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ORIGINAL PAPER

Soret Effect Due to Mixed Convection on Unsteady Magnetohydrodynamic Flow Past a Semi Infinite Vertical Permeable Moving Plate in Presence of Thermal Radiation, Heat Absorption and Homogenous Chemical Reaction

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Abstract In this article we have investigated the Soret effect due to mixed convection on unsteady magneto hydrodynamic flow past a semi-infinite vertical permeable moving plate in presence of thermal radiation, heat absorption and homogenous chemical reaction, subjected to variable suction. The plate is assumed to be embedded in a uniform porous medium and moves with a constant velocity in the flow direction in the presence of a transverse magnetic field. The equations governing the flow are transformed into a system of nonlinear ordinary differential equations by using perturbation technique. Graphical results for the velocity distribution, temperature distribution and concentration distribution based on the numerical solutions are presented and discussed. We also discuss the effects of various parameters on the skin-friction coefficient and the rate of heat transfer in the form of Nusselt number and rate of mass transfer in the form of Sherwood number at the surface. Velocity distribution is observed to increase with an increase in Soret number and in the presence of permeability, where as it shows reverse effects in the case of heat absorption coefficient, magnetic parameter, radiation parameter and chemical reaction parameter.

Keywords Soret effect · MHD · Radiation · Heat absorption · Chemical reaction · Porous medium · Mixed convection · Semi-infinite vertical plate

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List of Symbols

A	Suction velocity parameter
B_0	Magnetic induction
C	Concentration
C_p	Specific heat at constant pressure
C_f	Skin friction coefficient
D	Mass diffusion coefficient
D_1	Thermal diffusion coefficient
$e_{b\lambda}$	Plank's function
F	Radiation parameter
g	Acceleration due to gravity
Gr	Grash of number
Gm	Modified Grash of number
K	Permeability of the porous medium
K_r	Chemical reaction parameter
K_λ	Absorption coefficient
M	Magnetic field parameter
N	Dimension less material parameter
n	Dimension less exponential index
Nu	Nusselt number
Pr	Prandtl number
Q_0	Heat absorption coefficient
Re_x	Local Reynolds number
Sc	Schmidt number
Sh	Sherwood number
T	Temperature
$t^/$	Dimensional time
t	Dimension less time
U_0	Scale of free streem velocity
$u^/, v^/$	Dimensional velocity components
u, v	Velocity components
V_0	Scale of suction velocity
$x^/, y^/$	Dimentional distances along and perpendicular to the plate respectively
x, y	Distance along and perpendicular to the plate respectively

Greek Symbols

α	Thermal diffusivity of the fluid
β_c	Coefficient of volumetric concentration expansion
β_T	Coefficient of volumetric thermal expansion
ε	Scalar constant
χ	Dimension less material parameter
η	Dimensiona less normal distance
ϕ	Dimensiona less heat absorption coefficient
κ	Thermal conductivity
σ	Electrical conductivity
ρ	Density of the fluid

μ	Dynamic viscosity
υ	Kinematic viscosity
τ	Friction coefficient
θ	Dimension less temperature

Subscripts and Superscripts

/	Dimentional properties
p	Plate
w	Wall condition
∞	Free streem condition

Introduction

Convective flows with concurrent heat and mass transfer under the influence of a magnetic field, chemical reaction and thermal radiation arise in many transport processes that has applications in many branches of science and engineering. This phenomenon plays a vital role in the chemical industry, chemical vapor deposition on surfaces, cooling of nuclear reactors, power and cooling industry for drying, and petroleum industries. (Anjalidevi and Kandaswamy [1], Elbashbeshy [2], Shateyi and Motsa [3]). At higher temperatures the significance of radiation effect cannot be neglected. The applications of thermal radiation can be seen in space technology, such as cosmically flight aerodynamics rocket, propulsion systems, space craft re-entry aerothermodynamics and plasma physics etc. For a radiative fully developed vertical channel fluid in the optically thin limit was investigated by several authors like Cramer and Pai [4], Grief et al. [5], Hossain et al. [6], Youn [7], Singh and Kumar [8], Srinivas and Muthuraj [9], Takhar et al. [10], Ravikumar et al. [11]. Many natural phenomena and technological problems are susceptible to the analysis of MHD. In particular, Geophysics encounters MHD characteristics in the interfaces of conducting fluids and magnetic fields. MHD principle can be employed, in the design of heat exchangers pumps and flow meters, thermal protection, in space vehicle propulsion, in creating novel power generating systems braking, control and re-entry etc. Classical studies of the above phenomena of magneto convection have been made by many. Some of them are Cussler [12], Sharma et al. [13], and Grief et al. [5]. Convection flows in porous media has gained significant attention in recent years because of their importance in the field of engineering applications such as geothermal systems, thermal insulations, solid matrix heat exchangers, oil extraction and to store nuclear waste materials. Acharya et al. [14], Ahmed [15], Chamkha [16–18], Ferraro and Plumpton [19], Kandasamy et al. [20], Nikodijevic et al. [21], Sharma [22], Reddy et al. [23] and many others contributed in this field. An exclusive study on the influence of heat generation or absorption in moving fluids is of course being very important in complications which deal with chemical reactions and those related with separating fluids. Heat generation effects may generally alter the temperature distribution as a result the particle deposition rate in nuclear reactors, electronic chips and semiconductor wafers etc. Heat generation/absorption effect on MHD flow of a uniformly stretched vertical permeable surface in the presence of chemical reaction was studied by Cogly et al. [24], Makinde and Aziz [25]. In wide-ranging of applications, the thermal diffusion (Soret) effects are of a smaller order of magnitude than the effects described by well-known Fourier's or Fick's laws and are often may be neglected in heat and mass transfer processes. However, the Soret effect, for example, has been used for isotope separation and in mixtures between gases with less molecular weight (H2, He) and medium molecular weight. Accordingly, the main aim of this paper is to study the Soret effects due to mixed convection on unsteady magneto hydrodynamic, reactive flow past a semi-infinite vertical permeable moving plate with radiation and heat absorption. Reddy et al. [26,27], Hayat and Qasim [28], Ravikumar et al. [29]. Sharma [22], Shateyi and Motsa [3] and several others [30–38] contributed in this field. As far as the author's knowledge is concern none of the above studies have gone through the effects of thermal diffusion, thermal radiation, and chemical reaction in the presence of heat absorption on boundary layer mixed MHD flow over a vertical surface through a porous medium. Very recently, Ravikumar et al. [11], studied MHD double diffusive and chemically reactive flow through porous medium confined by two vertical plates. This manuscript is an extension for the work of Chamkha [18], in which we have included thermal radiation, Soret, and chemical reaction effects on mixed convection MHD flow past a vertical plate with suction over a porous medium in the occurrence of heat absorption.

