospheric re-entry, chemical devices and process equipments. Ferdows *et al.* [22] however, considered a variable suction in a boundary layer flow at a vertical plate with thermal radiation with convection. Samad and Rahman [23] investigated the thermal radiation interaction on an absorbing emitting fluid past a vertical porous plate immersed in a porous medium. Cortell [24] studied the effects of viscous dissipation and radiation on thermal boundary layer over a non-linearly stretching sheet. Very recently, Raju *et al.*[25] investigated heat transfer in MHD free convective, dissipative boundary layer flow past a porous vertical surface in the with chemical reaction and constant suction

When heat and mass transfer occur simultaneously in a moving fluid, the relations between the fluxes and the driven potential are important. It has been found that the energy flux can be generated not only by temperatures gradients but also by composition gradient. The energy caused by a composition gradient is called the Dufour or the diffusion-thermo effect. The Dufour effect is neglected in this study because it is of a smaller order of magnitude than the volumetric heat generation effect which exerts a stronger effect on the energy flux generation. The mass fluxes can also be created by the temperature gradients and this is called the Soret or thermal diffusion effect. In all the above studies the effect of thermal diffusion was ignored. This assumption is true when the concentration level is very low. The thermal diffusion effect (known as Soret effect) is applied for isotope separation and in mixtures between gases with very high molecular weight (H_2, He) and medium molecular weight (N_2, air) where the Soret effect is found to be of a magnitude such that it cannot be neglected.

Motivated by the above reference work and the numerous possible industrial applications of the problem, it is of paramount interest to investigate the effects of Soret and thermal radiation on MHD flow through two infinite vertical porous plates with constant heat source or sink. The dimensionless governing equations are solved analytically using perturbation technique. The effects of various governing parameters on the velocity, temperature, concentration, skin friction, rate of heat transfer and rate of mass transfer are shown in figures and analyzed in detail. We depict the mathematical model and argue the non dimensionalization of the governing equations in Section 2 and Section 4 contains results and discussions. Finally, Section 5 highlights the important conclusions derived from the present study.

2. MATHEMATICAL ANALYSIS

We consider the flow of an incompressible viscous electrically conducting fluid through a porous medium bounded by two infinite vertical porous plates separated by a distance h in presence of transverse magnetic field by making the following assumptions

1. All the fluid properties except the density in the buoyancy force term are constants.
2. The ohmic dissipation of the energy equation is negligible.
3. The magnetic Reynolds number is so small that the induced magnetic field can be neglected.

We introduce a coordinate system $(\bar{x}, \bar{y}, \bar{z})$ with $x-$axis vertically upwards along a plate. $y-$ axis perpendicular to it directed in to the fluid region and $z-$ axis along the width of the either plates. Let $\bar{q} = \bar{u}\hat{i} + \bar{v}\hat{j}$ be the fluid velocity at the points $(\bar{x}, \bar{y}, \bar{z})$ and $\bar{B} = B_0\hat{j}$ be the applied magnetic field, $\hat{i}$ and $\hat{j}$ be the unit vectors along $x-$axis and $y-$axis respectively. Since the plates are infinite in length therefore all the physical quantities except the pressure P are independent of $\bar{x}$.

The equations governing the flow, heat and mass transfers are given by

$$\frac{d\bar{v}}{d\bar{y}} = 0 \tag{1}$$

$$-v_0 \frac{d\bar{u}}{d\bar{y}} = \upsilon \frac{d^2\bar{u}}{d\bar{y}^2} + g\beta(\bar{T} - \bar{T}_s) + g\bar{\beta}(\bar{C} - \bar{C}_s) - \frac{\upsilon\bar{u}}{K} - \frac{\sigma B_0^2 \bar{u}}{\rho} \tag{2}$$

$$-v_0 \frac{d\bar{T}}{d\bar{y}} = \frac{\lambda}{\rho c_p}\frac{d^2\bar{T}}{d\bar{y}^2} + \frac{Q}{\rho c_p}(\bar{T} - \bar{T}_s) - \frac{1}{\rho c_p}\frac{dq_r}{d\bar{y}} \tag{3}$$

$$-\bar{v}_0 \frac{d\bar{C}}{d\bar{y}} = D_M \frac{d^2\bar{C}}{d\bar{y}^2} + D_T \frac{d^2\bar{T}}{d\bar{y}^2} \tag{4}$$

