RESEARCH ARTICLE OPEN ACCESS

Analytical study of MHD free convective, dissipative boundary layer flow pasta porous vertical surface with conjugate Soret effect andinfluence of heat source in the presence of thermal radiation, chemical reaction and constant suction

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ABSTRACT

An analytical solution of MHD free convective, dissipative boundary layer flow past a vertical surface embedded with porous matrix with conjugate effect of thermophoresis and heat source in the presence of thermal radiation, chemical reaction and constant suction, under the influence of uniform magnetic field which is applied normal to the surface in addition with thermal and solutal buoyancy combined effect is analysed. The exact solutions of governing equations are solved by using analytical regular perturbation technique. The expressions for velocity, temperature and concentration fields are evaluated. With the aid of these, the expressions for the coefficient of skin friction, the rate of heat transfer in the form of Nusselt number and the rate of mass transfer in the form of Sherwood number are expressed in a precise numerical form. Finally the effects of various physical parameters of the flow phenomenon are studied with the help of graphs and tables. It is observed that the velocity and concentration distribution increase during a generative reaction and decrease in a destructive reaction. The same observed to be true for the behaviour of the fluid temperature. The presence of magnetic field and radiation reduces the velocity boundary layer and also the temperature field.

KEYWORDS: Boundary layer,free convection, Chemical reaction, MHD,Radiation, Porous medium, vertical surface, thermophoresis, heat source/sink

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Date of Submission: 01-06-2020 Date of Acceptance: 16-06-2020

I. INTRODUCTION

In nature, there arise various types of fluid and flows which are caused not only by the temperature differences but also by concentration differences as a result the rate of heat transfer takes place. Many transports processes that exist in industrial sector in which the simultaneous occurrence of heat and mass transfer phenomenon that takes place, as a result of combined buoyancy effect of thermal diffusion and diffusion thermo chemical species. This phenomenon frequently exists in chemically processed industries such as polymer productionand foodprocessing (see Cussler [1]). Free convective flows in different geometries are of vital interest in a number of industrial applications such asgranular insulation and geothermal systems, fiber. Besides that convective flow through porous medium has found various applications in thermal energy storage, oil extraction,geothermal energy recovery and flow through filtering devices.

Boundary-layer behaviour over a moving continuous solid surface is an important type of flow occurring in several engineering and science. Such processes include heat-treated materials travelling between a feed roll and a wind-up roll or materials manufactured by extrusion process and many others. Since the pioneering work of Sakiadis [2], various aspects of the problem have been analysed by many authors. Crane [3] and Gupta and Gupta [4] have discussed the stretching problem with constant surface temperature, while Soundalgekar [5] analyse the Stokes problem for a viscoelastic fluid. Similar flow model was discussed by Siddappa and Khapate [6] for a special class of non-Newtonian fluids known as second-order fluids, which are viscoelastic in nature. Danberg and Fansler [7] investigated the solution for the boundary-layer flow past along a wall that is stretched with a speed proportional to the distance along the wall.

Currently, magneto hydrodynamics is very much attracting the attention of the many researchers and authors due to its applications in engineering and geophysics. Raju and Varma [8], Magyari et al. [9], Ravikumar et al. [10], Chamkha [11], Makinde and Mhone [12], Hayat et al. [13], etc. are the few name mentioned over here who provide significant contributions in this area. When high temperatures attained in some engineering devices, such as, gas, can be ionized and so becomes a good electrical conductor. The plasma or ionized gas interacts with the magneticand alters heat transfer and friction characteristic. Since, some fluids can also emit and absorb thermal radiation, therefore it put keen attentionto study the behaviour of magnetic field on the temperature distribution and heat transfer when the fluid is not only an electrical conductor but also capable of emitting and absorbing thermal radiation. This is of so interest because heat transfer by thermal radiation is becoming of greater importance when we are concerned with higher operating temperatures and space applications. Soundalgekar and Takhar [14],analysed the effect of radiation using the Cogley–Vincentine–Gilles equilibrium model on the natural convection flowof a gas past along a semi-infinite plate. For the same gas Takhar et al. [15] analysed the radiation effect on the MHD free convection flow past along a semi-infinite vertical plate. Later, Hossain et al. [16] studied the effect of radiation on free convection from a porous vertical plate. Muthucumarswamy and Kumar [17] studied theeffect of thermal radiation on moving infinite vertical plate having variable temperature. Mazumdar and Deka [18] investigated MHD flow past an impulsively started infinite vertical plate in presence of thermal radiation. Combined effects of radiation and mass transfer on a free convection flow through a porous medium bounded by a vertical surface were analysed by Raju et al. [19]. Satya Narayana et al. [36] studied the influence of Hall current and radiation absorption on MHD micropolar fluid in a rotating system.

The growing need for chemical reactions in hydrometallurgical and chemicalindustries requires the analysis of heat and mass transfer process in the presence of chemical reaction. The presence of a foreign mass in a fluid provides some kind of chemical reaction. This can be presented either by itself or as mixtures with a fluid. In various chemical engineering practices, a chemical reaction occurs between a foreign mass and the fluid in which the plate is moving. These phenomenons take place in several industrial fields, such as,manufacturing of ceramics, polymer productionor glassware and food processing. A chemical reaction can be classified as either a heterogeneous or homogenous process that depends on whether it occurs on an interface or a single phase volume reaction. The influence of chemical reaction on heat and mass transfer process in a laminar boundary layer flowhas been investigated under different conditions by various researchers[20–28]. The influence of a chemical reaction on a moving isothermal vertical surface having injection orsuctionhas been discussed by Muthucumarswamy [29]. Presently, Manivannan et al. [30]analysed effectof chemical reaction and radiation on isothermal vertical oscillating plate having variable mass diffusion. The chemical reaction and radiation effects on unsteady MHD free convection flow and mass transfer through viscous incompressible fluid past a heated vertical plate immersed in porous medium in addition with of heat source was studied by Sharma et al. [31]. The effects of chemical reaction on free convection flow through a porous medium bounded by a vertical surface was analysed by Mahapatra et al. [32].

Motivated by the above cited work, here we have made an attempt to analyse the influence of heat and mass transfer phenomenon on a steady flow of viscous fluid embedded in a porous medium bounded by a porous surface subjected to suction or injection with a constant viscosity in the presence of thermal and mass buoyancy, radiation and homogenous chemical reaction of first order, which is an extension to the work of Raju et al. [45].

In few decades of our time, both experimental and theoretical analysis of viscous incompressible Non-Newtonian fluids has been examined extensively. Theoretical analysis of such kind of flow of fluid past along an infinite heated vertical porous plate is found useful due to its huge applications in many industrial fields such as various scientific and engineering processing like polymer processing, food processing, coating,paper production and extraction of polymer sheets,glass-fibre production and hot rolling.

