IOSR Journal of Mathematics (IOSR-JM)
e-ISSN: 2278-5728, p-ISSN: 2319-765X. Volume 13, Issue 3 Ver. I1 (May. - June. 2017), PP 18-29
www.iosrjournals.org

Radiation effect on Unsteady MHD free convective Heat and Mass transfer flow over an inclined porous plate with Thermal diffusion and Heat source

Pavan [1], G. S. S. Raju[2]
[1] *Research Scholar, JNT University Anantapur, Anantapuram*
[2] *Department of Mathematics, J N T U A College of Engg. Pulivendula*

Abstract : *The present study deals with an Unsteady MHD free convective Heat and Mass transfer flow over an inclined plate embedded in porous medium, which moves with time dependent velocity in a viscous, electrically conducting incompressible fluid, under the influence of uniform magnetic field, applied normal to the plate. The presence of thermal radiation, heat source and Soret effect are considered. The dimensionless governing equations i.e. momentum equation which is coupled with the energy and mass diffusion equations are analytically solved in closed form by Laplace transform technique. The expressions for velocity, temperature, concentration, skin friction, rate of heat and mass transfer are studied graphically for different physical parameters.*

Keywords: *MHD, Free convection, Heat and Mass transfer, Radiation, Thermal diffusion, Heat source, inclined porous plate and Laplace transform technique.*

I. Introduction

Natural convection flows are frequently encountered in physical and engineering problems such as chemical catalytic reactors, nuclear waste materials etc. Transient free convection is important in many practical applications, such as furnaces electronic components, solar collectors, thermal regulation process, security of energy systems etc. when a conductive fluid moves through a magnetic field and an ionized gas is electrically conductive, the fluid may be influenced by the magnetic field. Magneto hydrodynamic free convection heat transfer flow is of considerable interest in the technical field due to its frequent occurrence in industrial technology and geothermal application, liquid metal fluids and MHD power generation systems etc.

Study of MHD flow with heat and mass transfer play an important role in various industrial applications. Some important applications are cooling of nuclear reactors, liquid metals fluid, power generation system and aero dynamics. It is of importance in connection with many engineering problems, such as sustained plasma confinement for controlled thermo nuclear fusion and electromagnetic casting of metals.MHD finds applications in electromagnetic pumps, crystals growing, MHD couples and bearing, plasma jets and chemical synthesis. Radioactive heat and mass transfer play an important role in manufacturing industries for the design reliable equipment. Nuclear power plants, gas turbines and various propulsion devices for aircraft, missiles, satellites and space vehicles are examples of such engineering applications.

In several problems related to demanding of efficient transfer of mass over inclined beds related to geophysical, petroleum, chemical, bio-mechanical, chemical technology and in situations the viscous drainage over an inclined porous plane is a subject of considerable interest to both theoretical and experimental investigators. Especially, in the flow of oil through porous rock, the extraction of geo-thermal energy from the deep interior of the earth to the shallow layers, the evaluation of the capability of heat removal from particulate nuclear fuel debris that may result from hypothetical accident in a nuclear reactor, the filtration of solids from liquids, flow of liquids through ion exchange beds, drug permeation through human glands, chemical reactor for economical separation or purification of mixtures flow through porous medium has been the subject of considerable research activity in recent years due to its notable applications. An important application in the petroleum industry where crude oil is trapped from natural underground reservoirs in which oil is entrapped since the flow behavior of fluids in petroleum reservoir rock depends to a large extent on the properties of the rock, techniques that yield new or additional information on the characteristics of the rock would enhance the performance of petroleum reservoirs. An important bio medical application is the flow of fluids in lungs, blood vessels, arteries and so on, where the fluid is bounded by two layers which are held together by a set of fairly regularly spaced tissues.

The study of effects of magnetic field on free convection flow is important in liquid-metals, electrolytes and ionized gases. The thermal physics of hydro magnetic problems with mass transfer is of interest in power engineering and metallurgy. Moreover, there are several engineering situations wherein combined heat and mass transport arise viz. humidifiers, dehumidifiers, desert coolers, chemical reactors etc. The usual way to study these phenomena is to consider a characteristic moving continuous surface.