In spite of all the previous studies, influence of magnetic field on mixed convection heat generation/absorption fluid with thermal diffusion and radiation in the presence of a reacting species over an infinite permeable plate has received slight attention. Encouraged by the above referenced work and the numerous likely industrial applications of the problem as mentioned above, it is of paramount interest in this study to investigate the Soret effect due to mixed convection on magneto hydrodynamic flow past a semi-infinite vertical permeable stirring plate in presence of thermal radiation, heat absorption and regular chemical reaction, subjected to time varying suction. The plate is assumed to be in a uniform porous medium and moves with a uniform velocity direction of the flow in the presence of a transverse magnetic field. The equations govern the flow are transformed into a set of nonlinear differential equations and solved by using a perturbation method. The expressions are obtained for velocity, temperature and concentration and studied with the help of graphs in the presence of various physical parameters. The effects of various parameters on the skin-friction coefficient and the rate of heat and mass transfer at the surface are also studied.

Formulation of the Problem

We have considered unsteady MHD two dimensional flows of a laminar, viscous, incompressible, electrically conducting, double diffusive and absorbing fluid past a semi infinite vertical permeable moving plate embedded in a uniform porous medium and subjected to a uniform transverse magnetic field in the presence of thermal radiation and homogeneous chemical reaction. It is assumed that there is no applied voltage which implies the absence of an electrical field. The transversely applied magnetic field and magnetic Reynolds number are assumed to be very small so that the induced magnetic field and the Hall Effect are negligible. $x^{/}$-axis is taken in the upward direction along with the flow and $y^{/}$-axis is taken perpendicular to it. Initially the plate is assumed to be moving with a uniform velocity $u_p^{/}$ in the direction of the fluid flow, and the free stream velocity follows the exponentially increasing small perturbation law. Besides that, it is assumed that the temperature and the concentration at the wall as well as the suction velocity are exponentially varying with time. By considering the above assumptions, the governing equations are given by

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

$$\frac{\partial u^{/}}{\partial t^{/}} + v^{/}\frac{\partial u^{/}}{\partial y^{/}} = -\frac{1}{\rho}\frac{\partial p^{/}}{\partial x^{/}} + \upsilon\frac{\partial^2 u^{/}}{\partial y^{/2}} + g\beta_T\left(T^{/} - T^{/}_{\infty}\right) + g\beta_C\left(C^{/} - C^{/}_{\infty}\right)\frac{\sigma B_0^2 u^{/}}{\rho} - \upsilon\frac{u^{/}}{k^{/}} \tag{2}$$

$$\frac{\partial T^{/}}{\partial t^{/}} + v^{/}\frac{\partial T^{/}}{\partial y^{/}} = \frac{\kappa}{\rho C_p}\frac{\partial^2 T^{/}}{\partial y^{/2}} - \frac{1}{\rho C_p}\frac{\partial q_r^{/}}{\partial y^{/}} + \frac{Q^{/}}{\rho C_p}\frac{\partial T^{/}}{\partial y^{/}} \tag{3}$$

$$\frac{\partial C^{/}}{\partial t^{/}} + v^{/}\frac{\partial C^{/}}{\partial y^{/}} = D\frac{\partial^2 C^{/}}{\partial y^{/2}} + D_1\frac{\partial^2 T^{/}}{\partial y^{/2}} - K_c\left(C^{/} - C^{/}_{\infty}\right) \tag{4}$$

Under the above assumptions, the appropriate boundary conditions for the distributions of velocity, temperature and concentration are given by

$$u^{/} = u^{/}_{p}, T^{/} = T^{/}_{w} + \varepsilon\left(T^{/}_{w} - T^{/}_{\infty}\right)e^{n^{/}t^{/}}, C^{/} = C^{/}_{w} + \varepsilon\left(C^{/}_{w} - C^{/}_{\infty}\right)e^{n^{/}t^{/}} at y^{/} = 0 \tag{5}$$

$$u^{/} \to U^{/}_{\infty} = U_0\left(1 + \varepsilon e^{n^{/}t^{/}}\right), T^{/} \to T^{/}_{\infty}, C^{/} \to C^{/}_{\infty} \;\; as \;\; y \to \infty \tag{6}$$

It is known from Eq. (1) that the suction velocity at the plate surface is a function of time only and it is assumed in the following form,

$$v^{/} = -V_0\left(1 + \varepsilon A e^{n^{/}t^{/}}\right) \tag{7}$$

Outside the boundary layer Eq. (2) modifies as

$$-\frac{1}{\rho}\frac{dp^{/}}{dx^{/}} = \frac{dU^{/}_{\infty}}{dt^{/}} + \frac{\upsilon}{k^{/}}U^{/}_{\infty} + \frac{\sigma}{\rho}B_0^2 U^{/}_{\infty} \tag{8}$$

We consider a mathematical model, for an optically thin limit gray gas near equilibrium in the form given by Cramer and Pai [4]. Later Grief et al. [5]:

$$\frac{\partial q_r^{/}}{\partial y^{/}} = 4\left(T^{/} - T^{/}_{w}\right)I \tag{9}$$

Where $I = \int_0^{\infty} K_{\lambda w}\left(\frac{\partial e_{b\lambda}}{\partial T}\right)_w d\lambda$, $K_{\lambda w}$ is the absorption coefficient at the wall and $e_{b\lambda}$ is Planck's function.

By introducing the following non-dimensional variables and parameters

$$u = \frac{u^{/}}{U_0}, v = \frac{v^{/}}{V_0}, \eta = \frac{V_0 y^{/}}{\upsilon}, U_{\infty} = \frac{U^{/}_{\infty}}{U_0}, U_p = \frac{u^{/}_{p}}{U_0}, t = \frac{t^{/}V_0^2}{\upsilon}, \theta = \frac{T^{/} - T^{/}_{\infty}}{T^{/}_{w} - T^{/}_{\infty}},$$
$$C = \frac{C^{/} - C^{/}_{\infty}}{C^{/}_{w} - C^{/}_{\infty}}, n = \frac{n^{/}\upsilon}{V_0^2}, k = \frac{k^{/}V_0^2}{\upsilon}, \Pr = \frac{\mu C_p}{\kappa}, Sc = \frac{\upsilon}{D}, M = \frac{\sigma B_0^2\upsilon}{\rho V_0^2},$$
$$S_0 = \frac{D_1\left(T^{/}_{w} - T^{/}_{\infty}\right)}{\upsilon\left(C^{/}_{w} - C^{/}_{\infty}\right)}, K_r = \frac{K^{/}_{c}\upsilon}{V_0^2}, F = \frac{4I_1\upsilon}{\rho C_p V_0^2}, Gr = \frac{\upsilon\beta_T g\left(T^{/}_{w} - T^{/}_{\infty}\right)}{U_0 V_0^2},$$
$$Gm = \frac{\upsilon\beta_C g\left(C^{/}_{w} - C^{/}_{\infty}\right)}{U_0 V_0^2}, \phi = \frac{Q^{/}}{\rho C_p V_0}. \tag{10}$$