However, the heat and mass transfer problem for flow model of a laminar boundary layer over a stretching sheet in a saturated porous medium has found useful application in the metallurgy field and chemical engineering process (see [39–42] for review). Chemical reaction can be classified as either homogeneous or heterogeneoustype; this depends on whether the reaction occurs at an interface or as a single phase volume reaction. Direct effect of chemicalreaction depends on the nature of the reaction whether the reaction is heterogeneous or homogeneous. According to Cussler [43], a homogeneous reaction is one that occurs uniformly throughout a given phase. On the other hand, a heterogeneous reaction takes place in a restricted area or within the boundary of a phase. In most of the cases of chemical reactions, the reaction rate depends on the concentration of the species itself. A reaction is of order n, if the reaction rate is proportional to the nth power of concentration. In particular, a reaction is of first order, if the rate of reaction is directly proportional to concentration itself (see Salem and El-Aziz [44]). Changes in fluid density gradients may be caused by non-reversible chemical reaction in the system as well as by the differences in molecular weight between values of the reactants and the products.

II. MATHEMATICAL MODEL

We consider a viscous, incompressible, electrically conducting and radiating fluid through a porous medium occupying a semi-infinite region of the space bounded by a vertical infinite surface. The x^* axis is taken along the surface in an upward direction and the y^* axis is normal to it. A uniform magnetic field B_0 is assumed to be applied in a direction perpendicular to the surface. Heat source Q_0 is subjected to the system. The properties of a fluid are assumed to be constant except for the density in the body force term. In addition a chemically reactive species is assumed to be emitted from the vertical surface into a hydrodynamic flow field. It diffuses into the fluid, where it under goes a homogenous chemical reaction. Due to the effect of thermophoresis to all phases of liquid matter, the Soret effect exhibits different responses to the force of a temperature gradient. The reaction is assumed to take place entirely in the stream. Then the fully developed flow under the above assumptions through a highly porous medium is governed by the following set of equations:

$$\frac{\partial v^*}{\partial y^*} = 0 \quad \text{..........} (1)$$

$$v^*\frac{\partial u^*}{\partial y^*} = \nu\frac{\partial^2 u^*}{\partial y^{*2}} + g\beta_T(T^* - T_\infty^*) + g\beta_C(C^* - C_\infty^*) - \frac{\sigma B_0^2}{\rho}u^* - \frac{\nu u^*}{k_p} \quad \text{..........} (2)$$

$$v^*\frac{\partial T^*}{\partial y^*} = \frac{k}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}} + \frac{\nu}{C_p}\left(\frac{\partial u^*}{\partial y^*}\right)^2 - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y^*} + \frac{Q_0}{\rho C_p}(T^* - T_\infty^*) \quad \text{..........} (3)$$

$$v^*\frac{\partial C^*}{\partial y^*} = D\frac{\partial^2 C^*}{\partial y^{*2}} - k(C^* - C_\infty^*) - \frac{\partial}{\partial y^*}(V_T C) \quad \text{..........} (4)$$

It is assumed that the level of species concentration is very low; hence the heat generated due to chemical reaction is neglected. The relevant boundary conditions are given as follows

$$\left.\begin{array}{l} u^* = 0, T^* = T_W, C^* = C_w, \ at \ \ y^* = 0 \\ u^* \to 0, T^* \to T_\infty^*, C^* \to C_\infty^*, \ at \ \ y^* \to \infty \end{array}\right\} \quad \text{..........} (5)$$

Equation (1) gives that $v^* = \text{constant} = -v_0$ ....(6)

In the optically thick limit, the fluid does not absorb its own emitted radiation in which there is no self-absorption, but it does absorb radiation emitted by the boundaries. Cogley et al. [27] showed that in the optically thick limit for a non-gray gas near equilibrium as given below.

$$\frac{\partial q_r}{\partial y^*} = 4(T^* - T_\infty^*)\int_0^\infty K_{\lambda w}\left(\frac{de_{b\lambda}}{dT^*}\right)_w d\lambda = 4I_1(T^* - T_\infty^*) \quad \text{..........} (7)$$

On introducing the following nondimensional quantities,

$$\left.\begin{array}{l} u=\dfrac{u^*}{v_0}, y=\dfrac{v_0 y^*}{\nu}, \theta=\dfrac{T^*-T_\infty^*}{T_W-T_\infty^*}, C=\dfrac{C^*-C_\infty^*}{C_W-C_\infty^*}, \\ \Pr=\dfrac{\mu C_p}{k}, Sc=\dfrac{\nu}{D}, M=\dfrac{\sigma B_0^2 \nu}{\rho v_0^2}, k=\dfrac{v_0^2 k_p}{\nu^2} \\ Gm=\dfrac{\nu g \beta_c (C_W-C_\infty^*)}{v_0^3}, E=\dfrac{v_0^2}{c_p(T_W-T_\infty^*)}, \\ F=\dfrac{4I_1\nu^2}{kv_0^2}, S=\dfrac{\nu^2 Q_0}{Kv_0^2}, Sr=\dfrac{T_f \Delta C}{t_p \Delta T}=\dfrac{T_f(C_W-C_\infty^*)}{t_p(T_W-T_\infty^*)} \\ k_0=\dfrac{\nu k_c}{v_0^2}, V_T=\dfrac{t_p \mu}{\rho T_f}\dfrac{\partial T^*}{\partial y^*},, Gr=\dfrac{\nu g \beta_T (T_W-T_\infty^*)}{v_0^3} \end{array}\right\} \text{..(8)}$$

The non-dimensional form of the governing equations (2) – (4) reduce to

$$\left.\begin{array}{l} u''+u'=-Gr\theta-GmC+M_1 u \\ \theta''+\Pr\theta'=-\Pr Eu'^2+(F-S)\theta \\ C''+ScC'=k_0 ScC+\dfrac{Sc}{Sr}\theta'' \end{array}\right\} \text{..(9)}$$

Where $M_1=M+\dfrac{1}{k}$,

The corresponding boundary conditions (5) are reduced to nondimensional form given by

$$\left.\begin{array}{l} u=0, \theta=1, C=1 \;\; at \;\; y=0 \\ u\to 0, \theta\to 0, C\to 0, \;\; at \;\; y\to\infty \end{array}\right\} \text{...(10)}$$

III. SOLUTION OF THE PROBLEM

In order to solve the coupled nonlinear system of equations (9)with the boundary conditions (10), the following simple regular perturbation technique is used. The governing system of equations (9) is expanded in Powers of Eckert number $E\ (<<1)$.

$$\left.\begin{array}{l} u=u_0+Eu_1+O(E^2) \\ \theta=\theta_0+E\theta_1+O(E^2) \\ C=C_0+EC_1+O(E^2) \end{array}\right\} \text{...(11)}$$

Substituting equations (11) into system of equations (9) and equating the coefficients at the terms with the same powers of E, and neglecting the terms of higher order, the following equations are obtained.