Free convection flow with mass transfer past a vertical moving plate has been studied by Soundalgeker [1], Revankar [2], Soundalgeker *et al*. [3], Das et al. [4], Muthukumaraswamy et al. [5] and Panda *et al*.[6]. The effects of heat and mass transfer on a free convection flow near an infinite vertical porous plate has been extensively investigated by Takhar *et al*.[7], Hossain *et al*. [8], Israel *et al*.[9], Sahoo *et al*[10] ,Ali[11], Chaudhary and Jain[12]. Das [13] developed the problem by considering the magnetic effect on free convection flow in presence of thermal radiation. The forced convection flow in a horizontal channel permeated by uniform vertical magnetic fluid in the presence of radiation was studied by Viskanta [14]. Takhar et al. [15] investigated the effects of radiation on the MHD free convection flow past a semi-infinite vertical plate.

Chaudhary et.al. [16] Have studied the MHD flow past an infinite vertical oscillating plate through porous medium, taking account of the presence of free convection and mass transfer. Das et al.[17] have analyzed radiation effects on flow past an impulsively started infinite isothermal vertical plate. Recently, Ramana Reddy et al. [18] have studied the mass transfer and radiation effects of unsteady MHD free convective fluid flow embedded in porous medium with heat generation/absorption. Radiation effects on MHD free convection flow over a vertical plate with heat and mass flux was studied by Sivaiah et al. [19].

The objective of the present investigation is to analyze the effects of heat and mass transfer on the unsteady free convection flow of a viscous, electrically conducting incompressible fluid near an infinite inclined embedded in porous plate which moves with time dependent velocity under the influence of uniform magnetic field, applied normal to the plate with Thermal radiation, heat source and Soret effects. A general exact solution of the governing partial differential equation is obtained by using Laplace transform technique.

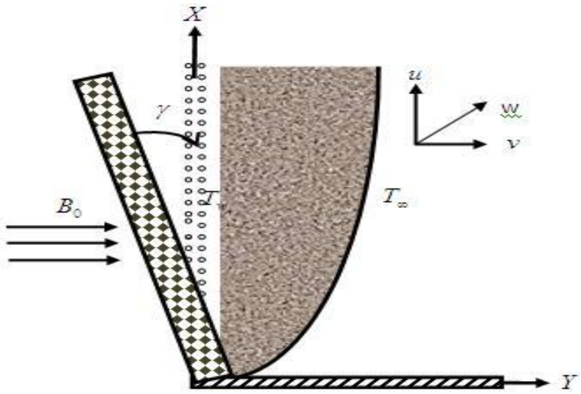

Fig.1 A schematic of the problem and coordinate system

II. Formulation Of The Problem

Let us consider an unsteady free convection and mass transfer flow of a viscous incompressible and electrically conducting fluid along an infinite non-conducting inclined plate through a porous medium in presence of a uniform transverse magnetic field B_0 applied perpendicularly on this plate. The applied magnetic field is assumed to be strong enough so that the induced magnetic field due to the fluid motion is weak and can be neglected. This assumption is physically justified for partially ionized fluids and metallic liquids because of their small magnetic Reynolds number. Since there is no applied or polarization voltage imposed on the flow field, the electric field due to polarization of charges is zero.

Initially, both the fluid and the plate are at rest with constant temperature $T\infty'$and constant concentration $C\infty'$. At time $t' > 0$, the plate is given a sudden jerk, and the motion is induced in the direction of flow against the gravity with uniform velocity U0 in its own plane along the x′-axis, instantaneously the temperature of the plate and the concentration are raised to T_w' and C'_w respectively, which are hereafter regarded as constant. Since the flow of the fluid is assumed to be in the direction of the x*-axis, so the physical quantities are functions of the space co-ordinate y* and time t* only. The fluid considered here is gray, absorbing/emitting radiation but anon-scattering medium. Then by usual Boussinesq's approximation, the unsteady free convective flow is governed by the following equations.

$$\frac{\partial u^*}{\partial t^*} = \vartheta \frac{\partial^2 u^*}{\partial y^{*2}} + g\beta_T (T^* - T^*_\infty)\cos\alpha + g\beta_C (C^* - C^*_\infty)\cos\alpha - \frac{\vartheta}{K^*}u^* - \frac{\sigma B_0^2}{\rho}u^* \quad (1)$$