In view of Eqs. (7)–(10), (2)–(4) are reduced to the following non-dimensional form,

$$\frac{\partial u}{\partial t} - \left(1 + \varepsilon A e^{nt}\right)\frac{\partial u}{\partial \eta} = \frac{dU_\infty}{dt} + \frac{\partial^2 u}{\partial \eta^2} + Gr\theta + GmC + N(U_\infty - u) \quad (11)$$

$$\frac{\partial \theta}{\partial t} - \left(1 + \varepsilon A e^{nt}\right)\frac{\partial \theta}{\partial \eta} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial \eta^2} - \chi\theta \quad (12)$$

$$\frac{\partial C}{\partial t} - \left(1 + \varepsilon A e^{nt}\right)\frac{\partial C}{\partial \eta} = \frac{1}{Sc}\frac{\partial^2 C}{\partial \eta^2} - K_c C + S_0\frac{\partial^2 \theta}{\partial \eta^2} \quad (13)$$

Where $N = M + \frac{1}{k}, \chi = \phi + F$

The dimension less form of the boundary conditions (5) and (6) become

$$u = U_p, \quad \theta = 1 + \varepsilon e^{nt}, \quad C = 1 + \varepsilon e^{nt} \quad at \quad \eta = 0 \quad (14)$$

$$u \to U_\infty = 1 + \varepsilon e^{nt}, \quad \theta \to 0, \quad C \to 0 \;\; as \;\; \eta \to \infty \quad (15)$$

Solution of the Problem

The set of Eqs. (11)–(13) are partial differential equations which cannot be solved in closed form. However, these can be solved by reducing them into a set of ordinary differential equations using the following perturbation method. We now represent the velocity, temperature and concentration distributions in terms of harmonic and non-harmonic functions as

$$u = u_0(\eta) + \varepsilon \exp(nt) u_1(\eta) + O(\varepsilon^2) + ------- \quad (16)$$

$$\theta = \theta_0(\eta) + \varepsilon \exp(nt) \theta_1(\eta) + O(\varepsilon^2) + ------- \quad (17)$$

$$C = C_0(\eta) + \varepsilon \exp(nt) C_1(\eta) + O(\varepsilon^2) + ------- \quad (18)$$

Substituting Eqs. (16)–(18) into Eqs. (11)–(13), and equating the harmonic and non-harmonic terms, and neglecting the higher order terms of ε, we obtain the following pairs of equations of order zero and order one.

$$u_0^{//} + u_0^{/} - Nu_0 = -N - Gr\theta_0 - GmC_0 \quad (19)$$

$$u_1^{//} + u_1^{/} - (N + n)u_1 = -(N + n) - Au_0^{/} - Gr\theta_1 - GmC_1 \quad (20)$$

$$\theta_0^{//} + \Pr\theta_0^{/} - \Pr\chi\theta_0 = 0 \quad (21)$$

$$\theta_1^{//} + \Pr\theta_1^{/} - \Pr(n - \chi)\theta_1 = -A\Pr\theta_0^{/} \quad (22)$$

$$C_0^{//} + ScC_0^{/} - ScKc\theta_0 = -ScS_0\theta_0^{//} \quad (23)$$

$$vC_1^{//} + ScC_1^{/} - (KcSc + Scn)C_1 = -ScS_0\theta_1^{//} - AScC_0 \quad (24)$$

Where the prime denotes differentiation with respect to η. The corresponding boundary conditions are now given by

$$u_0 = U_p, \quad u_1 = 0, \quad \theta_0 = 1, \quad \theta_1 = 1, \quad C_0 = 1, \quad C_1 = 1 \;\; at \;\; \eta = 0 \quad (25)$$

$$u_0 = 1, \quad u_1 = 1, \quad \theta_0 \to 0, \quad \theta_1 \to 0, \quad C_0 \to 0, \quad C_1 \to 0 \;\; as \;\; \eta \to \infty \quad (26)$$

Now by using the boundary conditions (24)–(25) and solving the set of Eqs. (18)–(23), we get the following solutions.

$$u_0 = 1 + c_9 \exp(-m_9\eta) + (k_{12} + k_{14}) \exp(-m_1\eta) + k_{13} \exp(-m_6\eta) \tag{27}$$

$$u_1 = 1 + c_{11} \exp(-m_{11}\eta) + k_{15} \exp(-m_9\eta) + k_{20} \exp(-m_7\eta) + k_{25} \exp(-m_3\eta) + k_{26} \exp(-m_1\eta) \tag{28}$$

$$\theta_0 = \exp(-m_1\eta) \tag{29}$$

$$\theta_1 = c_3 \exp(-m_3\eta) + k_1 \exp(-m_1\eta) \tag{30}$$

$$C_0 = c_6 \exp(-m_6\eta) + k_2 \exp(-m_1\eta) \tag{31}$$

$$C_1 = c_6 \exp(-m_7\eta) + k_8 \exp(-m_6\eta) + k_{10} \exp(-m_3\eta) + (k_9 + k_{10}) \exp(-m_1\eta) \tag{32}$$

In view of the above solutions, the velocity, temperature and concentration distributions in the boundary layer become

$$u(\eta, t) = 1 + c_9 \exp(-m_9\eta) + (k_{12} + k_{14}) \exp(-m_1\eta) + k_{13} \exp(-m_6\eta) + \varepsilon \exp(nt) \begin{pmatrix} 1 + c_{11} \exp(-m_{11}\eta) + k_{15} \exp(-m_9\eta) + k_{20} \exp(-m_7\eta) \\ + k_{25} \exp(-m_3\eta) + k_{26} \exp(-m_1\eta) \end{pmatrix} \tag{33}$$

$$\theta(\eta, t) = \exp(-m_1\eta) + \varepsilon \exp(nt) (c_3 \exp(-m_3\eta) + k_1 \exp(-m_1\eta)) \tag{34}$$

$$C(\eta, t) = c_6 \exp(-m_6\eta) + k_2 \exp(-m_1\eta) + \varepsilon \exp(nt) (c_6 \exp(-m_7\eta) + k_8 \exp(-m_6\eta) + k_{10} \exp(-m_3\eta) + (k_9 + k_{10}) \exp(-m_1\eta)) \tag{35}$$

Skin friction:

Very important physical parameter at the boundary is the skin friction which is given in the non-dimensional form and derives as

$$C_f = \frac{\tau_w^{/}}{\rho U_0 V_0} = \left.\frac{\partial u}{\partial \eta}\right|_{\eta=0} = (-c_9 m_9 - m_1(k_{12} + k_{14}) - m_6 k_{13}) + \varepsilon \exp(nt) (-c_{11} m_{11} - m_9 k_{15} - m_7 k_{20} - m_6 k_{24} - m_3 k_{25} - m_1 k_{26}) \tag{36}$$

Another physical parameter like rate of heat transfer in the form of Nusselt number and the rate of mass transfer in the form of Sherwood number are also derived and given below respectively

$$N_u = x \frac{\left.\frac{\partial T^{/}}{\partial y^{/}}\right|_{y=0}}{T_w^{/} - T_\infty^{/}} \Rightarrow N_u \ \mathrm{Re}_x^{-1} = \left.\frac{\partial \theta}{\partial \eta}\right|_{\eta=0} = -m_1 + \varepsilon \exp(nt) (-c_3 m_3 - m_1 k_1) \tag{37}$$

$$S_h = x \frac{\left.\frac{\partial C^{/}}{\partial y^{/}}\right|_{y=0}}{C_w^{/} - C_\infty^{/}} \Rightarrow S_h \ \mathrm{Re}_x^{-1} = \left.\frac{\partial C}{\partial \eta}\right|_{\eta=0} = (-c_6 m_6 - m_1 k_2) + \varepsilon \exp(nt) (-c_7 m_7 - m_6 k_8 - m_3 k_{10} - m_1 (k_9 + k_{11})) \tag{38}$$

Results and Discussion

In order to get a physical insight into the problem, factors such as velocity u, Temperature θ, Concentration C, Skin friction τ, Nusselt number Nu have been discussed by assigning numerical values to various parameter like heat absorption coefficient ϕ, Magnetic parameter M, Radiation Parameter F,chemical reaction parameter Kc, Sorret number So, Permeability parameter k, Schmidt number Sc, and the solutions are shown in Figs, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12. Figure 1 represents the Velocity Profiles for different values of heat absorption coefficient ϕ. It is observed that ‘u’ decreases when φ increases for fixed values A = 0.5, Pr = 0.71,

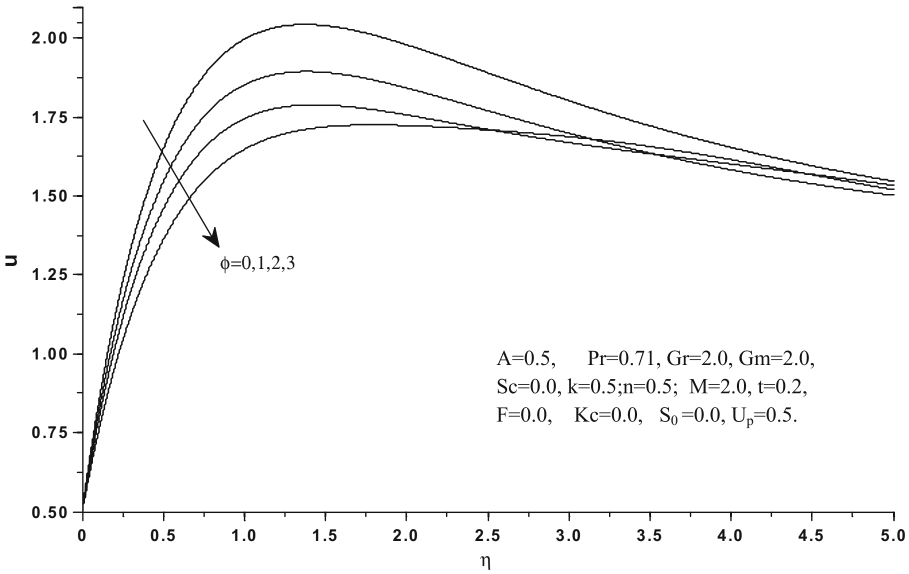

Fig. 1 Effects of ϕ on velocity when So = 0, F = 0, Kc = 0

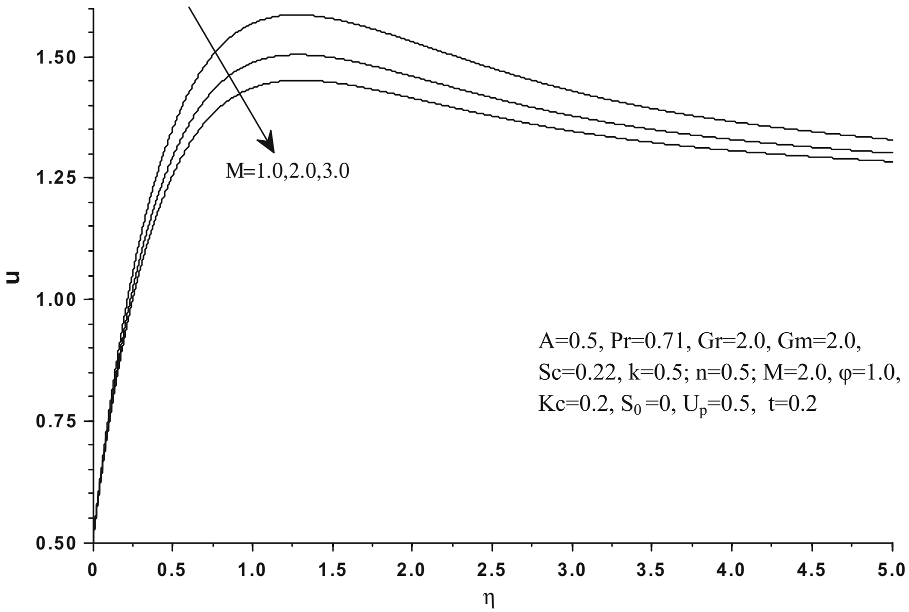

Fig. 2 Effects of M on velocity

Gr = 2.0, Gm = 2.0, k = 0.5, n = 0.5, M = 2.0, $U_p = 0.5$, t = 0.2 and in the absence of Sc, F, Kc and So. These results are found to be in good agreement with the existing results of Chamkha [18]. Figure 2 reveals the effects of magnetic Parameter M on the velocity distribution. As expected, velocity is observed to decrease with an increase in M. This is physically