Zero order terms:

$$\left.\begin{aligned} & u_0'' + u_0' = -Gr\theta_0 - GmC_0 + M_1 u_0 \\ & \theta_0'' + \Pr\theta_0' - (F-S)\theta_0 = 0 \\ & C_0'' + ScC_0' = k_0 ScC_0 + \frac{Sc}{Sr}\theta_0'' \end{aligned}\right\} \quad \text{...} (12)$$

First order terms:

$$\left.\begin{aligned} & u_1'' + u_1' = -Gr\theta_1 - GmC_1 + M_1 u_1 \\ & \theta_1'' + \Pr\theta_1' - (F-S)\theta_1 = -\Pr u_0'^2 \\ & C_1'' + ScC_1' = k_0 ScC_1 + \frac{Sc}{Sr}\theta_1'' \end{aligned}\right\} \quad \text{...} (13)$$

The corresponding boundary conditions are

$$\left.\begin{aligned} & u_0 = 0, u_1 = 0, \theta_0 = 1, \theta_1 = 0, \\ & C_0 = 1, C_1 = 0, \ at \ \ y = 0 \\ & u_0 \to 0, u_1 \to 0, \theta_0 \to 0, \theta_1 \to 0, \\ & C_0 \to 0, C_1 \to 0 \ \ at \ \ y \to \infty \end{aligned}\right\} \quad \text{...} (14)$$

Solving system of equations (12) and (13) under the boundary conditions (14), the following solutions are obtained.

$$C_0 = (1 - L_1)\exp(k_2 y) + L_1 \exp(k_4 y) \text{...} (15)$$

$$k_1 = \frac{-Sc + \sqrt{Sc^2 + 4k_0 Sc}}{2}, k_2 = \frac{-Sc - \sqrt{Sc^2 + 4k_0 Sc}}{2}$$

$$k_3 = \frac{-\Pr + \sqrt{\Pr^2 + 4(F-S)}}{2}, k_4 = \frac{-\Pr - \sqrt{\Pr^2 + 4(F-S)}}{2}$$

$$\theta_0 = \exp(k_4 y) \qquad (16)$$

$$u_0 = k_8 \exp(k_2 y) + L_{10} \exp(k_4 y) + k_{10} \exp(k_6 y) \qquad (17)$$

$$L_{10} = k_7 + k_9, k_5 = \frac{-1+\sqrt{1+4M_1}}{2},$$
$$k_6 = \frac{-1-\sqrt{1+4M_1}}{2}, k_7 = \frac{-Gr}{(k_4-k_5)(k_4-k_6)},$$
$$k_8 = \frac{L_1-1}{(k_2-k_5)(k_2-k_6)}, k_9 = \frac{-GmL_1}{(k_4-k_5)(k_4-k_6)}$$
$$L_1 = \frac{Sc}{Sr}\frac{k_4{}^2}{(k_4-k_1)(k_4-k_2)}$$

$$\theta_1 = k_{29} \exp(k_4 y) + k_{23} \exp(k_{17} y) + k_{24} \exp(k_{18} y)$$
$$+k_{25} \exp(k_{19} y) + k_{26} \exp(k_{20} y) + k_{27} \exp(k_{21} y)$$
$$+k_{28} \exp(k_{22} y) \qquad (18)$$

$$k_{10} = -(k_7 + k_8 + k_9), k_{11} = k_{10}{}^2 k_6{}^2,$$
$$k_{12} = \left\{(k_7 + k_9)k_4\right\}^2, k_{13} = k_2{}^2 k_8{}^2,$$
$$k_{14} = 2k_{10}k_6\left\{(k_7 + k_9)k_4\right\}, k_{15} = 2k_8k_2\left\{(k_7 + k_9)k_4\right\},$$
$$k_{16} = 2k_{10}k_6k_8k_2, k_{17} = 2k_6, k_{18} = 2k_4, k_{19} = 2k_2,$$
$$k_{20} = k_6 + k_4, k_{21} = k_2 + k_4, k_{22} = k_6 + k_2,$$
$$k_{23} = \frac{-\Pr k_{11}}{(k_{17}-k_3)(k_{17}-k_4)}, k_{24} = \frac{-\Pr k_{12}}{(k_{18}-k_3)(k_{18}-k_4)},$$
$$k_{25} = \frac{-\Pr k_{13}}{(k_{19}-k_3)(k_{19}-k_4)}, k_{26} = \frac{-\Pr k_{14}}{(k_{20}-k_3)(k_{20}-k_4)},$$
$$k_{27} = \frac{-\Pr k_{15}}{(k_{21}-k_3)(k_{21}-k_4)}, k_{28} = \frac{-\Pr k_{16}}{(k_{22}-k_3)(k_{22}-k_4)},$$
$$k_{29} = -(k_{23} + k_{24} + k_{25} + k_{26} + k_{27} + k_{28})$$

$$k_{30} = \frac{Sc}{Sr} k_{29} k_4{}^2, k_{31} = \frac{Sc}{Sr} k_{23} k_{17}{}^2,$$
$$k_{32} = \frac{Sc}{Sr} k_{24} k_{18}{}^2, k_{33} = \frac{Sc}{Sr} k_{25} k_{19}{}^2$$
$$k_{34} = \frac{Sc}{Sr} k_{26} k_{20}{}^2, k_{35} = \frac{Sc}{Sr} k_{27} k_{21}{}^2$$
$$k_{36} = \frac{Sc}{Sr} k_{28} k_{22}{}^2, k_{37} = \frac{k_{30}}{(k_4 - k_1)(k_4 - k_2)}$$
$$k_{38} = \frac{k_{31}}{(k_{17} - k_1)(k_{17} - k_2)}, k_{39} = \frac{k_{32}}{(k_{18} - k_1)(k_{18} - k_2)},$$
$$k_{40} = \frac{k_{33}}{(k_{19} - k_1)(k_{19} - k_2)}, k_{41} = \frac{k_{34}}{(k_{20} - k_1)(k_{20} - k_2)},$$
$$k_{42} = \frac{k_{35}}{(k_{21} - k_1)(k_{21} - k_2)}, k_{43} = \frac{k_{36}}{(k_{22} - k_1)(k_{22} - k_2)}$$
$$k_{44} = -(k_{37} + k_{38} + k_{39} + k_{40} + k_{41} + k_{42} + k_{43})$$

$$\begin{aligned} C_1 &= k_{44} \exp(k_2 y) + k_{37} \exp(k_4 y) + k_{38} \exp(k_{17} y) \\ &+ k_{39} \exp(k_{18} y) + k_{40} \exp(k_{19} y) + k_{41} \exp(k_{20} y) \\ &+ k_{42} \exp(k_{21} y) + k_{43} \exp(k_{22} y) + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(19) \end{aligned}$$

