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Soret Effect on Transient MHD Convective Flow past a Semi-infinite Vertical Porous Plate with Heat Sink and Chemical Reaction

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Abstract

This problem concerns with an analytical study of heat and mass transfer on unsteady MHD convective flow past a semi-infinite porous vertical plate in presence of thermal diffusion, heat sink and chemical reaction. A uniform magnetic field is imposed transversely to the plate. The governing equations are solved by perturbation technique. The expressions for the velocity, temperature and concentration fields as well as transport properties are obtained in non-dimensional form. The influence of the physical parameters like magnetic field parameter, Schmidt number, Prandtl number, heat sink parameter, chemical reaction parameter and Soret number on these fields is discussed through graphs and tables. It is found that the presence of thermal diffusion enhances the fluid motion.

Keywords: Heat and mass transfer; thermal diffusion; Nusselt number; Sherwood number; suction; chemical reaction

MSC 2010 No.: 76W05, 80A20

Nomenclature

B_0	Strength of the applied magnetic field
$\vec{B}$	Magnetic induction vector
C^*	Species concentration
C^*_∞	Species concentration in free stream
C^*_w	Species concentration at the plate

C_p	Specific heat at constant pressure
D_M	Mass diffusion coefficient
$\vec{E}$	Electric field
Gr	Grashof number for heat transfer
Gm	Grashof number for mass transfer
g	Acceleration due to gravity
$\vec{J}$	Current density
K^*	Rate of first order chemical reaction
K	Chemical reaction parameter
k^*	Permeability of porous medium
k	Permeability parameter
K_T	Thermal diffusion ratio
M	Magnetic parameter
Nu	Nusselt number
Pr	Prandtl number
Q	Heat sink parameter
Q^*	Heat sink
Sr	Soret number
Sh	Sherwood number
T^*	Fluid temperature
T_∞^*	Temperature at the free stream
T_w^*	Temperature at the plate
T_M	Mean fluid temperature
t	Dimensionless time
μ	Coefficient of viscosity
κ	Thermal conductivity
υ	Kinematic viscosity
σ	Electrical conductivity
ρ	Fluid density
θ	Dimensionless temperature
ϕ	Dimensionless concentration
β	Coefficient of volume expansion for heat transfer
β^*	Coefficient of volume expansion for mass transfer

1. Introduction

The study of magnetic field on viscous incompressible flow of electrically conducting fluid has stimulated the interest of many researchers because of its wide applications in various fields. MHD (Magneto hydrodynamics) plays an important role in agriculture, petroleum industries, geophysics and in astrophysics. MHD is the discipline that deals with the motion of electrically conducting fluids in presence of magnetic field. It concerns with the investigation of the interaction of magnetic fields and electrically conducting fluids (e.g., plasma, electrolytes, liquid metals etc.). Such types of works in MHD flow were carried out by researchers like Seth et al. (2011), Takhar et al. (1996), Sengupta (2015), Oahimire et al. (2014) and many more. Johari et al. (2008) analyzed unsteady MHD flow through porous medium and heat transfer past a porous vertical moving plate with heat source. Sattar and Kalim (1996) investigated the unsteady free convection interaction with thermal radiation in a boundary layer flow past a vertical porous plate.

The effect of chemical reaction on an unsteady MHD free convection flow past an infinite vertical porous plate with variable suction was studied by Sarada and Shanker (2013). Ahmed and Das (2013) studied MHD mass transfer flow past a vertical porous plate in porous medium in a slip flow regime with radiation and chemical reaction. Balamurugan et al. (2015) investigated unsteady MHD free convective flow past a vertical plate with time dependent suction and chemical reaction in a slip flow regime. Prakash et al. (2011) have made a systematic investigation of fluid flow with chemical reaction on unsteady MHD mixed convective flow over a moving vertical porous plate. Chamkha (2004) studied unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption. Mythreye et al. (2015) examined chemical reaction on unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption. Recently Ahmed and Agarwalla (2016) studied effect of heat sink on transient MHD mass transfer flow past an accelerated vertical plate with chemical reaction.

The process of mass transfer that occurs by the combine effects of concentration as well as temperature gradients is known as *thermal diffusion* or *Soret effect*. The experimental investigation of the thermal diffusion effect on mass transfer related problems was first performed by Charles Soret in 1879. Unsteady MHD free convective mass transfer flow past an infinite vertical porous plate with variable suction and Soret effect has been studied by Reddy et al. (2011). Hossain et al. (2015) considered the study of unsteady MHD free convection flow past a vertical plate with thermal diffusion and chemical recation. Devi and Raj (2011) investigated thermo diffusion effects on unsteady hydromagnetic free convection flow with heat and mass transfer past a moving vertical plate with time dependent suction and heat source in a slip flow regime. Mythreye et al. (2017) considered chemical reaction and Soret effect on MHD free convective flow past an infinite vertical porous plate with variable suction. The Soret effect on MHD free convective flow over a vertical plate with heat source was investigated by Bhavana et al. (2013). Very recently Ahmed et al. (2017) studied the effects of heat and mass transfer in MHD free convective flow past a moving vertical plate with time dependent plate velocity in a porous medium.

The present work is concerned with the Soret effect on MHD convective heat and mass transfer flow of an unsteady viscous incompressible electrically conducting fluid past a semi-infinite vertical porous plate in presence of chemical reaction and heat sink. The governing equations of motion are solved analytically by using perturbation technique. In this work, we have generalized the work done by Mythreye et al. (2015) by considering thermal diffusion.