Where $\frac{dq_r}{d\bar{y}} = 4\alpha^2(\bar{T}_s - \bar{T})$

The boundary conditions for velocity, temperature and species concentration fields are given as follows

$$\begin{aligned} &\bar{u} = 0, \quad \bar{T} = \bar{T}_0, \quad \bar{C} = \bar{C}_0; \quad at \quad \bar{y} = 0 \\ &\bar{u} = 0, \quad \bar{T} = \bar{T}_1, \quad \bar{C} = \bar{C}_1; \quad at \quad \bar{y} = h \end{aligned} \tag{5}$$

We now introduce the non-dimensionless parameters as follows

$$\begin{aligned} &y = \frac{\bar{y}}{h},\ u = \frac{\bar{u}}{v_0},\ \theta = \frac{\bar{T} - \bar{T}_s}{\bar{T}_0 - \bar{T}_s},\ \phi = \frac{\bar{C} - \bar{C}_s}{\bar{C}_0 - \bar{C}_s},\ \Pr = \frac{\mu c_p}{\lambda}, \\ &\mathrm{Re} = \frac{v_0 h}{\upsilon},\ Sc = \frac{\upsilon}{D_M},\ Gr = \frac{hg\bar{\beta}(\bar{T}_0 - \bar{T}_s)}{v_0^2},\ Gm = \frac{hg\bar{\beta}(\bar{C}_0 - \bar{C}_s)}{v_0^2}, \\ &k = \frac{K}{h^2},\ M = \frac{\sigma B_0^2 h^2}{\rho\upsilon},\ H = \frac{h^2 Q}{\lambda},\ R = \frac{4\alpha^2 h^2}{\lambda},\ So = \frac{D_T(\bar{T}_0 - \bar{T}_s)}{\upsilon(\bar{C}_0 - \bar{C}_s)}, \\ &m = \frac{\bar{T}_1 - \bar{T}_s}{\bar{T}_0 - \bar{T}_s},\ n = \frac{\bar{C}_1 - \bar{C}_s}{\bar{C}_0 - \bar{C}_s} \end{aligned} \tag{6}$$

The dimensionless governing equations together with the appropriate boundary conditions can be written as

$$-\frac{du}{dy} = \frac{1}{\mathrm{Re}}\frac{d^2u}{dy^2} + G_r\theta + G_m\phi - \frac{u}{\mathrm{Re}\,k} - \frac{Mu}{\mathrm{Re}} \tag{7}$$

$$-\frac{d\theta}{dy} = \frac{1}{\Pr\mathrm{Re}}\frac{d^2\theta}{dy^2} + (H + R)\theta \tag{8}$$

$$-\frac{d\phi}{dy} = \frac{1}{Sc\,\mathrm{Re}}\frac{d^2\phi}{dy^2} + \frac{So}{\mathrm{Re}}\frac{d^2\theta}{dy^2} \tag{9}$$

The dimensionless boundary conditions can be reduced to

$$\begin{aligned} &u = 0, \quad \theta = 1, \quad \phi = 1 \quad at \quad y = 0 \\ &u = 0, \quad \theta = m, \quad \phi = n \quad at \quad y = 1 \end{aligned} \tag{10}$$

SOLUTION OF THE PROBLEM

$$\begin{aligned} &u = u_0(y) + \varepsilon u_1(y) + \varepsilon^2 u_2(y) + \ldots\ldots\ldots\ldots. \\ &\theta = \theta_0(y) + \varepsilon\theta_1(y) + \varepsilon^2\theta_2(y) + \ldots\ldots\ldots\ldots. \\ &\phi = \phi_0(y) + \varepsilon\phi_1(y) + \varepsilon^2\phi_2(y) + \ldots\ldots\ldots\ldots. \end{aligned} \tag{11}$$

Substituting from the equations (11) in (7) - (9), and by equating the coefficients of similar powers of ε and neglecting the higher powers of ε the following equations for $u_0\ ,u_1\ ,\theta_0,\theta_1,\phi_0,\phi_1$ are obtained.