$$L_{44} = \frac{-Grk_{29}}{(k_4 - k_5)(k_4 - k_6)}, k_{45} = \frac{-Grk_{23}}{(k_{17} - k_5)(k_{17} - k_6)},$$
$$k_{46} = \frac{-Grk_{24}}{(k_8 - k_5)(k_{18} - k_6)}, k_{47} = \frac{-Grk_{25}}{(k_{19} - k_5)(k_{19} - k_6)},$$
$$k_{48} = \frac{-Grk_{26}}{(k_{20} - k_5)(k_{20} - k_6)}, k_{49} = \frac{-Grk_{27}}{(k_{21} - k_5)(k_{21} - k_6)},$$
$$k_{50} = \frac{-Grk_{28}}{(k_{22} - k_5)(k_{22} - k_6)}, k_{51} = \frac{-Gmk_{44}}{(k_2 - k_5)(k_2 - k_6)},$$
$$k_{52} = \frac{-Gmk_{37}}{(k_4 - k_5)(k_4 - k_6)}, k_{53} = \frac{-Gmk_{38}}{(k_{17} - k_5)(k_{17} - k_6)},$$
$$k_{54} = \frac{-Gmk_{39}}{(k_{18} - k_5)(k_{18} - k_6)}, k_{55} = \frac{-Gmk_{40}}{(k_{19} - k_5)(k_{19} - k_6)},$$
$$k_{56} = \frac{-Gmk_{41}}{(k_{20} - k_5)(k_{20} - k_6)}, k_{57} = \frac{-Gmk_{42}}{(k_{21} - k_5)(k_{21} - k_6)},$$
$$k_{58} = \frac{-Gmk_{43}}{(k_{22} - k_5)(k_{22} - k_6)},$$
$$k_{59} = -\left(k_{44} + k_{45} + k_{46} + k_{47} + k_{48} + k_{49} + k_{50} + k_{51} + k_{52} + k_{53} + k_{54} + k_{55} + k_{56} + k_{57} + k_{58}\right)$$

$k_{60} = k_{52} + k_{44}, k_{61} = k_{53} + k_{45},$
$k_{62} = k_{54} + k_{46}, k_{63} = k_{55} + k_{47},$
$k_{64} = k_{56} + k_{48}, k_{65} = k_{57} + k_{49},$
$k_{66} = k_{58} + k_{50}, L_{10} = k_9 + k_7,$

$$u_1 = k_{59}\exp(k_6 y) + k_{60}\exp(k_4 y) + k_{61}\exp(k_{17} y) + k_{62}\exp(k_{18} y) + k_{63}\exp(k_{19} y) + k_{64}\exp(k_{20} y) + k_{65}\exp(k_{21} y) + k_{66}\exp(k_{22} y) + k_{51}\exp(k_2 y) \qquad (20)$$

$$u = u_0 + Eu_1 = k_8\exp(k_2 y) + L_{10}\exp(k_4 y) + k_{10}\exp(k_6 y) + E\begin{pmatrix} k_{59}\exp(k_6 y) + k_{60}\exp(k_4 y) + k_{61}\exp(k_{17} y) + \\ k_{62}\exp(k_{18} y) + k_{63}\exp(k_{19} y) + k_{64}\exp(k_{20} y) + \\ k_{65}\exp(k_{21} y) + k_{66}\exp(k_{22} y) + k_{51}\exp(k_2 y) \end{pmatrix} \qquad (21)$$

$$\theta = \theta_0 + E\theta_1 = \exp(k_4 y) + E\begin{pmatrix} k_{29}\exp(k_4 y) + k_{23}\exp(k_{17} y) + k_{24}\exp(k_{18} y) \\ +k_{25}\exp(k_{19} y) + k_{26}\exp(k_{20} y) + k_{27}\exp(k_{21} y) \\ +k_{28}\exp(k_{22} y) \end{pmatrix} \qquad (22)$$

$$C = C_0 + EC_1 = (1 - L_1)\exp(k_2 y) + L_1\exp(k_4 y) + E\begin{pmatrix} k_{44}\exp(k_2 y) + k_{37}\exp(k_4 y) + k_{38}\exp(k_{17} y) \\ +k_{39}\exp(k_{18} y) + k_{40}\exp(k_{19} y) + k_{41}\exp(k_{20} y) \\ +k_{42}\exp(k_{21} y) + k_{43}\exp(k_{22} y) + \end{pmatrix} \qquad (23)$$

IV. RESULTS AND DISCUSSION

In order to point out the effects of various flow parameters over velocity distribution, temperature field and concentration species of flow characteristic, the followingdiscussion is set out. The graphs are analysed on the basis of following set of datas (M= 1.2;k = 0.1; E=0.0001; Gr = 5.0; Gm = 5.0; Pr =0.71; Sr=0.75; Sc = 1.02; S =0.5; k0=0.01, F=2) keeping fixed and varying some of the pertinent parameters such as permeable parameter, radiation parameter, chemical reaction parameter, Heat source parameter,Soret number,Magnetic parameter, Schmidt number.