2. Basic Equations

The equations governing the flow of a viscous incompressible and electrically conducting fluid in the presence of magnetic field are

Equation of continuity

$$\vec{\nabla}.\vec{q}=0. \tag{1}$$

Momentum equation

$$\rho\left[\frac{\partial\vec{q}}{\partial t^*}+(\vec{q}.\vec{\nabla})\vec{q}\right]=-\vec{\nabla}p+\vec{J}\times\vec{B}+\rho\vec{g}+\mu\nabla^2\vec{q}-\frac{\mu}{k^*}\vec{q}. \tag{2}$$

Ohm's law

$$\vec{J}=\sigma\left[\vec{E}+\left(\vec{q}\times\vec{B}\right)\right]. \tag{3}$$

Gauss' law of magnetism

$$\vec{\nabla}.\vec{B}=0. \tag{4}$$

Energy equation

$$\rho C_p\left[\frac{\partial T^*}{\partial t^*}+\left(\vec{q}.\vec{\nabla}\right)T^*\right]=\kappa\nabla^2T^*-Q^*\left(T^*-T_\infty^*\right). \tag{5}$$

Species continuity equation

$$\frac{\partial C^*}{\partial t^*}+\left(\vec{q}.\vec{\nabla}\right)C^*=D_M\nabla^2C^*+K^*(C^*_\infty-C^*)+\frac{D_MK_T}{T_M}\nabla^2T^*. \tag{6}$$

All the physical quantities are defined in the Nomenclature.

3. Mathematical Formulation

Let us consider a flow of an incompressible viscous electrically conducting fluid past an infinite vertical porous plate. We introduce a Cartesian coordinate system (x^*,y^*,z^*) with X axis along the infinite vertical plate, Y axis normal to the plate and Z axis along the width of the plate. Initially the plate and the fluid were at same temperature T_∞^* with concentration level C_∞^* at all points. At time $t^*>0$ the plate temperature is suddenly raised to $T_w^*+\varepsilon\left(T_w^*-T_\infty^*\right)e^{n^*t^*}$ and the concentration level at the plate rose to $C_w^*+\varepsilon\left(C_w^*-C_\infty^*\right)e^{n^*t^*}$. A uniform magnetic field is applied normal to the plate. Due to semi-infinite plane surface assumptions, all the flow variables except pressure are functions of y* and t* only.

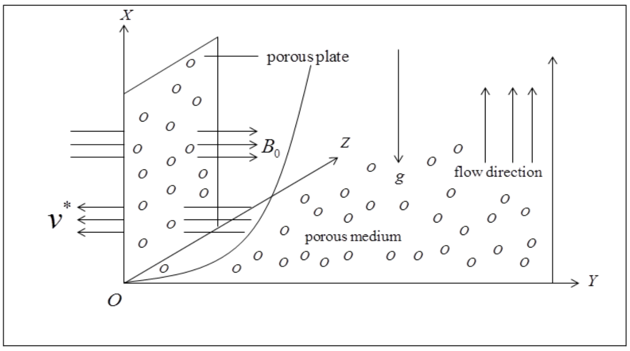

Figure 1: Flow configuration of the problem

Our investigation is restricted to the following assumptions:

i) All the fluid properties are considered constants except the influence of the variation in density in the buoyancy force term.
ii) Viscous dissipation and Ohmic dissipation of energy are negligible.
iii) Magnetic Reynolds number is assumed to be small enough to neglect the induced magnetic field.
iv) Induced electric field is neglected.

The governing equations of motion are

Equation of continuity

$$\frac{\partial v^*}{\partial y^*} = 0. \tag{7}$$

Momentum equation

$$\frac{\partial u^*}{\partial t^*} + v^* \frac{\partial u^*}{\partial y^*} = -\frac{1}{\rho}\frac{\partial p*}{\partial x^*} + \upsilon \frac{\partial^2 u^*}{\partial y^{*2}} + g\beta\left(T^* - T_\infty^*\right) + g\beta^*\left(C^* - C_\infty^*\right) - \frac{\upsilon u^*}{k^*} - \frac{\sigma}{\rho}B_0^2 u^*. \tag{8}$$

Energy equation

$$\rho C_p\left(\frac{\partial T^*}{\partial t^*} + v^*\frac{\partial T^*}{\partial y^*}\right) = \kappa\frac{\partial^2 T^*}{\partial y^{*2}} - Q^*\left(T^* - T_\infty^*\right). \tag{9}$$

Species continuity equation

$$\frac{\partial C^*}{\partial t^*} + v^*\frac{\partial C^*}{\partial y^*} = D_M\frac{\partial^2 C^*}{\partial y^{*2}} + \frac{D_M K_T}{T_M}\frac{\partial^2 T^*}{\partial y^{*2}} - K^*\left(C^* - C_\infty^*\right). \tag{10}$$

The initial and boundary conditions are

$$\begin{aligned} &u^* = u_p^*, T^* = T_w^* + \varepsilon\left(T_w^* - T_\infty^*\right)e^{n^*t^*}, C^* = C_w^* + \varepsilon\left(C_w^* - C_\infty^*\right)e^{n^*t^*} \text{ at } y^* = 0, \\ &u^* \to U_\infty^* = U_0\left(1 + \varepsilon e^{n^*t^*}\right), T \to T_\infty, C \to C_\infty \quad \text{as } y^* \to \infty, \end{aligned} \tag{11}$$

where ε and n^* are scalar constants which are less than unity and $\varepsilon << 1$.