$$u_0'' + \mathrm{Re}\,u_0' - Au_0 = -Gr\,\mathrm{Re}\,\theta_0 - Gm\,\mathrm{Re}\,\phi_0 \tag{12}$$

$$u_1'' + \mathrm{Re}\,u_1' - Au_1 = -Gr\,\mathrm{Re}\,\theta_1 - Gm\,\mathrm{Re}\,\phi_1 \tag{13}$$

$$\theta_0'' + \Pr\mathrm{Re}\,\theta_0' + (H+R)\theta_0 = 0 \tag{14}$$

$$\theta_1'' + \Pr\mathrm{Re}\,\theta_1' + (H+R)\theta_1 = 0 \tag{15}$$

$$\phi_0'' + Sc\,\mathrm{Re}\,\phi_0' = -ScSo\theta_0'' \tag{16}$$

$$\phi_1'' + Sc\,\mathrm{Re}\,\phi_1' = -ScSo\theta_1'' \tag{17}$$

Where $A = \dfrac{1}{k} + M$

The boundary conditions (10) reduced to

$$\begin{aligned} &u_0 = 0,\ \ \theta_0 = 1,\ \ \varphi_0 = 1,\ \ u_1 = 0,\ \ \theta_1 = 0,\ \ \varphi_1 = 0\,; \quad at \quad y = 0 \\ &u_0 = 0,\ \ \theta_0 = m,\ \ \varphi_0 = n,\ \ u_1 = 0,\ \ \theta_1 = 0,\ \ \varphi_1 = 0\,; \quad at \quad y = 1 \end{aligned} \tag{18}$$

The solutions of the equations (12) to (17) subject to boundary conditions (18) are as follows

$$u(y) = A_9 e^{\lambda_1 y} + A_{10} e^{\lambda_2 y} - R_8 e^{\lambda_3 y} - R_9 e^{\lambda_4 y} - R_{10} e^{-B_2 y} + R_{11} e^{\lambda_3 y} + R_{12} e^{\lambda_4 y} + R_{13} \tag{19}$$

$$\theta(y) = A_1 e^{\lambda_3 y} + A_2 e^{\lambda_4 y} \tag{20}$$

$$\phi(y) = A_5 + A_6 e^{-B_2 y} - R_6 e^{\lambda_3 y} - R_7 e^{\lambda_4 y} \tag{21}$$

Where the constants λ_1, λ_2.......... are given in Appendix.

SKIN-FRICTION

The skin friction in the non-dimensional form on the plate $y = 0$ is given by

$$\tau = \left[\frac{du}{dy}\right]_{\substack{y=0\\ y=1}}$$

NUSSELT NUMBER

The rate of heat transfer in terms of Nusselt number at the plate $y = 0$ is given by

$$Nu = -\left[\frac{d\theta}{dy}\right]_{\substack{y=0\\ y=1}}$$

SHERWOOD NUMBER

Knowing the concentration field, the rate of species concentration co-efficient in terms of the Sherwood number at the plate is given by

$$Sh = -\left[\frac{d\phi}{dy}\right]_{\substack{y=0\\ y=1}}$$

APPENDIX

$$\lambda_1 = \frac{-\mathrm{Re} + \sqrt{\mathrm{Re}^2 + 4A}}{2}, \quad \lambda_2 = \frac{-\mathrm{Re} - \sqrt{\mathrm{Re}^2 + 4A}}{2},$$

$$\lambda_3 = \frac{-\Pr\mathrm{Re} + \sqrt{(\Pr\mathrm{Re})^2 - 4(H+R)}}{2}, \quad \lambda_4 = \frac{-\Pr\mathrm{Re} - \sqrt{(\Pr\mathrm{Re})^2 - 4(H+R)}}{2},$$

$$R_6 = \frac{ScSoA_1\lambda_3^{\,2}}{\lambda_3^{\,2} + Sc\,\mathrm{Re}\,\lambda_3}, \quad R_7 = \frac{ScSoA_2\lambda_4^{\,2}}{\lambda_4^{\,2} + Sc\,\mathrm{Re}\,\lambda_4}, \quad R_8 = \frac{Gr\,\mathrm{Re}\,A_1}{\lambda_3^{\,2} + \mathrm{Re}\,\lambda_3 - A}, \quad R_9 = \frac{Gr\,\mathrm{Re}\,A_2}{\lambda_4^{\,2} + \mathrm{Re}\,\lambda_4 - A},$$

$$R_{10} = \frac{Gm\,\mathrm{Re}\,A_6}{B_2^{\,2} - B_2\,\mathrm{Re} - A},\; R_{11} = \frac{Gm\,\mathrm{Re}\,R_6}{\lambda_3^{\,2} + \mathrm{Re}\,\lambda_3 - A},\; R_{12} = \frac{Gm\,\mathrm{Re}\,R_7}{\lambda_4^{\,2} + \mathrm{Re}\,\lambda_4 - A},\; R_{13} = \frac{Gm\,\mathrm{Re}\,A_5}{A},$$