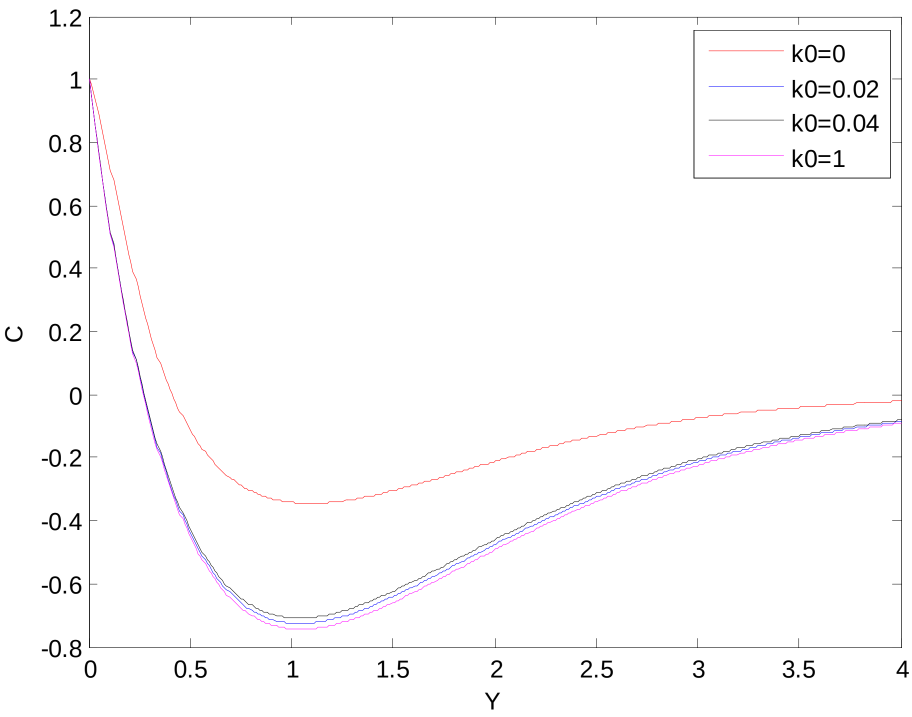

Fig.1 Effect of permeable parameter over concentration field

Fig. 1 depicts the concentration profiles for different values of chemical reaction parameter k_0. It is found that k_0 decreases the fluid concentration species. The concentration profiles variation for different values of k_0 is analysed from which it is noticed that concentration decreases with an increase in chemical reaction parameter. This is due to the chemical reaction mass diffuses from higher concentration levels to lower concentration levels. Sivaraj and Rushi Kumar [29] and Muthucumarswamyand Ganesan [15], also observed the similar result.

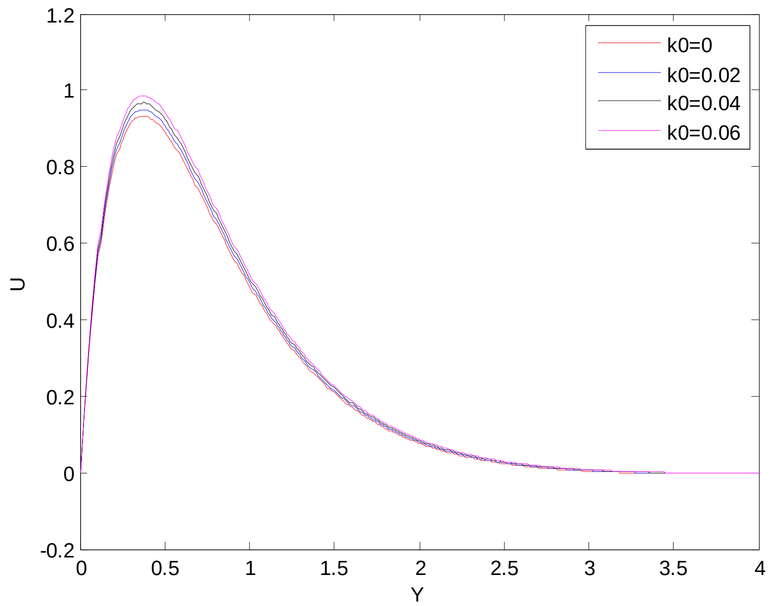

Fig.2 Effect of chemical reaction parameter over velocity field

Fig. 2 depicts the velocity profiles for various values of $k0$. From this figure it is observed that fluid velocity increases as $k0$ increases and reaches its maximum over a very short distance from the plate and then gradually reaches to zero. Physically, an increase in the chemical reaction parameter leads the rise in the flow of fluid through it.

In order to assess the accuracy of the numerical results, we have compared our results with accepted data sets for the velocity, temperature and concentration profiles for a stationary vertical porous plate subject to the action of uniform magnetic field and in presence of thermal and mas buoyancy corresponding to the case computed by Raju (45)i.e., in the absence of the Soret effects, radiation parameter and Schmidt number we observed that the effects of all parameters on velocity and temperature profiles are in good agreement with the comparison of Raju (45).

Figure 2 illustrates the behaviour of the velocity for different values of chemical reaction parameter k0. It is seen that the velocity increases with increasing chemical reaction parameter K0. For large value of chemical reaction parameter effect on velocity is negligible as Y increases.

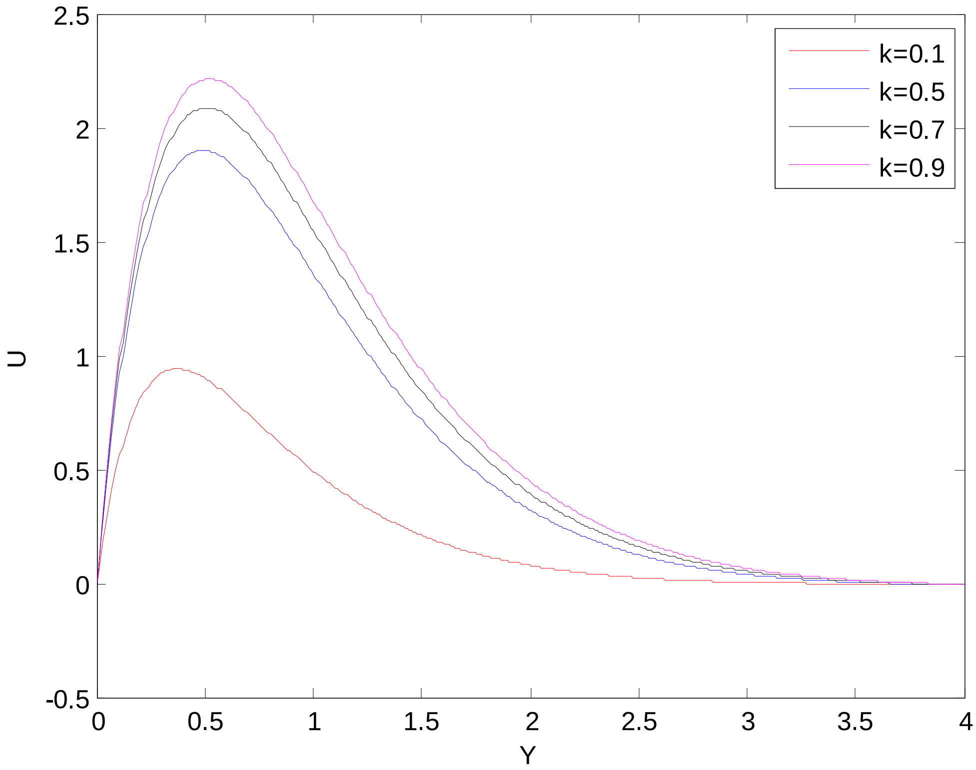

Fig.3 Effect of permeable parameter over velocity field

Fig.3 depicts the behaviour of physical parameter permeable parameter of the porous medium over velocity field. It is observed that the velocity distribution increases with the increase of permeable parameter. Hence it tends to rises the velocity boundary layer and fluid flow velocity rises.

When the holes of the porous medium become large, the resistance of the medium may be neglected. The similar result is seen by Ravikumar et al. [22] and Raju et al. [28]. In their study Mishra et al. [32] showed that, the free convection current due to thermal buoyancy, mass buoyancy and porosity of the medium enhances the fluid velocity. Gireesh Kumar and Satyanarayana [31] observed that the velocity profile increases with increase of thermal Grashof number (Gr) and Solutal Grashof number (Gm) and they have also observed that the velocity decreases with increase in magnetic parameter. Hence our observation in respect of these parameters agrees with [31, 32] in the absence of radiation and chemical reaction. Thus, the above result indicates that heavier species with lower thermal conductivity reduces the fluid flow.