The plate is subjected to a variable suction and to satisfy the equation of continuity, v^* is chosen as follows

$$v^* = -V_0\left(1 + \varepsilon A e^{n^*t^*}\right), \tag{12}$$

where A is a real positive constant, ε and εA are small less than unity, V_0 is the scale of the suction velocity which has a non-zero positive constant.

Outside the boundary layer, Equation (8) gives

$$-\frac{1}{\rho}\frac{\partial p^*}{\partial x^*}=\frac{dU_\infty}{dt^*}+\frac{\upsilon}{k^*}U_\infty^*+\frac{\sigma}{\rho}B_0^2U_\infty^*. \tag{13}$$

To normalize the mathematical model of the physical problem, we introduce the following non-dimensional quantities and parameters

$$u=\frac{u^*}{U_0},\ v=\frac{v^*}{V_0},\ y=\frac{V_0y^*}{\upsilon},\ U_\infty=\frac{U_\infty^*}{U_0},\ U_p=\frac{u_p^*}{U_0},\ t=\frac{t^*V_0^2}{\upsilon},$$
$$\theta=\frac{T^*-T_\infty^*}{T_w^*-T_\infty^*},\ \phi=\frac{C^*-C_\infty^*}{C_w^*-C_\infty^*},\ n=\frac{n^*\upsilon}{V_0^2},k=\frac{k^*V_0^2}{\upsilon^2},\ Pr=\frac{\mu C_p}{\kappa},$$
$$Sc=\frac{\upsilon}{D_M},M=\frac{\sigma B_0^2\upsilon}{\rho V_0^2},Q=\frac{\upsilon Q^*}{\rho c_pV_0^2},K=\frac{K^*\upsilon}{V_0^2},Sr=\frac{D_MK_T\left(T_w^*-T_\infty^*\right)}{\upsilon T_M\left(C_w^*-C_\infty^*\right)},$$
$$Gr=\frac{\upsilon\beta g\left(T_w^*-T_\infty^*\right)}{U_0V_0^2},Gm=\frac{\upsilon\beta^*g\left(C_w^*-C_\infty^*\right)}{U_0V_0^2}.$$

The non-dimensional form of the equations (8) to (10) are

$$\frac{\partial u}{\partial t}-\left(1+\varepsilon Ae^{nt}\right)\frac{\partial u}{\partial y}=\frac{dU_\infty}{dt}+\frac{\partial^2u}{\partial y^2}+Gr\theta+Gm\phi+\xi\left(U_\infty-u\right). \tag{14}$$

$$\frac{\partial \theta}{\partial t}-\left(1+\varepsilon Ae^{nt}\right)\frac{\partial \theta}{\partial y}=\frac{1}{Pr}\frac{\partial^2\theta}{\partial y^2}-Q\theta. \tag{15}$$

$$\frac{\partial \phi}{\partial t}-\left(1+\varepsilon Ae^{nt}\right)\frac{\partial \phi}{\partial y}=\frac{1}{Sc}\frac{\partial^2\phi}{\partial y^2}-K\phi+Sr\frac{\partial^2\theta}{\partial y^2}. \tag{16}$$

The corresponding initial and boundary conditions are

$$\begin{aligned}&u=U_p,\theta=1+\varepsilon e^{nt},\ \phi=1+\varepsilon e^{nt}\ \text{ at }\ y=0,\\&u\to U_\infty=1+\varepsilon e^{nt},\ \theta\to 0,\phi\to 0\ \text{ as }\ y\to\infty.\end{aligned} \tag{17}$$

4. Method of Solution

In order to solve the non-linear partial differential equations (14)-(16) subject to the condition (17), the expressions for the velocity, temperature and concentration are assumed to be of the asymptotic form

$$\left.\begin{aligned}u&=u_0(y)+\varepsilon e^{nt}u_1(y)+O(\varepsilon^2),\\\theta&=\theta_0(y)+\varepsilon e^{nt}\theta_1(y)+O(\varepsilon^2),\\\phi&=\phi_0(y)+\varepsilon e^{nt}\phi_1(y)+O(\varepsilon^2).\end{aligned}\right\} \tag{18}$$

On substitution of (18) in equations (14)-(16), the following ordinary linear differential equations are obtained

$$u_0'' + u_0' - \left(M + \frac{1}{k}\right)u_0 = -Gr\theta_0 - Gm\phi_0 - \left(M + \frac{1}{k}\right), \tag{19}$$

$$u_1'' + u_1' - \left(M + n + \frac{1}{k}\right)u_1 = -Gr\theta_1 - Gm\phi_1 - Au_0' - \left(M + n + \frac{1}{k}\right). \tag{20}$$

$$\theta_0'' + Pr\theta_0' - QPr\theta_0 = 0, \tag{21}$$

$$\theta_1'' + Pr\theta_1' - (n+Q)Pr\theta_1 = -APr\theta_0'. \tag{22}$$

$$\phi_0'' + Sc\phi_0' - ScK\phi_0 = -ScSr\theta_0'', \tag{23}$$

$$\phi_1'' + Sc\phi_1' - Sc(K+n)\phi_1 = -ASc\phi_0' - ScSr\theta_1''. \tag{24}$$

Subject to the boundary conditions

$$\left.\begin{array}{ll} u_0 = U_p, u_1 = 0, \theta_0 = 1, \theta_1 = 1, \phi_0 = 1, \phi_1 = 1 & \text{at } y = 0, \\ u_0 = 1, u_1 = 1, \theta_0 \to 0, \theta_1 \to 0, \phi_0 \to 0, \phi_1 \to 0 & \text{as } y \to \infty. \end{array}\right\} \tag{25}$$