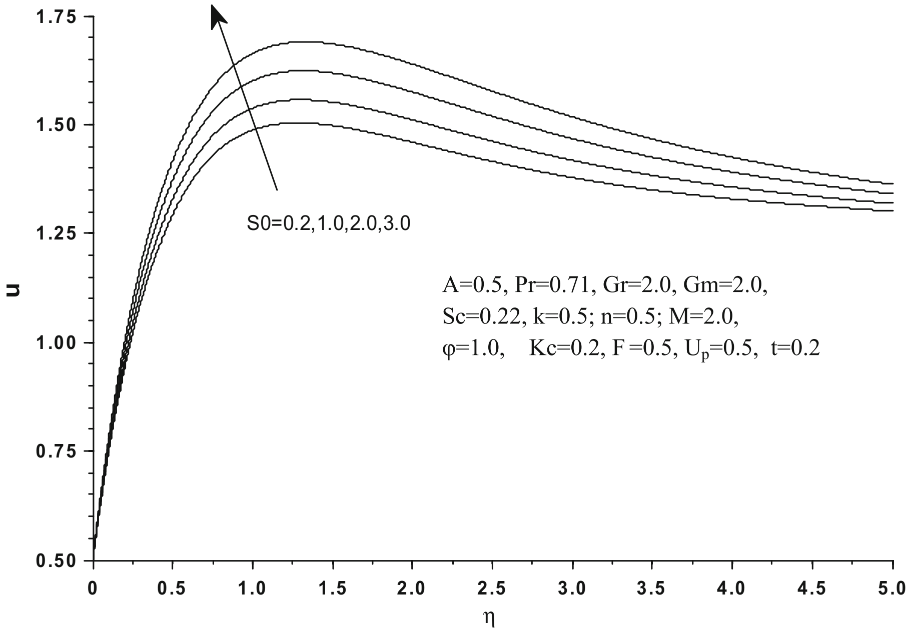

Fig. 3 Effect of So on velocity

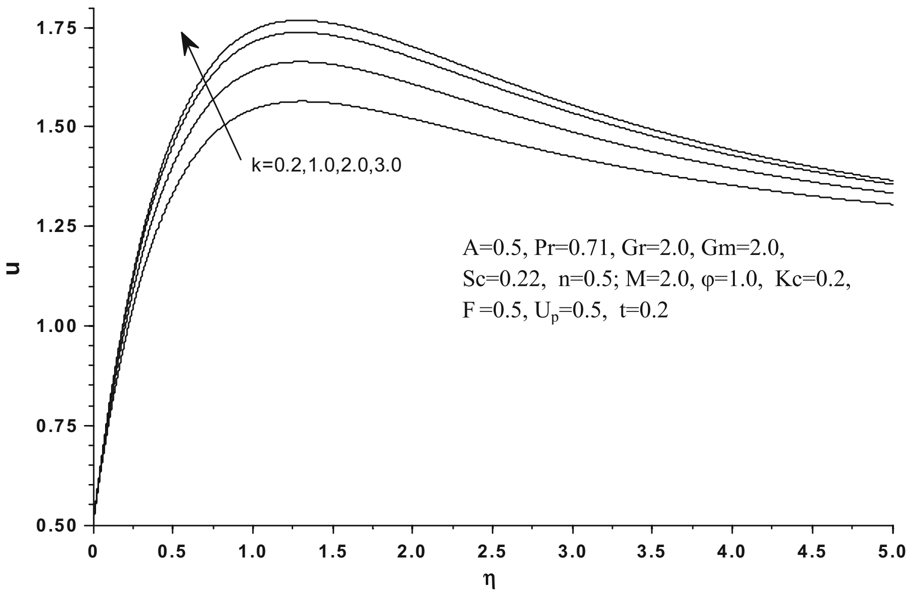

Fig. 4 Effect of k on velocity

true because magnetic force acts as Lorentz force that retards the flow therefore the thickness of the momentum boundary layer is condensed. Similar results are noticed by Raju et al. [30,31]. Figure 3 displays the effects of Soret number So on the Velocity field, it is found that the Velocity increases with an increase in So. The effects of permeability parameter k

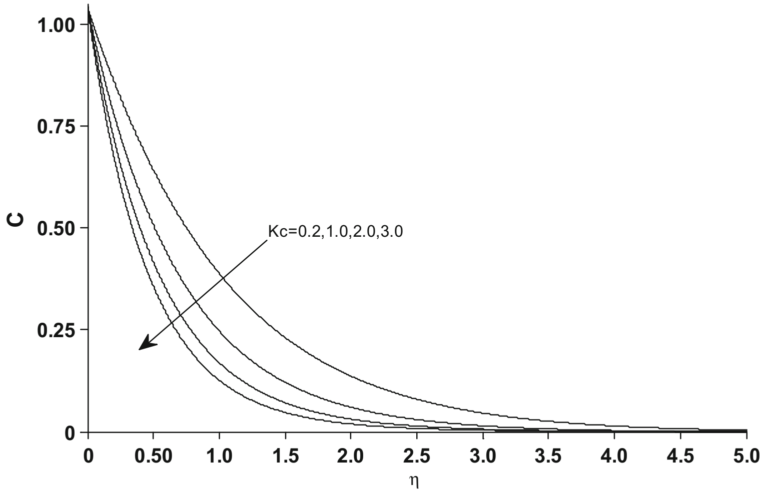

Fig. 5 Effects of Kc on concentration

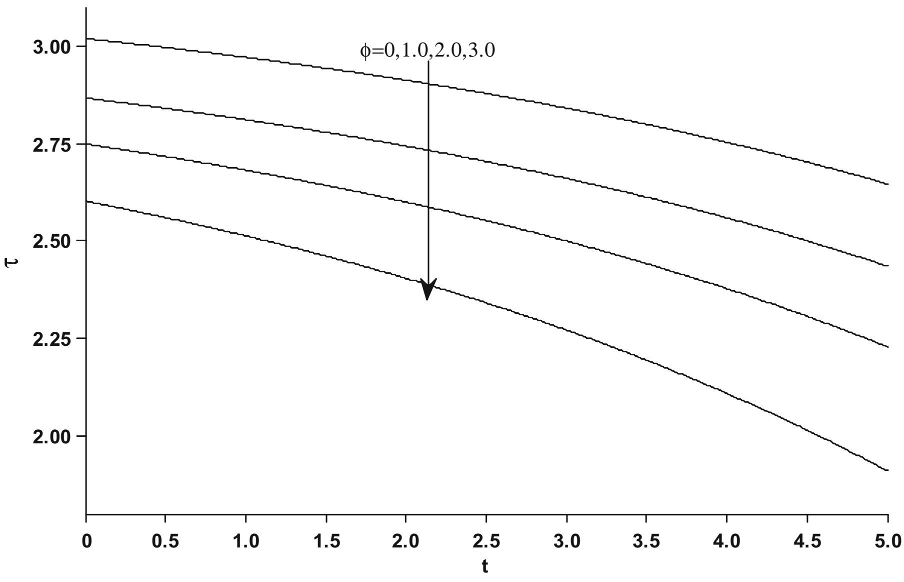

Fig. 6 Effect of ϕ on skin friction

on the velocity field is depicted in Fig. 4. From this figure it is observed that 'u' increases with an increase in 'k'. physically, an increase in the permeability of porous medium leads 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. So that velocity at the insulated bottom is observed to be zero and gradually it increases as it reaches the free surface and attains a maximum there in (see Raju et al. [31]).