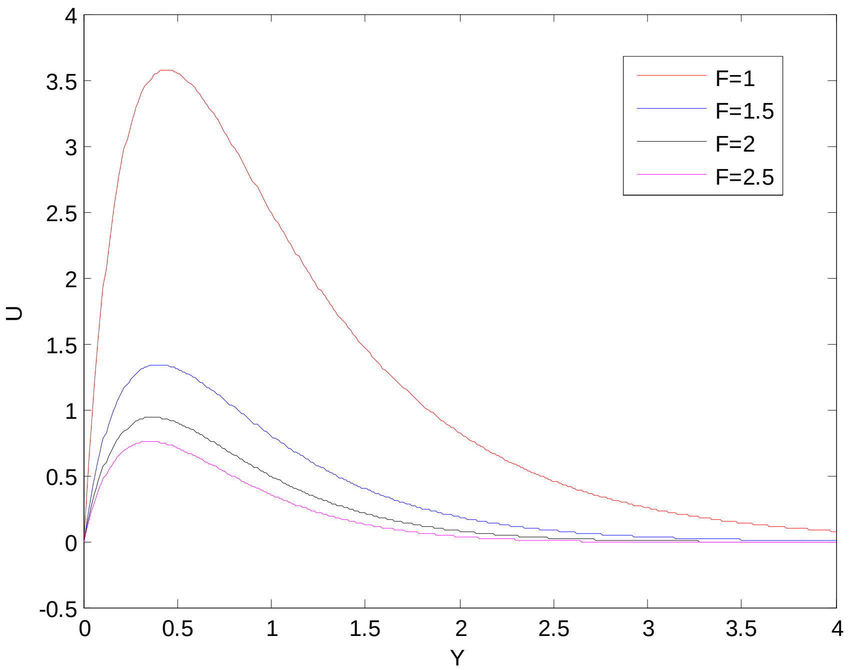

Fig.4 Effect of radiation parameter over velocity field

Velocity profiles for different values of radiation parameter are presented in Fig. 4. It is noticed that velocity boundary layer and velocity distribution decreases with an increase in radiation parameter. Manivannan et al. [24] also concluded the same result.

The influence of radiation parameter (F) on velocity profiles is shown in Figs. 4 and it can be observed that there is a decrement in the velocity profiles when there is an increase in the radiation parameter. This may happen due to the fact that an increase in the radiation parameter reduces the thermal boundary layer. In view of this we can conclude that influence of radiation is more significant as $F \rightarrow \neq 0$ (0) and it can be neglected as $F \rightarrow \infty$. This agrees with the general physical behaviour of the radiation parameter. Also, it is observed that an increase in radiation parameter shows more impact on the velocity profiles of the radiating fluid compared with the Newtonian fluid.

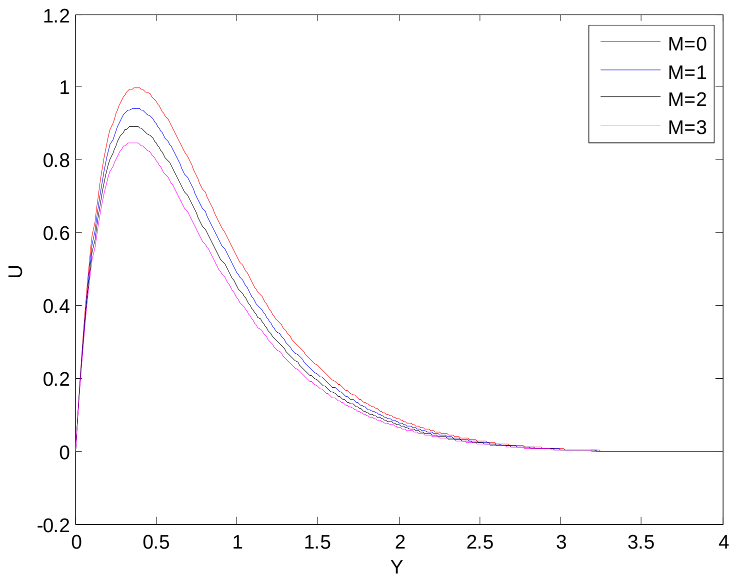

Fig.5 Effect of magnetic parameter over velocity field

Fig. 5 shows the effect of magnetic parameter M on the velocity. From this figure it is observed that velocity decreases as the values of M is increased. This is due to the application of a magnetic field to an electrically conducting fluid produces a dragline force which causes reduction in the fluid velocity (see Raju et al. [21, 28]).

The Nusselt number is the ratio of convective to conductive heat across a boundary in a fluid. The convection and conduction heat flows are parallel to each other and to the surface normal of the boundary surface, and are perpendicular to the mean fluid flow in the simple case. The rate of heat transfer in terms of the Nusselt number is given by

$$Nu = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0}$$

$$= -k_4 - E\left(k_{29}k_4 + k_{23}k_{17} + k_{24}k_{18} + k_{25}k_{19} + k_{26}k_{20} + k_{27}k_{21} + k_{28}k_{22}\right)\text{.............}(24)$$

The skin friction coefficient is a dimensionless skin shear stress which is non-dimensionalised by the dynamic pressure of a free stream. Skin friction coefficient refers to a local value and physically refers to the ratio between local shear stress to characteristic dynamics pressure.

The non-dimensional skin friction at the surface is given by

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} = \left[k_2 k_8 + k_{10} k_6 + L_{10} k_4\right]$$

$$+E\begin{pmatrix} k_6 k_{59} + k_4 k_{60} + k_{61} k_{17} + k_{62} k_{18} \\ +k_{63} k_{19} + k_{64} k_{20} + k_{65} k_{21} + k_{66} k_{22} + k_{51} k_2 \end{pmatrix}\text{...}(25)$$

Another important physical quantity of interest is the Sherwood number. The Sherwood number (Sh) also called the mass transfer Nusselt number is a dimensionless number used in mass-transfer operation. It represents the ratio of convective mass transfer to the rate of diffusive mass transport, which is in non-dimensional form is given by

$$Sh = -\left(\frac{\partial C}{\partial y}\right)_{y=0} = -k_2\left(1 - L_1\right) - k_4 L_1$$

$$-E\begin{pmatrix} k_{44} k_2 + k_{37} k_4 + k_{38} k_{17} \\ +k_{39} k_{18} + k_{40} k_{19} + k_{41} k_{20} \\ +k_{42} k_{21} + k_{43} k_{22} \end{pmatrix}\text{..}(26)$$

Comparison of the results: In order to assess the accuracy of our method, we have compared our results with accepted data sets for the velocity distribution for a case of MHD free convictive, dissipative boundary layer flow embedded with heat source past along a porous vertical surface, corresponding to the case computed by Mahapatra et al. [26] and Raju et al.[45], in the absence of magnetic field and the absence of thermal radiation by taking different values for Schmidtnumber, Soret number and keeping the other parameters fixed and these results are presented in graphs. Clearly the results of this comparison are found to be in good agreement.