The equations (19)-(24) are solved in sequence subject to the condition (25) and the solutions are given by

$$\theta_0 = e^{-m_1 y}, \tag{26}$$

$$\theta_1 = A_1 e^{-m_1 y} + A_2 e^{-m_2 y}. \tag{27}$$

$$\phi_0 = -A_3 e^{-m_1 y} + A_4 e^{-m_3 y}, \tag{28}$$

$$\phi_1 = -A_5 e^{-m_1 y} + A_6 e^{-m_2 y} + A_7 e^{-m_3 y} + A_8 e^{-m_4 y}. \tag{29}$$

$$u_0 = 1 + A_9 e^{-m_1 y} - A_{10} e^{-m_3 y} + A_{11} e^{-m_5 y}, \tag{30}$$

$$u_1 = 1 + A_{12} e^{-m_1 y} + A_{13} e^{-m_2 y} - A_{14} e^{-m_3 y} - A_{15} e^{-m_4 y} + A_{16} e^{-m_5 y} + A_{17} e^{-m_6 y}. \tag{31}$$

Substituting equations (26)-(31) in equation (18), we obtain the expressions for the velocity, temperature and concentration fields in the boundary layer as follows

$$u(y,t) = \left(1 + A_9 e^{-m_1 y} - A_{10} e^{-m_3 y} + A_{11} e^{-m_5 y}\right) + \varepsilon e^{nt} \begin{pmatrix} 1 + A_{12} e^{-m_1 y} + A_{13} e^{-m_2 y} - \\ A_{14} e^{-m_3 y} - A_{15} e^{-m_4 y} + A_{16} e^{-m_5 y} + A_{17} e^{-m_6 y} \end{pmatrix}. \tag{32}$$

$$\theta(y,t) = e^{-m_1 y} + \varepsilon e^{nt}\left(A_1 e^{-m_1 y} + A_2 e^{-m_2 y}\right). \tag{33}$$

$$\phi(y,t) = \left(-A_3 e^{-m_1 y} + A_4 e^{-m_3 y}\right) + \varepsilon e^{nt}\left(-A_5 e^{-m_1 y} + A_6 e^{-m_2 y} + A_7 e^{-m_3 y} + A_8 e^{-m_4 y}\right). \tag{34}$$

The constants are defined in the Appendix section.

5. Skin Friction

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

$$\begin{aligned}\tau &= \left[\frac{\partial u}{\partial y}\right]_{y=0} \\ &= \left(-m_1 A_9 + m_3 A_{10} - m_5 A_{11}\right) \\ &\qquad + \varepsilon e^{nt}\left(-m_1 A_{12} - m_2 A_{13} + m_3 A_{14} + m_4 A_{15} - m_5 A_{16} - m_6 A_{17}\right).\end{aligned} \tag{35}$$

6. Rate of heat transfer

The rate of heat transfer in terms of Nusselt number at the plate is given by

$$\begin{aligned}Nu &= \left[\frac{\partial \theta}{\partial y}\right]_{y=0} \\ &= -m_1 + \varepsilon e^{nt}\left(-m_1 A_1 - m_2 A_2\right).\end{aligned} \tag{36}$$

7. Rate of mass transfer

The rate of mass transfer in terms of Sherwood number at the plate is given by

$$\begin{aligned}Sh &= \left[\frac{\partial \phi}{\partial y}\right]_{y=0} \\ &= m_1 A_3 - m_3 A_4 + \varepsilon e^{nt}\left(m_1 A_5 - m_2 A_6 - m_3 A_7 - m_4 A_8\right).\end{aligned} \tag{37}$$

8. Results and Discussion

In order to get the physical insight of the problem, we have carried out numerical calculations for non-dimensional velocity field, temperature field, concentration field, coefficient of skin friction at the plate, the rate of heat transfer and the rate of mass transfer at the plate for different values of the physical parameters involved and these are demonstrated in graphs. The value of Prandtl number *Pr* is chosen to be 0.71 which corresponds to air and the value of Schmidt number *Sc* is taken to be 0.60 which corresponds to H_2O whereas the values of other parameters viz. thermal Grashof number *Gr*, solutal Grashof number *Gm*, magnetic parameter *M*, chemical reaction parameter *K*, Soret number *Sr* and heat source/sink parameter *Q* have been chosen arbitrarily.

Figures 2-8 exhibit the variation of the velocity distribution *u* versus normal coordinate *y* under the influence of magnetic parameter *M*, Soret number *Sr*, Schmidt number *Sc*, chemical reaction parameter *K*, heat source/sink parameter *Q*, thermal Grashof number *Gr* and solutal Grashof number *Gm*. Figure 2 shows that the fluid flow is retarded due to imposition of the transverse magnetic field. The presence of magnetic field in an electrically conducting fluid introduces a force called *Lorentz force* which acts against the flow if the magnetic field is applied normal to the fluid flow. This type of resistive force tends to slow down the flow field. Thus our observation and physical reality are consistent. Figure 3 displays the influence of Soret number over the dimensionless velocity. It is evident from this figure that the fluid flow is accelerated due to the effect of thermal diffusion. Figure 4 clearly shows that there is a substantial fall in the fluid velocity when the Schmidt number Sc is increased which indicates the fact that the fluid velocity increases significantly due to high mass diffusivity. It is recalled that an increase in Sc means a decrease in molecular diffusivity. It is noticed from Figure 5 that fluid motion is retarded due to chemical reaction. This shows that the consumption of chemical species leads to fall in the concentration field which in turn diminishes the buoyancy effects causing the flow to retard. The influence of the heat source/sink parameter Q on velocity has been depicted in Figure 6. It is observed that an increase in the values of Q leads to a fall in the velocity. Figure 7 and Figure 8 depict that thermal buoyancy force and solutal buoyancy force causes the flow to accelerate to a good extent near the plate.