Figure 5, depicts the influence of chemical reaction effect on concentration. This figure witness that concentration decreases with an increase in the values of chemical reaction

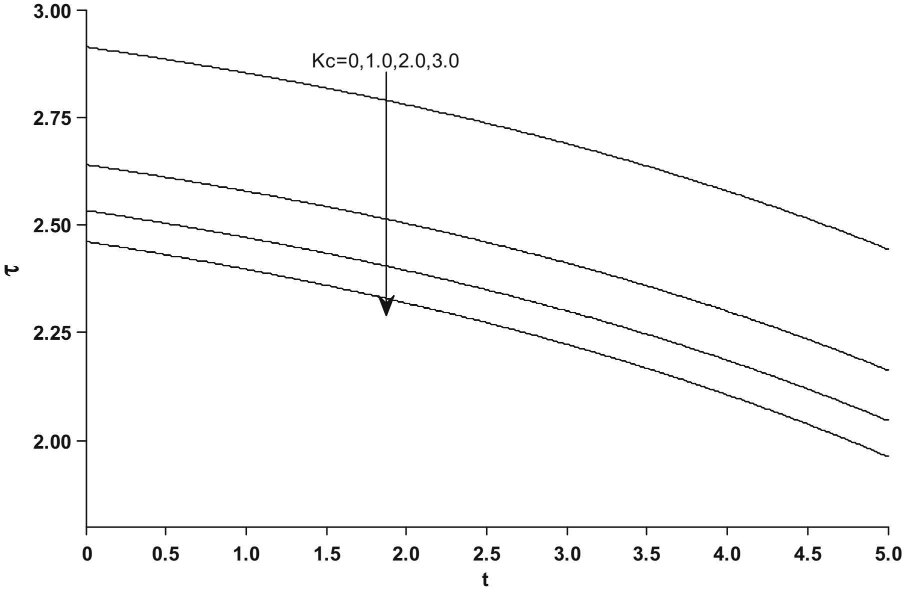

Fig. 7 Effect of Kc on τ

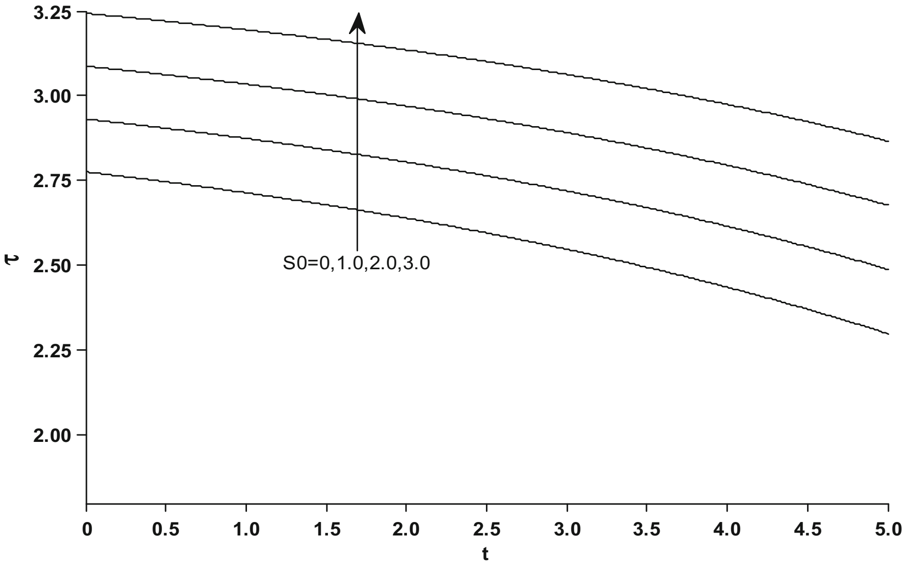

Fig. 8 Effect of So on τ

parameter. Figure 6 illustrates the influence of heat absorption coefficient ϕ on the Skin friction. From this figure it is observed that 'τ' decreases with an increase in ϕ.

The influences of the Rate of chemical reaction Kc on the Skin friction τ are shown in Fig. 7. From this figure it is seen that 'τ' decreases with an increase in Kc. Figure 8 represents

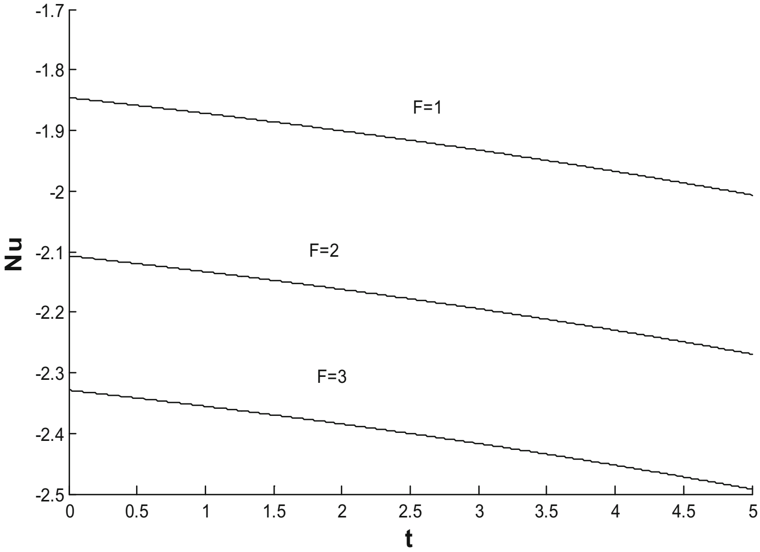

Fig. 9 Eeffect of F on Nu

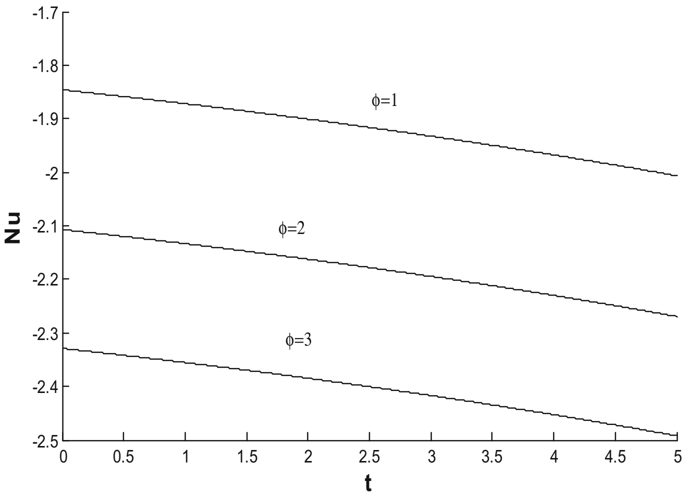

Fig. 10 Effect of ϕ on Nu

the effects of Soret number So on Skin friction τ. From this figure it is observed that 'τ' increases with an increase in So.