Energy Equation:

$$\frac{\partial T^*}{\partial t^*} = \frac{K^*}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{1}{\rho C_p}\frac{\partial q_r^*}{\partial y^*} - \frac{Q^*}{\rho C_p}(T^* - T_\infty{}^*) \quad (2)$$

Concentration equation:

$$\frac{\partial C^*}{\partial t^*} = D_M \frac{\partial^2 C^*}{\partial y^{*2}} - D_T \frac{\partial^2 T^*}{\partial y^{*2}} \tag{3}$$

Where u* velocity, T* is the temperature, C* is the species concentration and g is the acceleration due to gravity.

The initial and boundary conditions corresponding to the present problem are

$$\begin{aligned} &u^*(y^*,t^*) = 0,\ T^*(y^*,t^*) = T^*_\infty,\ C^*(y^*,t^*) = C^*_\infty \quad for\ y^* \geq 0\ and\ t^* \leq 0 \\ &u^*(0,t^*) = U_0,\ T^*(0,t^*) = T^*_w,\ C^*(0,t^*) = C^*_w \quad for\ t^* > 0) \\ &u^* \to 0,\quad T^* \to T^*_\infty,\quad C^* \to C^*_\infty \quad y^* \to \infty \quad and\ for\ t^* > 0 \end{aligned} \tag{4}$$

To reduce the above equations into non-dimensional form for convenience, let us introduce the following dimensionless variables and parameters:

$$\begin{aligned} &u = \frac{u^*}{U_0},\ y = \frac{y^* U_0}{\vartheta},\quad t = \frac{t^* U_0^2}{\vartheta}, \\ &G_r = \frac{\vartheta g \beta_T (T^*_w - T^*_\infty)}{U_0^3},\ M = \frac{\sigma B_0^2 \vartheta}{\rho U_0^2}, \\ &P_r = \frac{\rho \vartheta C_p}{K^*},\quad G_m = \frac{\vartheta g \beta_C (C^*_w - C^*_\infty)}{U_0^3} \\ &S_c = \frac{\vartheta}{D_M},\quad S_0 = \frac{(T^*_w - T^*_\infty) D_t}{(C^*_w - C^*_\infty)\vartheta}, \\ &K = \frac{K^* U_0^2}{\vartheta^2},\ \gamma = \frac{k_1^* \vartheta}{U^2},\ S_c = \frac{\vartheta}{D^*},\ \omega = \frac{\omega^* \vartheta}{U_0^2},\ Q = \frac{Q^* \vartheta^2}{k * U_0^2} \\ &\theta = \frac{(T^* - T^*_\infty)}{T^*_w - T^*_\infty},\ C = \frac{(C^* - C^*_\infty)}{C^*_w - C^*_\infty},\quad F = \frac{4\vartheta I^*}{K U_0^2}\quad F_1 = F + Q\quad N = M + \frac{1}{K} \end{aligned} \tag{5}$$

Where G_r is the thermal Grashof number, Gm is the mass Grashof number, K is the permeability parameter, M is the magnetic parameter, Pr is Prandtl number, Sc is Schmidt number, β_T is thermal expansion coefficient, β_C is concentration expansion coefficient and ω is frequency of oscillation. Other physical variables have their usual meanings.

With the help of (2.5), the governing equations (2.1) to (2.3) reduce to

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + (G_r \cos\alpha)\,\theta + (G_m \cos\alpha)\,C - Nu \tag{6}$$

$$\frac{\partial^2 \theta}{\partial y^2} - P_r \frac{\partial \theta}{\partial t} - P_r F_1 \theta = 0 \tag{7}$$

$$\frac{\partial^2 C}{\partial y^2} - S_c \frac{\partial C}{\partial t} + S_c S_0 \frac{\partial^2 \theta}{\partial y^2} = 0 \tag{8}$$

The corresponding initial and boundary conditions in non-dimensional form are :

$$\begin{aligned} &u(y,t) = 0, \theta(y,t) = 0, C(y,t) = 0\ \ for\ y \geq 0\ and t \leq 0 \\ &u(0,t) = 1,\ \theta(0,t) = 1,\ C(0,t) = 1\ for\ t > 0) \\ &u \to 0,\quad \theta \to 0,\quad C \to 0\quad y \to \infty\quad and\ for\ t > 0 \end{aligned} \tag{9}$$

III. Solution Of The Problem

In order to obtain the analytical solutions of the system of differential equations (6) to (8), we shell use the Laplace transform technique.