$$A = \frac{1}{k} + M,\quad B_2 = Sc\,\mathrm{Re},\quad A_1 = 1 - A_2,\quad A_2 = \frac{e^{\lambda_3} - m}{e^{\lambda_3} - e^{\lambda_4}},\quad A_5 = 1 - A_6 + R_6 + R_7,$$

$$A_6 = \frac{(1-n) - R_6\left(e^{\lambda_3} - 1\right) - R_7\left(e^{\lambda_4} - 1\right)}{\left(1 - e^{-B_2}\right)},\; A_9 = R_8 + R_9 + R_{10} - R_{11} - R_{12} - R_{13} - A_{10},$$

$$A_{10} = \frac{R_8\left(e^{\lambda_1} - e^{\lambda_3}\right) + R_9\left(e^{\lambda_1} - e^{\lambda_4}\right) + R_{10}\left(e^{\lambda_1} - e^{-B_2}\right) - R_{11}\left(e^{\lambda_1} - e^{\lambda_3}\right) - R_{12}\left(e^{\lambda_1} - e^{\lambda_4}\right) - R_{13}\left(e^{\lambda_1} - 1\right)}{\left(e^{\lambda_1} - e^{\lambda_2}\right)}$$

4. RESULTS AND DISCUSSION

The governing equations of the flow field were solved analytically using regular perturbation method. In order to get physical insight into the problem, the velocity, temperature, and concentration fields have been discussed by assigning numerical values of magnetic parameter M, Grashof number Gr, the modified Grashof number Gm, Prandtl number Pr, Schmidt number Sc, Soret number So, Radiation parameter R, etc.

The influence of Prandtl number on the velocity, temperature and concentration profiles are shown in figures 2(a)-2(c). From figures 2(a) & (c) it is observed that, as the Prandtl number Pr increases, the velocity and concentration profiles increases. Whereas Pr shows reverse trend in case of temperature distributions (See Fig. 2(b)). From this plot it is evident that temperature in the boundary layer falls very quickly for large value of the Prandtl number, because of the fact that thickness of the boundary layer decreases with increase in the value of the Prandtl number. This occurrence has a superior agreement with the physical realities. For various values of the Reynolds number Re, the velocity, temperature and concentration profiles against span wise coordinates are plotted in figures 3(a)-(c) respectively. It is obvious from the graphs that the effect of increasing values of Re results in an increasing velocity, concentration distribution and decreasing temperature distribution across the boundary layer.

The effect of heat source parameter on the velocity, temperature and concentration field are shown in Figures 4(a)-(c) respectively. While the values of other parameters involved in this study remain fixed. In this case, the fluid velocity, temperature field increases with the increase of heat source parameter H. From fig 4(c) we observed that concentration decreases with increasing values of heat source parameter. The influence of permeability parameter *k* on the velocity is described in Figure 5. It is obvious that the increased values of *k* tend to be increasing of velocity on the porous plate. It is expected that, an increase in the permeability of porous medium leads to the rise in the flow of fluid through it. When the holes of the porous medium become large, the resistance of the medium may be neglected. These results are clearly supported from the physical point of view [See Refs.5, 25].

Figure 6 illustrates the effect of Hartmann number M on velocity profile in the boundary layer. It is interesting to note from figure that the effect of magnetic field is to decrease the value of the velocity profile throughout the boundary layer. The peak value drastically decreases with increase in the value of the magnetic field, because, the presence of magnetic field in an electrically conducting fluid introduces a force called the Lorentz force, which acts against the flow if the magnetic field is applied in the normal direction. This type of resisting force slows down the fluid velocity as shown in the graph. These results are same as noted in the references [12, 29].

For various values of Radiation parameter R, the velocity, temperature and concentration profiles are plotted in Figures 7(a)-(c). It is obvious that with increasing values of R, the velocity and temperature distribution across the boundary layer increases. The results also show that the magnitude of concentration profile on the porous plate is decreased as R increases.

Figure 8(a) shows the local skin friction coefficient for different values of So and *Re* keeping all the parameters fixed. From figure it is seen that the magnitude and the tangent of phase shift of the shear stress increases with increase in So (at the wall *y=1)* and decreases at the wall *y=0.* Figure 8(b) depicts the behavior of the wall heat transfer coefficient (Nusselt number) *Nu* against *Re* for different values of *Pr*. We noticed that *Nu* increases, with an increase of *Pr*. We draw the graph of the rate of mass transfer (Sherwood number) against *Re* for different values of *So* in Figure 8(c). From the graph, we see that *Sh* decreases with increase in Soret number *So* at the wall *y=0* and increases at the wall $y = 1$. This performance is due to the fact that Soret effect produces a mass flux from lower to higher species concentration driven by temperature gradient.