The variation of temperature field θ against y under the influence of heat sink Q and Prandtl number Pr are demonstrated in Figures 9-10. It is seen from the figure 9 that the temperature decreases for increasing values of Prandtl number which indicates that thermal boundary layer thickness is reduced under the effect of Prandtl number. It is noticed from the figure 10 that there is a comprehensive fall in temperature for increasing heat sink within the fluid region.

Figures 11-13 demonstrate the variation of concentration field under the influence of the parameters Sc, Sr, and K. Figure 11 shows that the concentration level of the fluid is decreased for increasing Schmidt number. This is consistent with the fact that an increase in Sc means a decrease of molecular diffusivity which results in a fall in the thickness of the concentration boundary layer. It is seen from Figure 12 that concentration level rises in presence of thermal diffusion. It is noticed from Figure 13 that there is a comprehensive fall in the concentration level of the fluid due to chemical reaction which indicates a reduction in the thickness of the boundary layer.

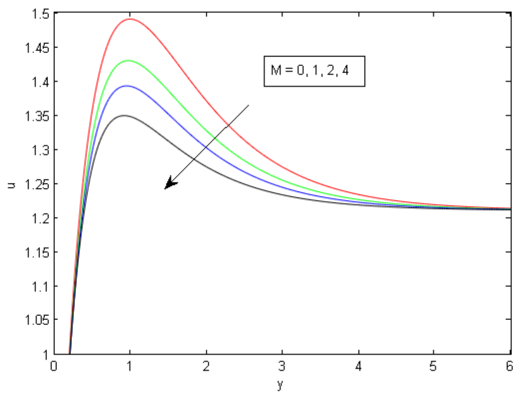

Figure 2: Velocity u versus y for M when $Q=1; Sc=0.6; Sr=1; K=0.5; Gr=2;$ $Gm=1; Pr=0.71; U_p=0.5; A=1;$ $\varepsilon=0.2; n=0.1; t=0.5; k=0.5$

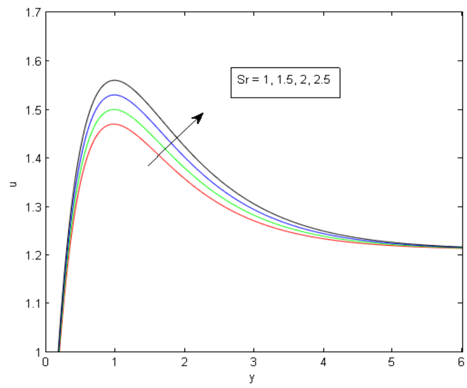

Figure 3: Velocity u versus y for Sr when $Q=1; Sc=0.6; M=1; K=0.5; Gr=2;$ $Gm=1; Pr=0.71; U_p=0.5; A=1;$ $\varepsilon=0.2; n=0.1; t=0.5; k=0.5$

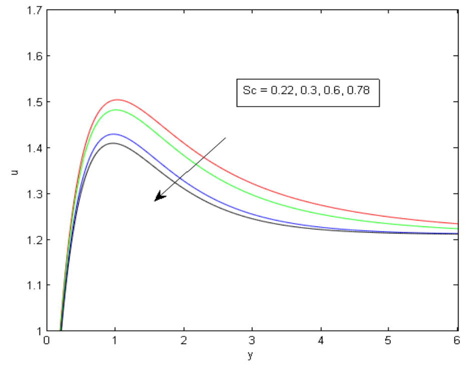

Figure 4: Velocity u versus y for *Sc* when $Q=1; Sr=1; M=1; K=0.5; Gr=2;$ $Gm=1; Pr=0.71; U_p=0.5; A=1;$ $\varepsilon=0.2; n=0.1; t=0.5; k=0.5$

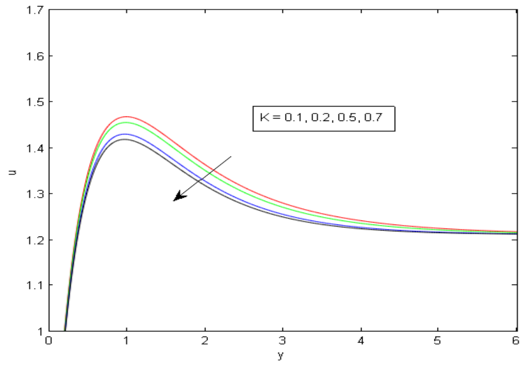

Figure 5: Velocity u versus y for *K* when $Q=1; Sr=1; M=1; Sc=0.6; Gr=2;$ $Gm=1; Pr=0.71; U_p=0.5; A=1;$ $\varepsilon=0.2; n=0.1; t=0.5; k=0.5$

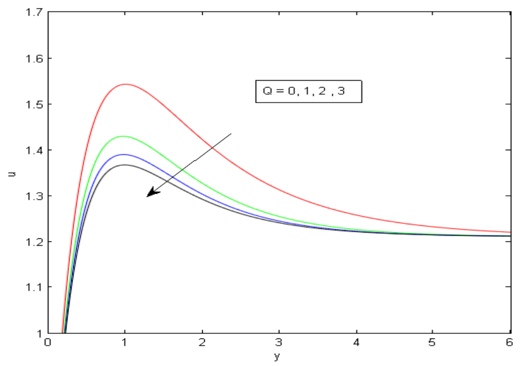

Figure 6: Velocity u versus y for *Q* when $M=1; Sr=1; Sc=0.6; K=0.5; Gr=2;$ $Gm=1; Pr=0.71; U_p=0.5; A=1;$ $\varepsilon=0.2; n=0.1; t=0.5; k=0.5$