Applying the Laplace transform (with respect to time t) to equations (6) to (9), we get

$$\bar{\theta} = \frac{1}{s}\exp\left(-y\sqrt{P_r}\sqrt{s+F_1}\right) \tag{10}$$

$$\begin{aligned} \bar{C} = &\frac{1}{s}\exp\left(-y\sqrt{S_c}\sqrt{s}\right) - A_2 \frac{1}{s+A_5}\exp\left(-y\sqrt{S_c}\sqrt{s}\right) \\ &-A_6 \frac{1}{s}\exp\left(-y\sqrt{S_c}\sqrt{s}\right) + \frac{A_6}{s+A_5}\exp\left(-y\sqrt{S_c}\sqrt{s}\right) \\ &+A_2 \frac{1}{s+A_3}\exp\left(-y\sqrt{P_r}\sqrt{s+F_1}\right) + A_6 \frac{1}{s}\exp\left(-y\sqrt{P_r}\sqrt{s+F_1}\right) \\ &-\frac{A_6}{s+A_5}\exp\left(-y\sqrt{P_r}\sqrt{s+F_1}\right) \text{ for } P_r \neq 1 \text{ and } S_c \neq 1 \end{aligned} \tag{11}$$

$$\bar{u}\,(y,s) = \bar{f}\,(s)\exp\left(-y\sqrt{s+N}\right) + \frac{A_{29}}{s}\exp\left(-y\sqrt{s+N}\right)$$
$$+\frac{A_{10}}{s+A_9}\exp\left(-y\sqrt{s+N}\right) + \frac{A_{30}}{s-A_{12}}\exp\left(-y\sqrt{s+N}\right)$$
$$+\frac{A_{31}}{s+A_3}\exp\left(-y\sqrt{s+N}\right) + \frac{A_{32}}{s+A_5}\exp\left(-y\sqrt{s+N}\right)$$
$$+\frac{A_{33}}{s+A_{21}}\exp\left(-y\sqrt{s+N}\right) + \frac{A_{34}}{s}\exp\left(-y\sqrt{P_r}\sqrt{s+F_1}\right)$$
$$-\frac{A_{10}}{s+A_9}\exp\left(-y\sqrt{P_r}\sqrt{s+F}\right) - A_{13}\frac{1}{s}\exp\left(-y\sqrt{S_c}\sqrt{s}\right)$$
$$+\frac{A_{35}}{s-A_{12}}\exp\left(-y\sqrt{S_c}\sqrt{s}\right) + \frac{A_{15}}{s+A_3}\exp\left(-y\sqrt{S_c}\sqrt{s}\right)$$
$$+\frac{A_{18}}{s-A_{12}}\exp\left(-y\sqrt{S_c}\sqrt{s}\right) + \frac{A_{19}}{s+A_5}\exp\left(-y\sqrt{S_c}\sqrt{s}\right)$$
$$+\frac{A_{36}}{s+A_{21}}\exp\left(-y\sqrt{P_r}\sqrt{s+F_1}\right) + \frac{A_{23}}{s+A_3}\exp\left(-y\sqrt{P_r}\sqrt{s+F_1}\right)$$
$$+\frac{A_{28}}{s+A_5}\exp\left(-y\sqrt{P_r}\sqrt{s+F_1}\right) \text{ for } P_r \neq 1 \text{ and } S_c \neq 1 \qquad (12)$$