5. CONCLUSIONS

The conclusions of the present study are as follows.

1. The fluid velocity profile is parabolic with maximum magnitude along the channel centreline and minimum at the walls. However, it is interesting to note that the magnitude of fluid velocity increases with an increase in radiation parameter and decreases with an increase in Hartmann number.
2. The effects of the permeability and magnetic parameters on velocity are opposite.
3. The effect of increasing the Prandtl number Pr and Reynolds number Re increases the velocity, concentration distribution and decreases the temperature distribution.
4. Increasing the heat source parameter H increases both velocity, temperature distributions and decreases the concentration distribution.
5. The velocity as well as concentration distributions decrease with an increase in the Schmidt number.
6. Skin friction increases with increase in So at the wall *y=1* and decreases at the wall *y=0.*

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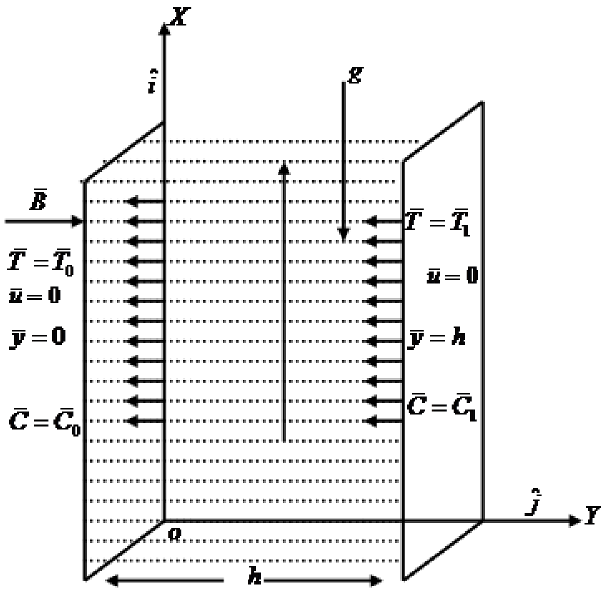