Nusselt number Nu is presented in Figs. 9 and 10 against time t for different values of radiation parameter F and heat absorption coefficient ϕ. From these figures it is found that the Nusselt number decreases with an increase in Radiation Parameter F and heat absorption coefficient ϕ. Share wood number is studied in Figs. 11 and 12 against time t for various values of Soret number and chemical reaction parameter. From these figures it is observed that Share wood number increases with an increase in Soret number So and decreases with an increase in rate of chemical reaction Kc.

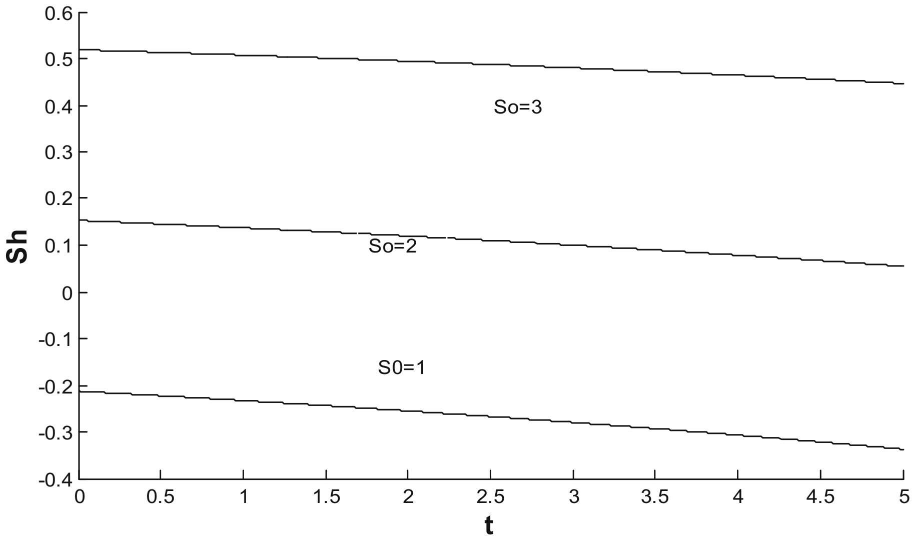

Fig. 11 Effect of So on Sherwood number

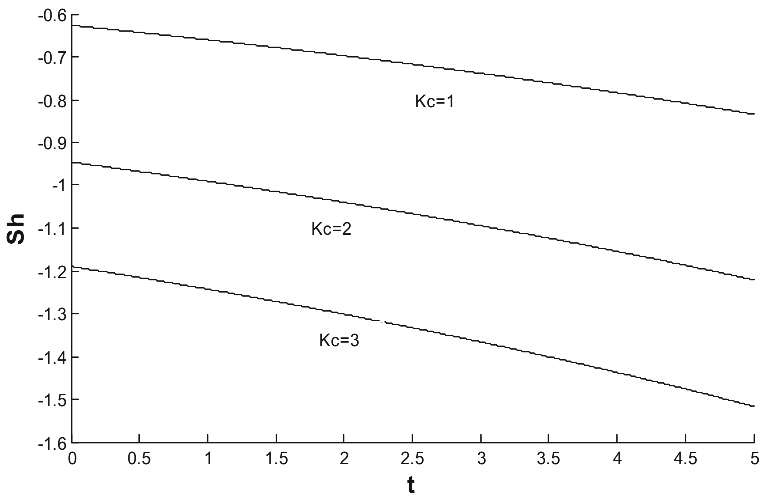

Fig. 12 Effect of Kc on Sherwood number

Conclusions

Soret effect due to mixed convection on unsteady magneto hydrodynamic flow past a semi-infinite vertical permeable moving plate in presence of thermal radiation, heat absorption and homogenous chemical reaction, subjected to variable suction is considered here. The following is the summery of the conclusions.

a. Velocity distribution is observed to increase with an increase in Soret number and in the presence of permeability, where as it shows reverse effects in the case of heat absorption coefficient, magnetic parameter, radiation parameter and chemical reaction parameter.

b. Temperature distribution increases with an increase in heat absorption coefficient where as it decreases with an increase in radiation parameter.
c. Concentration distribution decreases as the chemical reaction parameter increases, whereas, as expected it increases with the increase in Soret number.