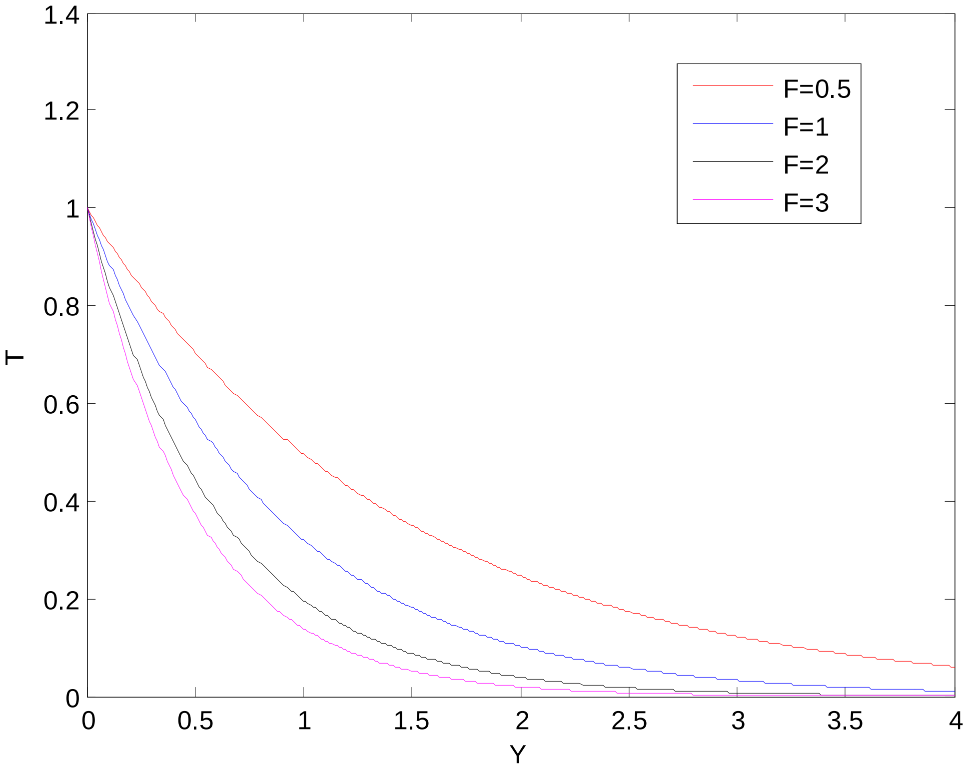

Fig.6 Effect of radiation parameter over temperature field

Temperature profiles are displayed through Figs. 6 and 7. In Fig. 6, the effect of radiation parameter F is observed on the temperature, it is known that temperature decreases with the increase in F. Hence the thermal boundary layer reduces due to this. A similar result is shown by Raju et al. [13].

Fig.7 depicts the effect of heat source parameter over temperature profile. It is observed that temperature field increase with rise of heat source parameter. Hence, thermal boundary layer and temperature of the fluid increases due to increment of heat source parameter. The result will not vary if we take the sink parameter instead of heat source parameter.

Fig.8 depicts the effect of Schmidt number over concentration field. It is observed that Schmidt number produces opposite behaviour i.e. concentration field reduces with the increase of Schmidt number. Hence the concentration species and concentration boundary layer also reduces with increment of Schmidt number.

Fig.9 reflects the effect of Soret number over concentration field. It is observed that Soret number increases with the rise of concentration distribution. Hence, the concentration boundary layer and concentration species of the fluid increases with the increases of Soret number.