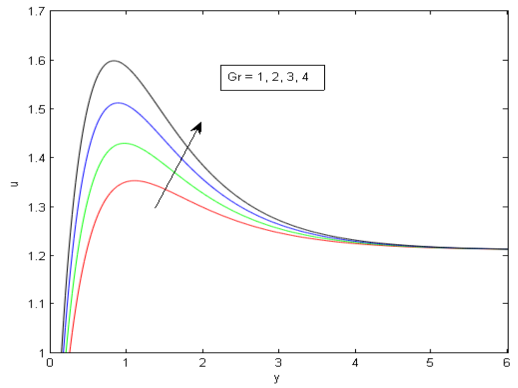

Figure 7: Velocity u versus y for *Gr* when $Q=1; Sr=1; M=1; K=0.5; Sc=0.6;$ $Gm=1; Pr=0.71; U_p=0.5; A=1;$ $\varepsilon=0.2; n=0.1; t=0.5; k=0.5$

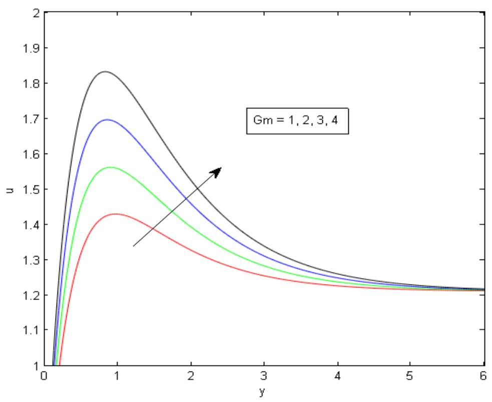

Figure 8: Velocity u versus y for *Gm* when $Q=1; Sr=1; M=1; K=0.5; Gr=2;$ $Sc=0.6; Pr=0.71; U_p=0.5; A=1;$ $\varepsilon=0.2; n=0.1; t=0.5; k=0.5$

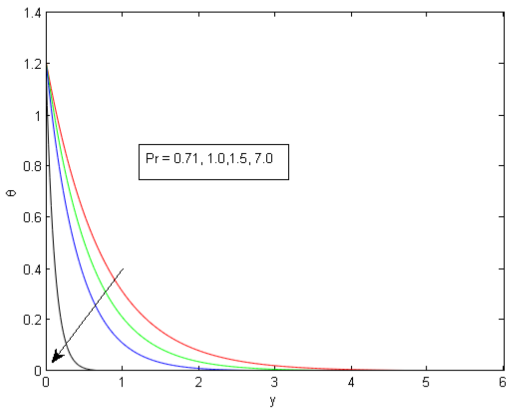

Figure 9: Temperature profile for variation in *Pr*

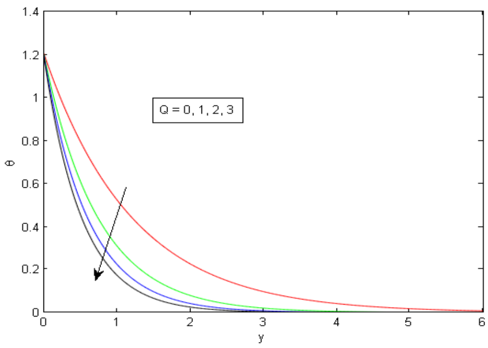

Figure 10: Temperature profile for variation in Q

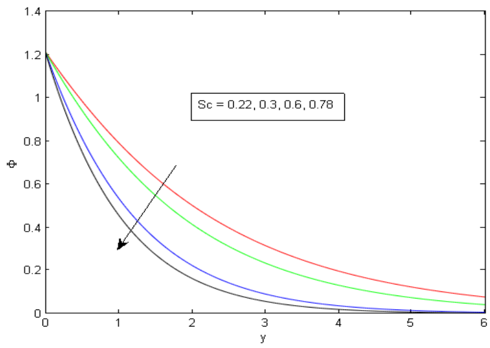

Figure 11: Concentration profile for variation in Sc

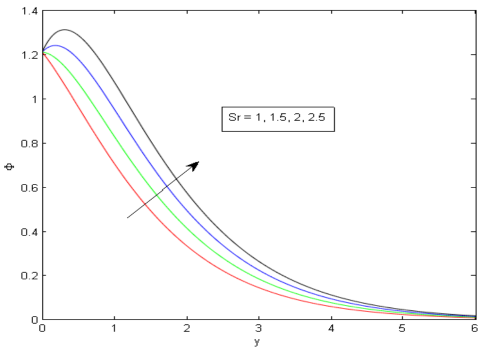

Figure 12: Concentration profile for variation in Sr

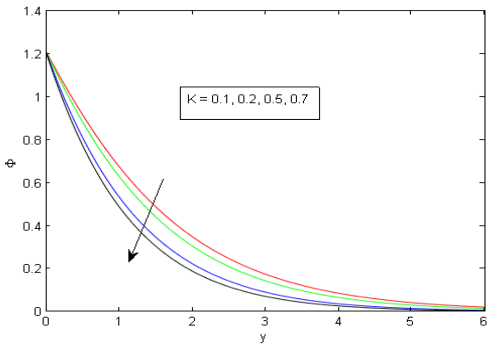

Figure 13: Concentration profile for variation in K

Table 1: Effects of various parameters on Skin friction for $Q=1; Sr=1; M=1; K=0.5; Gr=2;$ $Gm=1; Sc=0.6; Pr=0.71; U_p=0.5;$ $A=1;\ \varepsilon=0.2;\ n=0.1; t=0.5; k=0.5$