For $P_r = 1$ and $S_c = 1$

$$\bar{\theta} = \frac{1}{s}\exp\left(-y\sqrt{s+F_1}\right) \qquad (13)$$

$$\bar{C} = \frac{1}{s}\exp\left(-y\sqrt{s}\right) - B_1\frac{1}{s}\exp\left(-y\sqrt{s}\right) + \frac{S_0}{s}\exp\left(-y\sqrt{s}\right)$$
$$+B_1\frac{1}{s}\exp\left(-y\sqrt{s+F_1}\right) - \frac{S_0}{s}\exp\left(-y\sqrt{s+F_1}\right) \qquad (14)$$

$$\bar{u}\,(y,s) = \bar{f}\,(s)\exp\left(-y\sqrt{s+N}\right) - B_9\frac{1}{s}\exp\left(-y\sqrt{s+N}\right)$$
$$+B_8\exp\left(-y\sqrt{s+N}\right) + B_6\frac{1}{s}\exp\left(-y\sqrt{s+F_1}\right)$$
$$+B_7\frac{1}{s}\exp\left(-y\sqrt{s}\right) - B_8\exp\left(-y\sqrt{s}\right) \qquad (15)$$

Then, inverting equations (10) - (15) in the usual way we get the general solution of the problem for the temperature $\theta(y,t)$, the species concentration C(y, t) and velocity u(y, t) for t > 0 in the non dimensional form as

$$\theta = \frac{1}{2}\left[e^{-y\sqrt{P_rF_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}} - \sqrt{F_1t}\right) + e^{y\sqrt{P_rF_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}} + \sqrt{F_1t}\right)\right] \text{for } P_r \neq 1 \quad (16)$$

$$C = erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}\right) - A_2\{\frac{e^{-A_3t}}{2}[e^{-y\sqrt{S_c}\sqrt{-A_3}}\, erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}} - \sqrt{-A_3t}\right)$$
$$+e^{y\sqrt{S_c}\sqrt{-A_3}}\, erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}} + \sqrt{-A_3t}\right)]\} - A_6 erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}\right)$$
$$+A_6\left\{\frac{e^{-A_5t}}{2}\left[e^{-y\sqrt{S_c}\sqrt{-A_5}}\, erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}} - \sqrt{-A_5t}\right) + e^{y\sqrt{S_c}\sqrt{-A_5}}\, erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}} + \sqrt{-A_5t}\right)\right]\right\}$$
$$+A_2\{\frac{e^{-A_3t}}{2}[e^{-y\sqrt{P_r}\sqrt{-A_3+A_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}} - \sqrt{(-A_3+A_1)t}\right)]$$
$$+e^{y\sqrt{P_r}\sqrt{-A_3+A_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}} + \sqrt{(-A_3+A_1)t}\right)$$
$$+A_6\{\frac{1}{2}\left[e^{-y\sqrt{P_r}\sqrt{A_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}} - \left(\sqrt{A_1t}\right)\right) + e^{y\sqrt{P_r}\sqrt{A_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}} + \left(\sqrt{A_1t}\right)\right)\right]\}$$

$$-A_6\{\frac{e^{-A_5 t}}{2}[e^{-y\sqrt{P_r}\sqrt{-A_5+A_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}-\sqrt{(-A_5+A_1)t}\right)$$
$$+e^{y\sqrt{P_r}\sqrt{-A_5+A_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}+\sqrt{(-A_5+A_1)t}\right)]\} \quad (17)$$

for $P_r \neq 1$ and for $S_c \neq 1$

$$\theta = \frac{1}{2}[\exp(-y\sqrt{F_1})erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{F_1 t}\right) + \exp(y\sqrt{F_1})erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{F_1 t}\right)], \text{ for } P_r = 1 \quad (18)$$

$$C = B_1\frac{y}{2\sqrt{\pi t^3}}\exp\left(\frac{-y^2}{4t}-F_1 t\right) - B_1\frac{y}{2\sqrt{\pi t^3}}\exp\left(\frac{-y^2}{4t}\right)$$
$$+B_2 erfc\left(\frac{y}{2\sqrt{t}}\right) - \frac{s_0}{2}[\exp(-y\sqrt{F_1})erfc(\frac{y}{2\sqrt{t}}-\sqrt{F_1 t})$$
$$+\exp(y\sqrt{F_1})\, erf\left(\frac{y}{2\sqrt{t}}+\sqrt{F_1 t}\right)] \text{ for } P_r=1 \text{ and } S_c = 1 \quad (19)$$

$$u(y,t) = \frac{1}{2}\left[e^{-y\sqrt{N}}erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{Nt}\right)+e^{y\sqrt{N}}erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{Nt}\right)\right]+\emptyset(y,t) \quad (20)$$