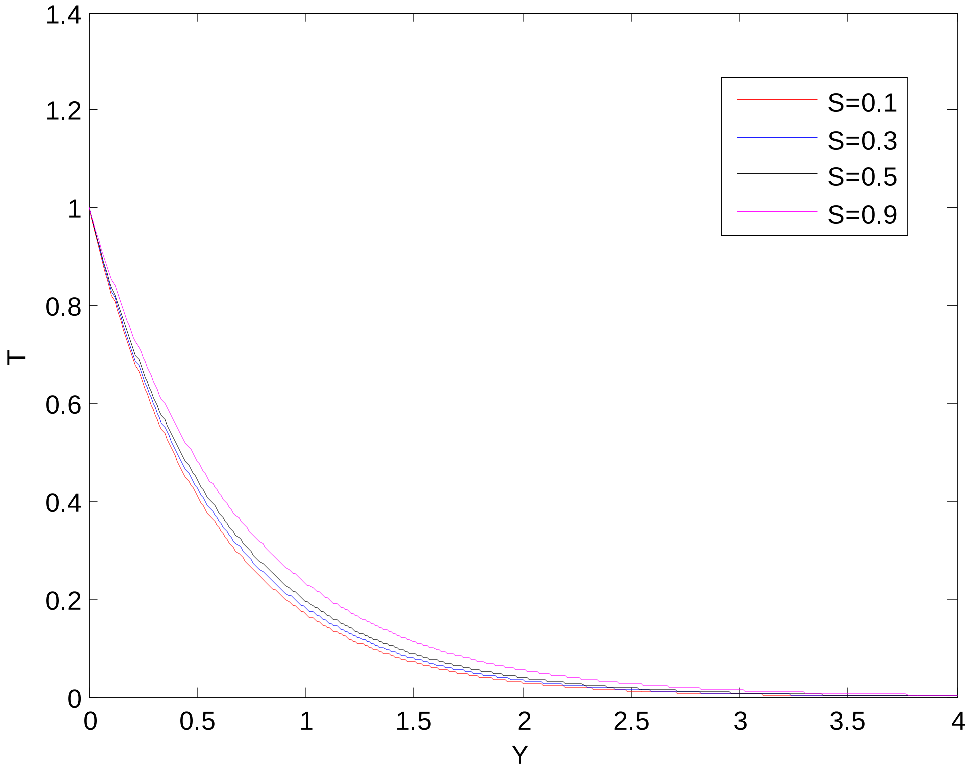

Fig.7 Effect of Heat source parameter over temperature field

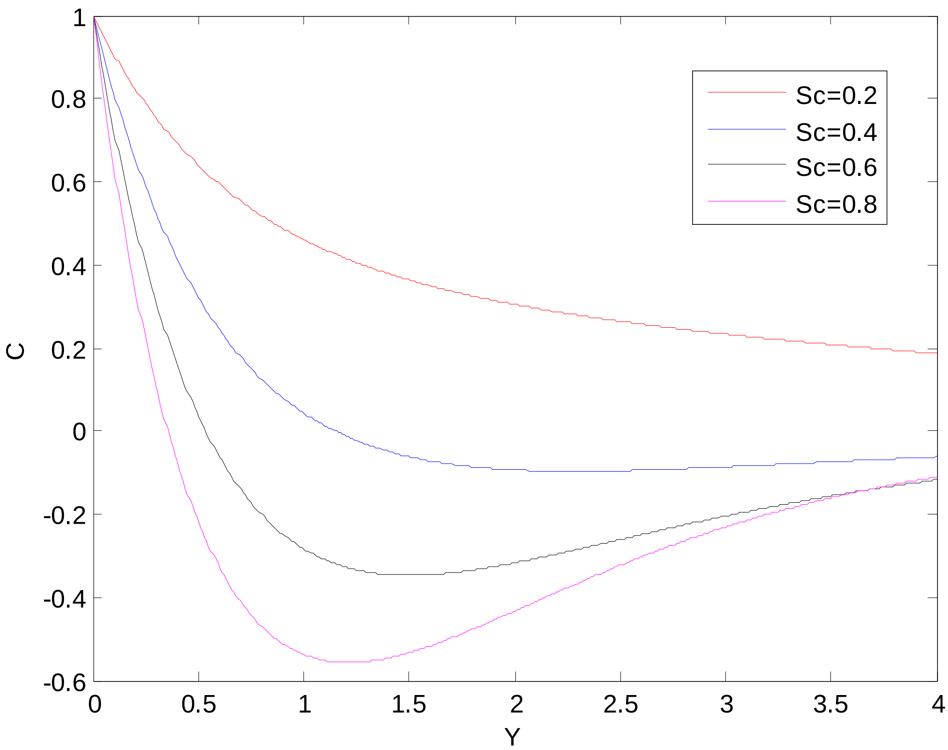

Fig.8 Effect of Schmidt number over concentration field

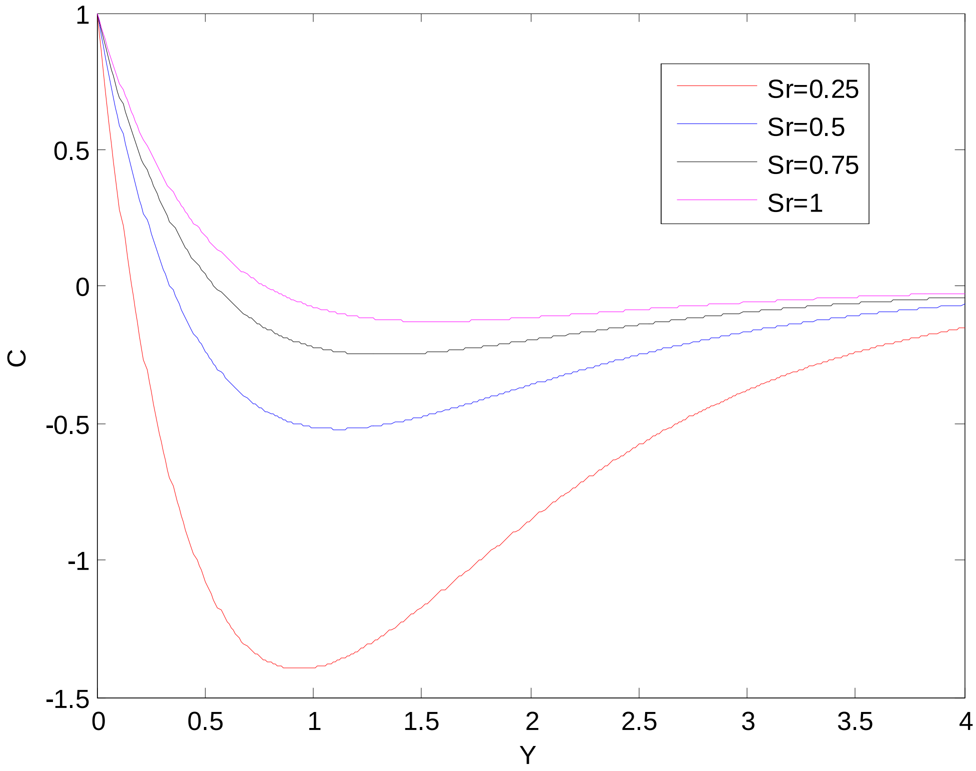

Fig.9 Effect of Soret number over concentration field

V. CONCLUSIONS

In this paper we have studied the effects of Soret number, chemical reaction and radiation, heat source, Schmidt number on MHD free convection flow through a porous medium bounded by a vertical surface subjected to the action of uniform magnetic field applied normal to the surface. In addition we have studied the combined effect and influence of thermal and solutal buoyancy associated to the flow characteristics. In the analysis of the flow the following conclusions are made

- The velocity of a fluid increases with the permeability parameter k and chemical reaction parameter where it decreases with the increase in magnetic parameter M, radiation parameter F.
- In most cases the velocity attains a maximum near the surface and there after decreases.
- Temperature decreases with the increase radiation parameter and increases with heat source parameter.
- Concentration decreases with an increase in chemical reaction parameter, Schmidt number where as it increases with an increase in Soret number.

Nomenclature

C : Non-dimensional fluid concentration
$C*$: Concentration
C_∞ : Fluid concentration far away from the wall
c_p : Specific heat at a constant pressure
D : Mass diffusivity
E : Eckert number
$e_{b\lambda}$: Planck function
F : Radiation parameter
Gm : Mass Grashof number
Gr : Thermal Grashof number
g : Gravitation due to acceleration
k : Non-dimensional permeability coefficient of a porous medium
k_0 : Non-dimensional rate of chemical reaction
Q_0 : Heat source
k_c : Rate of chemical reaction
k_p : Permeability of porous medium
$K_{\lambda w}$: Absorption coefficient
M : Magnetic parameter
Nu : Nusselt number
Pr : Prandtl number

qr : Radiative heat flux
Sc : Schmidt number
T_∞ : Fluid temperature far away from the wall
T^*: Temperature
$u^*,\ v^*$: Velocity components
u : Non-dimensional velocity
v_0 : suction velocity
S: Heat source parameter

Greek symbols
κ : Thermal conductivity
ν : Kinematic viscosity
σ : Electrical conductivity
μ : Dynamic viscosity
β_T : Co-efficient of volume expansion
β_c : Co-efficient of volume expansion with concentration
ρ : Fluid density
τ : Non-dimensional skin friction
θ : Non-dimensional temperature

Subscripts and super scripts
W : Wall
∞ : Far away from the wall
Prime: denotes differentiation with respect to y

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