Figure-1: Flow configuration of the problem

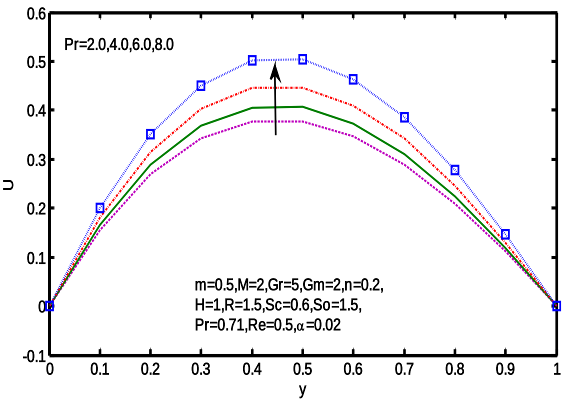

Figure-2(a): Effect of $\Pr$ on velocity

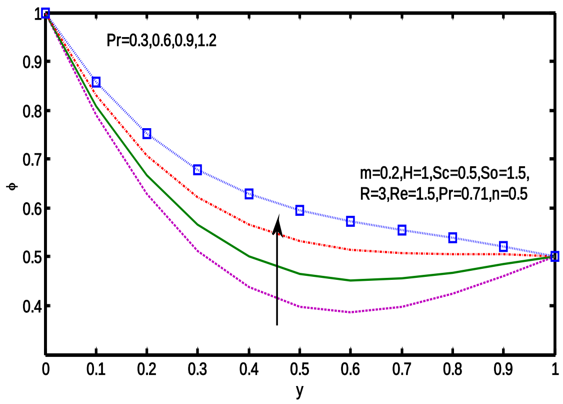

Figure-2(c): Effect of $\Pr$ on concentration

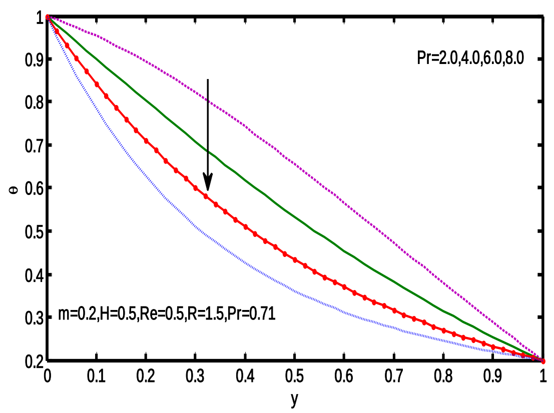

Figure-2(b): Effect of $\Pr$ on temperature

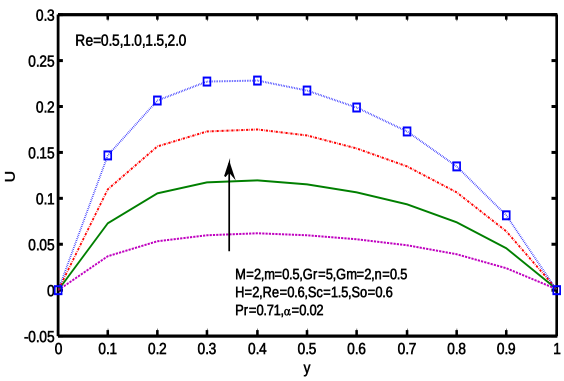

Figure-3(a): Effect of Re on velocity

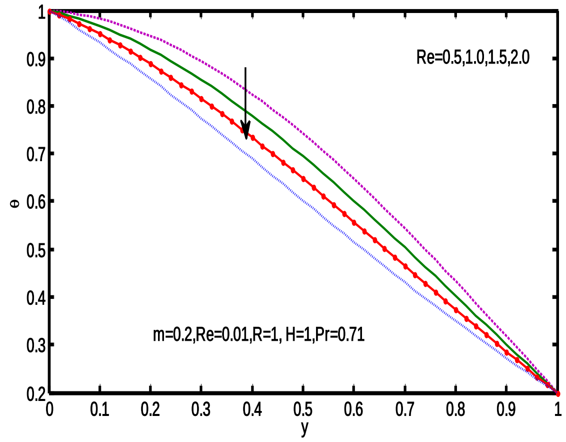

Figure-3(b): Effect of Re on temperature

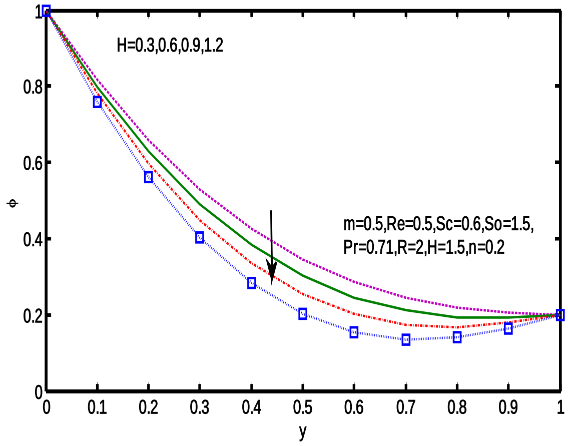