Sc	K	Q	Sr	τ
				3.2099
0.6	0.5	1	0.3	3.2420
				3.2933
0.22				3.3059
0.3	0.5	1	0.3	3.2776
0.6				3.2099
	0.1			3.3792
0.6	0.2	1	0.3	3.3464
	0.3			3.3200
		0		3.4103
0.6	0.5	1	0.3	3.2099
		2		3.1257
			1	3.2099
0.6	0.5	1	1.5	3.2641
			2	3.3182

Table 2: Effects of various parameters on Sherwood number for $Q=1; Sr=1; K=0.5; Sc=0.6; Pr=0.71;$ $A=1;\ \varepsilon=0.2; n=0.1; t=0.5$

Q	K	Sr	Sh
1			-0.7319
2	1	1	-0.5121
3			-0.3354
	0.1		-0.0023
1	0.2	1	-0.1249
	0.3		-0.4030
		1	-0.7319
1	1	1.5	-0.3889
		2	-0.0460

Table 3: Effects of various parameters on Nusselt number for $Q=1; Pr=0.71; A=1; \varepsilon=0.2; n=0.1; t=0.5$

Q	Pr	t	Nu
1			-1.5791
2	0.71	0.5	-1.9695
3			-2.2778
	0.71		-1.5950
1	2	0.5	-3.4816
	7.0		-10.2180
		0.1	-1.5665
1		0.2	-1.5696
		0.3	-1.5727

9. Comparison

In the absence of Soret effect (i.e., Sr = 0) the validity of our result is presented by comparing Figure 14 and Figure 15 (i.e., done by Mythreye et al. (2015)) of the present work. Both the figures show that a decrease in the velocity under the influence of heat sink parameter Q. Thereby showing an excellent agreement between the results of the present work and that obtained by Mythreye et al. (2015).

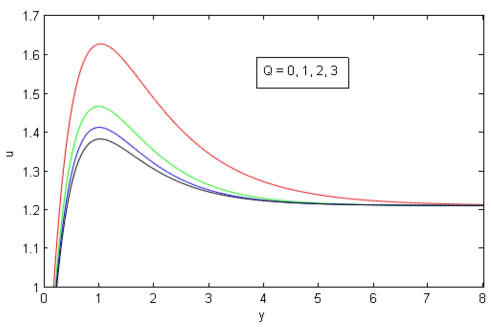

Figure 14. Velocity u versus y under the effect of Q

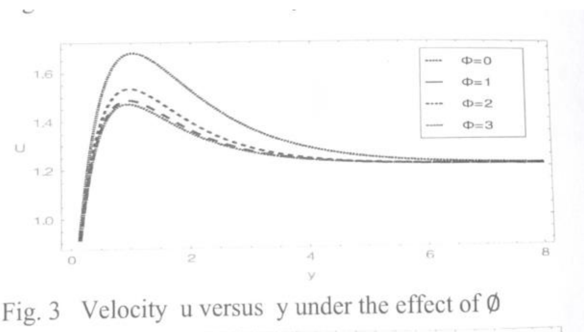

Figure 15. Scan copy of the work done by Mythreye et al. (2015)

10. Conclusions

The present investigation leads to the following conclusions:

- The fluid velocity decreases with the increase in chemical reaction and heat sink parameter whereas it is accelerated due to thermal diffusion.
- The fluid temperature drops with the increase in heat sink parameter and Prandtl number.
- The concentration level of the fluid rises with the increase in Soret number and falls due to Schmidt number and chemical reaction parameter.
- The skin-friction coefficient is increased under the effect of thermal diffusion whereas it is decreased with the increase in Schmidt number and heat sink parameter.
- The rate of mass transfer is decreased from the plate to the fluid region due to chemical reaction.

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REFERENCES

Ahmed, N. and Agarwalla, S. (2016). Effect of heat sink on transient MHD mass transfer flow past an accelerated vertical plate with chemical reaction, Advances and Application in Fluid Mechanics, 19, pp. 273-294.

Ahmed, N., Choudhury, K., Agarwalla, S. (2017). Hydromagnetic free convective flow past a vertical plate moving with time dependent plate velocity, Far East Journal of Applied Mathematics, 96(6), pp. 331-350.

Ahmed, N. and Das, K.K. (2013). MHD Mass transfer flow past a vertical porous plate embedded in a porous medium in a slip flow regime with thermal radiation and chemical reaction, Open Journal of Fluid Dynamics, 3, pp. 230-239.

Balamurugan, K.S., Ramaprasad, J.L., Varma, S.V.K. (2015). Unsteady MHD free convective flow past a moving vertical plate with time dependent suction and chemical reaction in a slip flow regime, Procedia Engineering 127, pp. 516-523.

Bhavana, M., Chenna, Kesavaiah. D., Sudhakaraiah, A. (2013). The Soret effect on free convective unsteady MHD flow over a vertical plate with heat source, International Journal of Innovative Research Science Engineering and Technology, 5, pp. 1617-1628.

Chamkha, A.J. (2004). Unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption, Int. Journal of Engg. Science, 42, pp. 217-230.