References

1. Anjalidevi, S.P., Kandasamy, R.: Effects of chemical reaction heat and mass transfer on MHD flow past a semi infinite plate. J. Appl. Math. Mech. **80**, 697–701 (2000)
2. Elbashbeshy, E.M.A.: The mixed convection along a vertical plate embedded in non-darcian porous medium with suction and injection. Appl. Math. Comput. **136**(1), 139–149 (2003)
3. Shateyi, S., Motsa, S.S.: Unsteady magneto hydrodynamic convective heat and mass transfer past an infinite vertical plate in a porous medium with thermal radiation, heat generation/absorption and chemical reaction. Adv. Top. Mass Trans. 145–162 (2010)
4. Cramer, K.P., Pai, S.I.: Magneto Fluid Dynamics for Engineers and Applied Physics. McGraw-Hill Book Co, New York (1973)
5. Grief, G., Habib, I.S., Lin, L.C.: Laminar convection of a radiating gas in a vertical channel. J. Fluid Mech. **45**, 513–520 (1971)
6. Hossain, M.A., Alim, M.A., Rees, D.A.S.: The effect of radiation on free convection from a porous vertical plate. Int. J. Heat Mass Transf. **42**, 181–191 (1999)
7. Youn, K.J.: Unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction. Int. J. Eng. Sci. **38**, 833–845 (2000)
8. Singh, K.D., Kumar, R.: Fluctuating heat and mass transfer on unsteady MHD free convection flow of radiating and reacting fluid past a vertical porous plate in slip-flow regime. J. Appl. Fluid Mech. **4**(4), 101–106 (2011)
9. Srinivas, S., Muthuraj, R.: Effects of thermal radiation and space porosity on MHD mixed convection flow in a vertical channel using Homotopy analysis method. Commun. Nonlinear Sci. Numer. Simul. **15**, 2098–2108 (2010)
10. Takhar, H.S., Chamkha, A.J., Nath, G.: Flow and mass transfer on a stretching sheet with a magnetic field and chemically reactive species. Int. J. Eng. Sci. **12**, 1303–1314 (2000)
11. Ravikumar, V., Raju, M.C., Raju, G.S.S., Chamkha, A.J.: MHD double diffusive and chemically reactive flow through porous medium bounded by two vertical plates. Int. J. Energy Technol. **5**(7), 1–8 (2013)
12. Cussler, E.L.: Diffusion Mass Transfer in Fluid Systems. Cambridge University Press, London (1998)
13. Sharma, B.K., Chaudhary, R.C., Agarwal, M.: Radiation effect on steady free convective flow along a uniform moving vertical porous plate in presence of heat source/sink and transverse magnetic field. Bull. Calcutta Math. Soc. **100**(5), 529–538 (2008)
14. Acharya, M., Dash, G.C., Singh, L.P.: Magnetic field effects on the free convection and mass transfer flow through porous medium with constant suction and constant heat flux. Indian J. Pure Appl. Math. **31**(1), 1–18 (2000)
15. Ahmed, N.: Magnetic field effect on a three-dimensional mixed convective flow with mass transfer along an infinite vertical porous plate. Int. J. Eng. Sci. Technol. 2 **134**(2), 117–135 (2010)
16. Chamaka, A.J.: Hydro magnetic combined heat and mass transfer by natural convection from a permeable surface embedded in a fluid saturated porous medium. Int. J. Numer. Methods Heat Fluid Flow **10**(5), 455–476 (2000)
17. Chamkha, A.J.: Unsteady MHD convective heat and mass transfer past a semi-ininite vertical permeable moving plate with heat absorption. Int. J. Eng. Sci. **38**, 217–230 (2004)
18. Chamkha, A.J.: MHD flow of a uniformly stretched vertical permeable surface in the presence of heat generation/absorption and a chemical reaction. Int. Commun. Heat Mass Transf. **30**(3), 413–422 (2003)
19. Ferraro, V.C.A., Plumpton, C.: An Introduction to Magneto Fluid Mechanics. Clarendon Press, Oxford (2006)
20. Kandasamy, R., Periasamy, K., Sivagnana Prabhu, K.K.: Effects of chemical reactions heat and mass transfer along a wedge with heat source in the presence of suction or injection. In. J. Heat Mass Transf. **48**, 1388–1393 (2005)
21. Nikodijevic, D., Boricic, Z., Milenkovic, D., Stamenkovic, Z.: Generalized similarity method in unsteady two dimensional MHD boundary layer on the body which temperature varies with time. Int. J. Eng. Sci. Tech. **1**(1), 206–215 (2009)
22. Sharma, P.K.: Fluctuating thermal and mass diffusion on unsteady free convection flow past a vertical plate in slip flow regime. Lat. Am. Appl. Res. **35**, 313–319 (2005)

23. Reddy, T.S., Varma, S.V.K., Raju, M.C.: Chemical reaction and radiation effects on unsteady MHD free convection flow near a moving vertical plate, i-manager's Journal on Future. Eng. Technol. **7**(4), 11–20 (2012)
24. Cogly, A.C., Vincenti, W.G., Gill, S.E.: Differential approximation for radiative transfer in a non gray gas near equilibrium. AIAA J. **6**, 551–553 (1968)
25. Makinde, O.D., Aziz, A.: MHD mixed convection from a vertical plate embedded in a porous medium with a convective boundary condition. Int. J. Therm. Sci. **49**, 1813–1820 (2010)
26. Reddy, N.A., Varma, S.V.K., Raju, M.C.: Thermo diffusion and chemical effects with simultaneous thermal and mass diffusion in MHD mixed convection flow with ohmic heating. J. Naval Archit. Mar. Eng. **6**, 84–93 (2009)
27. Reddy, N.A., Varma, S.V.K., Raju, M.C.: Soret effects on MHD three dimensional free convection couette flow with heat and mass transfer in presence of a heat sink. Int. J. Fluid Mech. **2**(1), 51–60 (2010)
28. Hayat, T., Qasim, M.: Influence of thermal radiation and Joule heating on flow of a Maxwell fluid in the presence of thermophoresis. Int. J. Heat Mass Transf. **53**(21–22), 4780 (2010)
29. Ravikumar, V., Raju, M.C., Raju, G.S.S.: Heat and mass transfer effects on MHD flow of viscous fluid through non-homogeneous porous medium in presence of temperature dependent heat source. Int. J. Contemp. Math. Sci. **7**(32), 1597–1604 (2012)
30. Raju, M.C., Varma, S.V.K., Seshaiah, B.: Heat transfer effects on a viscous dissipative fluid flow past a vertical plate in the presence of induced magnetic field. Ain Shams Eng. J. **6**(1), 333–339 (2015). doi:10.1016/j.asej.2014.07.009
31. Raju, K.V.S., Reddy, T.S., Raju, M.C., Satyanarayana, P.V., Venkataramana, S.: MHD convective flow through porous medium in a horizontal channel with insulated and impermeable bottom wall in the presence of viscous dissipation and Joule's heating. Ain Shams Eng. J. **5**(2), 543–551 (2014). doi:10.1016/j.asej.2013.10.007
32. Alam, S., Rahman, M.M., Maleque, A., Ferdows, M.: Dufour and Soret effects on steady MHD combined free-forced convective and mass transfer flow past a semi-Infinite vertical plate. Thammasat Int. J. Sci. Technol. **11**(2), 1–12 (2006)
33. Hayat, T., Mustafa, M., Pop, I.: Heat and mass transfer for Soret and Dufour's effect on mixed convection boundary layer flow over a stretching vertical surface in a porous medium filled with a viscoelastic fluid. Commun. Nonlinear Sci. Numer. Simul. **15**(5), 1183–1196 (2010)
34. Raju, M.C., Varma, S.V.K., Reddy, P.V., Saha, S.: Soret effects due to Natural convection between heated inclined plates with magnetic field. J. Mech. Eng. **39**, 43–48 (2008)
35. Shateyi, S., Motsa, S.S., Sibanda, P.: The effects of thermal radiation, Hall current, soret, and dufour on MHD flow by mixed convection over a vertical surface in porous media. Math. Probl. Eng. 1–20 (2010)
36. Shateyi, S., Motsa, S.S.: Thermal radiation effects on heat and mass transfer over an unsteady stretching surface. Math. Probl.Eng. 1–13 (2009)
37. Animasaun, I.L.: Effects of thermophoresis, variable viscosity and thermal conductivity on free convective heat and mass transfer of non-Darcian MHD dissipative Casson fluid flow with suction and nth order of chemical reaction. J. Niger. Math. Soc. **34**, 11–31 (2015)
38. Vidyasagar, B., Raju, M.C., Varma, S.V.K., Ramana, S.V.K.: Unsteady MHD free convection boundary layer flow of radiation absorbing Kuvshinski fluid through porous medium. Rev. Adv. Phys. Theor. Appl. **1**(3), 48–62 (2014)