Figure-4(c): Effect of H on concentration

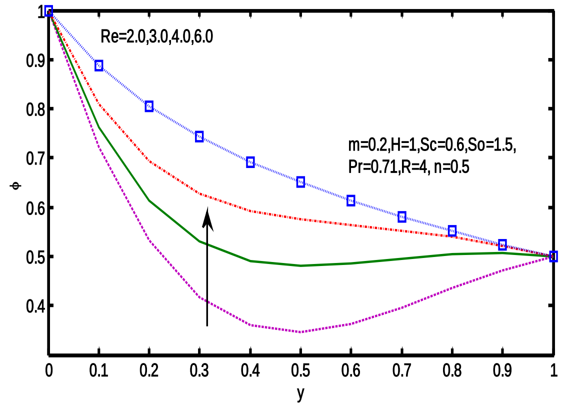

Figure-3(c): Effect of Re on C

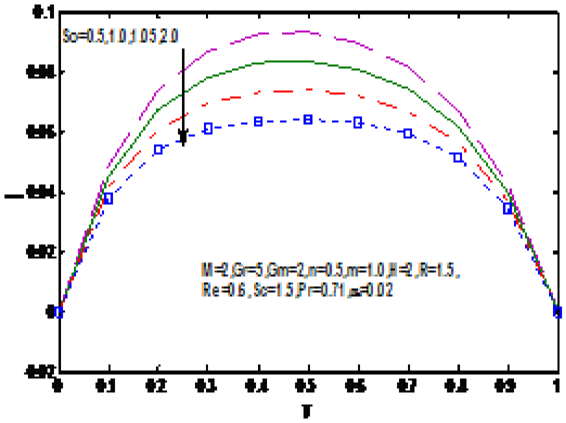

Figure-5(a): Effect of So on velocity

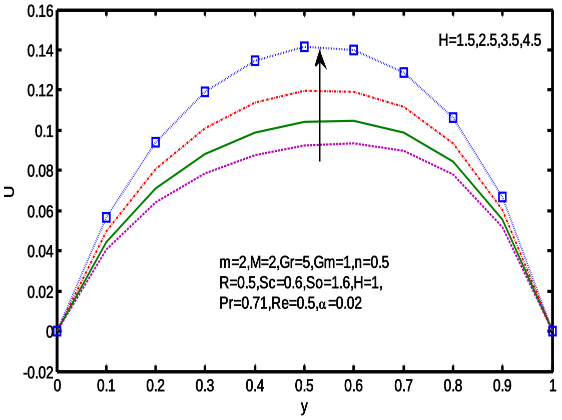

Figure-4(a): Effect of H on velocity

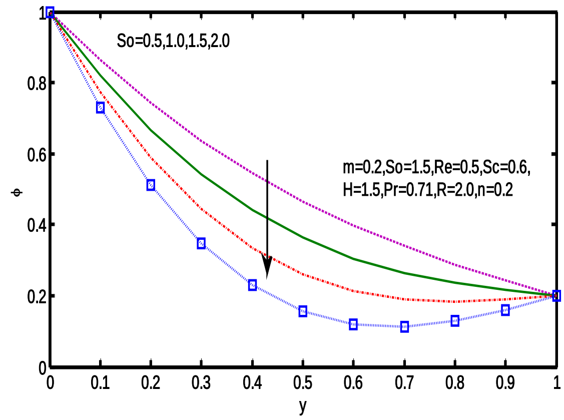

Figure-5(b): Effect of So on C

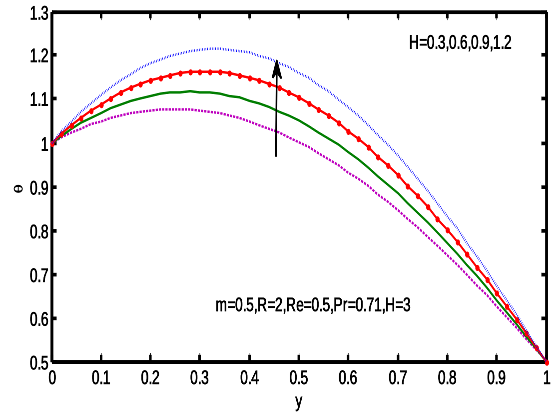

Figure-4(b): Effect of H on temperature

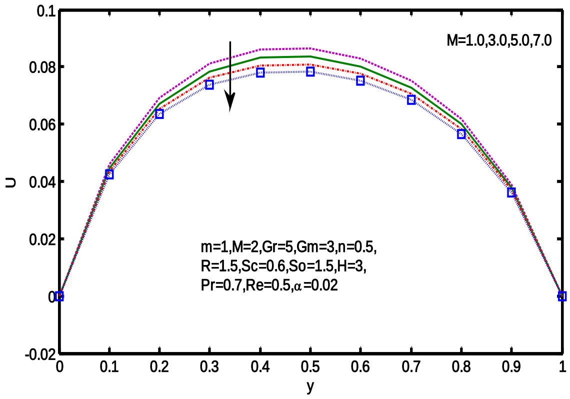

Figure-6: Effect of M on velocity

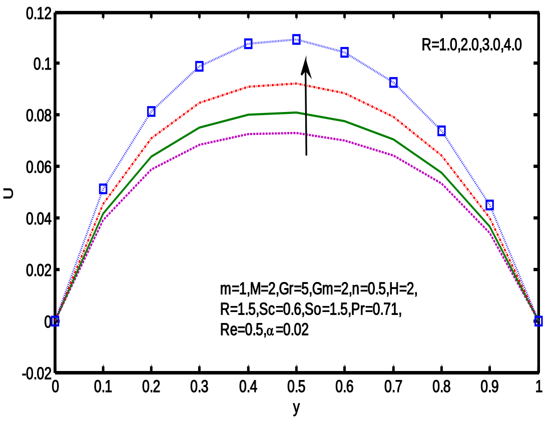