Devi, S.P., Anjali Raj, J.W.S. (2011). Thermo diffusion effects on unsteady hydro magnetic free convection flow with heat and mass transfer past a moving vertical plate with time dependent suction and heat source in a slip flow regime, Int. J. of Appl. Math and Mech. 7, pp. 20-51.

Hossain, M.S. Samanth, N. and Ahmed, S.F. (2015). Study of Unsteady MHD free convection flow past a vertical plate with thermal diffusion and chemical reaction, Int. J. of P. Math. Sc., 5(1), pp.206-215.
Johari, R. Saxena, A.M., Jha, R. (2008). Unsteady MHD flow through porous medium and heat transfer past a porous vertical moving plate with heat source, Acta Ciencia Indica XXXIV M, 4, 1683.
Mythreye, A. and Balamurugan, K.S. (2017). Chemical reaction and Soret effect on MHD free convective flow past an infinite vertical porous plate with variable suction, Int. J. of Chem. Engg. Res., 9, pp. 51-62.
Mythreye, A., Pramod, J.P., Balamurugan, K.S. (2015). Chemical reaction on Unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption, Procedia Engineering, 127, pp. 613-620.
Oahimire, J.I. and Olajuwan, B.I. (2014). Effects of radiation absorption and thermo-diffusion on MHD heat and mass transfer flow of a micro-polar fluid in the presence of heat source, Applications and Applied Mathematics, 9(2), pp. 763-779.
Prakash, J., Sivaraj, R. and Kumar, B.R. (2011). Influence of chemical reaction on unsteady MHD mixed convective flow over a moving vertical plate, Int. J. Fluid Mech., 3, pp. 1-14.
Reddy, G.V. Ramana, Murthy, C.V. Ramana and Reddy, N. Bhaskar (2011). Unsteady MHD free convective mass transfer flow past an infinite vertical porous plate with variable suction and Soret effect, Int. J. of Appl. Math and Mech, 7(21), pp. 70-84.
Sarada, K. and Shanker, B. (2013). Effect of chemical reaction on an Unsteady MHD free convection flow past an infinite vertical porous plate with variable suction, Int. J. of Mod. Eng. Res., 3(2), pp. 725-735.
Sengupta, S. (2015). Free convective chemically absorption fluid past an impulsively accelerated plate with thermal radiation variable wall temperature and concentration, Applications and applied Mathematics, 10(1), pp. 75-93.
Seth, G.S., Ansari and Nandkeolyan, R.M.S. (2011). MHD natural convection flow with radiative heat transfer past an impulsively moving plate with ramped wall temperature, Heat and mass transfer 47, pp. 551-561.
Sattar, Abdus MD and Kalim, Hamid MD (1996). Unsteady free convection interaction with thermal radiation in a boundary layer flow past a vertical porous plate, J. Math. Phys. Sci. 30, pp. 25-37.
Takhar, H.S., Gorla, R.S.R. and Soundalgekar, V.M. (1996). Radiation effects on MHD free convection flow of a radiating gas past a semi-infinite vertical plate, Int. J. Numerical Methods for Heat and Fluid Flow, 6(2), pp. 77-83.

APPENDIX

$$\xi = M + \frac{1}{k}, m_1 = \frac{Pr + \sqrt{Pr^2 + 4QPr}}{2}, m_2 = \frac{Pr + \sqrt{Pr^2 + 4(n+Q)Pr}}{2}, m_3 = \frac{Sc + \sqrt{Sc^2 + 4ScK}}{2},$$

$$m_4 = \frac{Sc + \sqrt{Sc^2 + 4Sc\left(K+n\right)}}{2}, m_5 = \frac{1 + \sqrt{1+4\xi}}{2}, m_6 = \frac{1 + \sqrt{1+4\left(\xi + n\right)}}{2}, A_1 = \frac{Am_1 Pr}{m_1^2 - Prm_1 - (n+Q)Pr},$$

$$A_2 = 1 - A_1, A_3 = \frac{ScSrm_1^2}{m_1^2 - Scm_1 - ScK}, A_4 = 1 + A_3, A_5 = \frac{A_1SrScm_1^2 + AA_3Scm_1}{m_1^2 - Scm_1 - Sc(K+n)},$$

$$A_6 = \frac{A_1SrScm_2^2 - SrScm_2^2}{m_2^2 - Scm_2 - Sc(K+n)}, A_7 = \frac{AScm_3 + AA_3Scm_3}{m_3^2 - Scm_3 - Sc(K+n)}, A_8 = 1 + A_5 - A_6 - A_7,$$

$$A_9 = \frac{GmA_3 - Gr}{m_1^2 - m_1 - \xi}, A_{10} = \frac{Gm + GmA_3}{m_3^2 - m_3 - \xi}, A_{11} = U_p - A_9 + A_{10} - 1,$$

$$A_{12} = \frac{Am_1A_9 + GmA_5 - GrA_1}{m_1^2 - m_1 - (n+\xi)}, A_{13} = \frac{GrA_1 - Gr - GmA_6}{m_2^2 - m_2 - (n+\xi)}, A_{14} = \frac{GmA_7 + Am_3A_{10}}{m_3^2 - m_3 - (\xi+n)},$$

$$A_{15} = \frac{GmA_8}{m_4^2 - m_4 - (\xi+n)}, A_{16} = \frac{Am_5A_{11}}{m_5^2 - m_5 - (\xi+n)}, A_{17} = -A_{12} - A_{13} + A_{14} + A_{15} - A_{16} - 1.$$