Figure-7(a): Effect of R on velocity

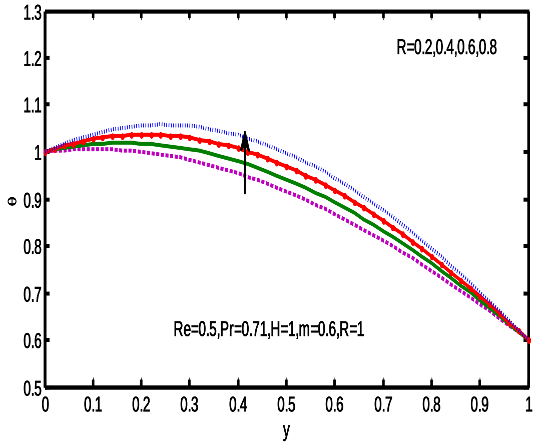

Figure-7(b): Effect of R on temperature

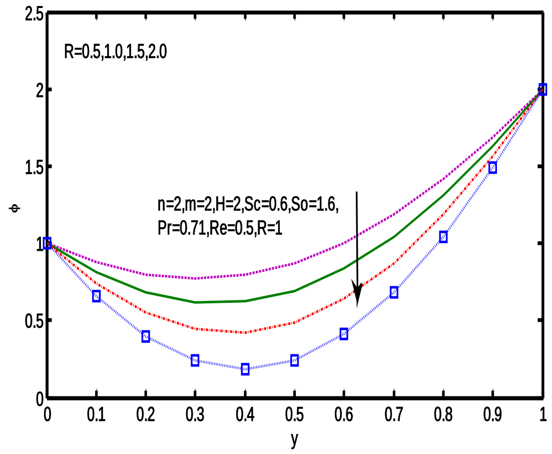

Figure-7(c): Effect of R on concentration

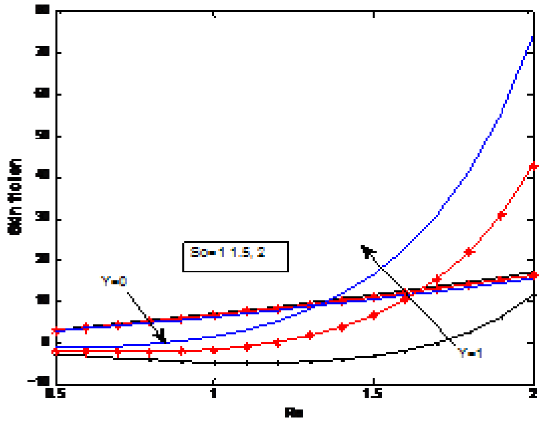

Figure-8(a): Effect of So on skin friction

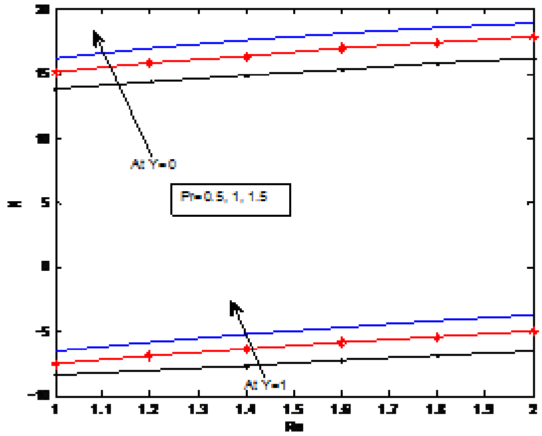

Figure-8(b): Effect of Pr on Nusselt Number

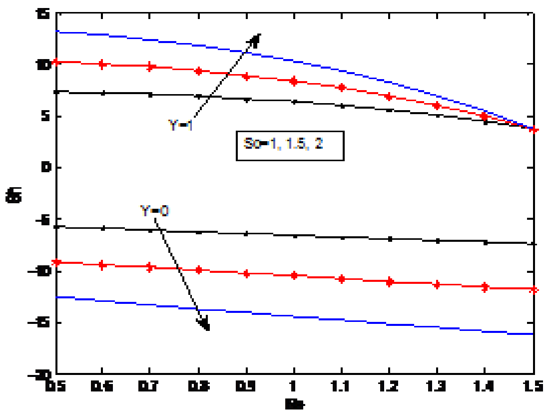

Figure-8(c): Effect of So on Sherwood Number

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