Where

$$\emptyset(y,t) = \frac{A_{29}}{2}\left[e^{-y\sqrt{N}}erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{Nt}\right)+e^{y\sqrt{N}}erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{Nt}\right)\right]$$
$$+A_{10}\frac{e^{-A_9 t}}{2}[e^{-y\sqrt{-A_9+N}}\, erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{(-A_9+N)t}\right)+e^{y\sqrt{-A_9+N}}\, erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{(-A_9+N)t}\right)]$$
$$+A_{30}\frac{e^{-A_{12} t}}{2}[e^{-y\sqrt{A_{12}+N}}\, erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{(A_{12}+N)t}\right)+e^{y\sqrt{A_{12}+N}}\, erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{(A_{12}+N)t}\right)]$$
$$+A_{31}\frac{e^{-A_3 t}}{2}[e^{-y\sqrt{-A_3+N}}\, erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{(-A_3+N)t}\right)+e^{y\sqrt{-A_3+N}}\, erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{(-A_3+N)t}\right)]$$
$$+A_{32}\frac{e^{-A_5 t}}{2}[e^{-y\sqrt{-A_5+N}}\, erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{(-A_5+N)t}\right)+e^{y\sqrt{-A_5+N}}\, erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{(-A_5+N)t}\right)]$$
$$+A_{33}\frac{e^{-A_{21} t}}{2}[e^{-y\sqrt{-A_{21}+N}}\, erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{(-A_{21}+N)t}\right)$$
$$+e^{y\sqrt{-A_{21}+N}}\, erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{(-A_{21}+N)t}\right)]$$
$$+\frac{A_{34}}{2}\left[e^{-y\sqrt{P_r}\sqrt{A_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}-(\sqrt{A_1 t})\right)+e^{y\sqrt{P_r}\sqrt{A_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}+(\sqrt{A_1 t})\right)\right]$$
$$-A_{10}\{\frac{e^{-A_9 t}}{2}[e^{-y\sqrt{P_r}\sqrt{-A_9+A_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}-\sqrt{(-A_9+A_1)t}\right)$$
$$+e^{y\sqrt{P_r}\sqrt{-A_9+A_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}\sqrt{(-A_9+A_1)t}\right)]\} - A_{13}erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}\right)$$
$$+A_{35}\{\frac{e^{A_{12} t}}{2}[e^{-y\sqrt{S_c}\sqrt{A_{12}}}\, erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}-\sqrt{A_{12} t}\right)$$
$$+e^{y\sqrt{S_c}\sqrt{A_{12}}}\, erfc\left(\frac{y\sqrt{S_c}}{2\sqrt{t}}+\sqrt{A_{12} t}\right)]\}$$
$$+A_{36}\{\frac{e^{-A_{21} t}}{2}[e^{-y\sqrt{P_r}\sqrt{-A_{21}+A_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}-\sqrt{(-A_{21}+A_1)t}\right)$$
$$+e^{y\sqrt{P_r}\sqrt{-A_{21}+A_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}+\sqrt{(-A_{21}+A_1)t}\right)]\}$$
$$+A_{23}\{\frac{e^{-A_3 t}}{2}[e^{-y\sqrt{P_r}\sqrt{-A_3+A_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}-\sqrt{(-A_3+A_1)t}\right)$$
$$+e^{y\sqrt{P_r}\sqrt{-A_3+A_1}}\, erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}+\sqrt{(-A_3+A_1)t}\right)]\}$$

$$+A_{28}\{\frac{e^{-A_5 t}}{2}[e^{-y\sqrt{P_r}\sqrt{-A_5+A_1}}\ erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}-\sqrt{(-A_5+A_1)t}\right)$$
$$+e^{y\sqrt{P_r}\sqrt{-A_5+A_1}}\ erfc\left(\frac{y\sqrt{P_r}}{2\sqrt{t}}+\sqrt{(-A_5+A_1)t}\right)]\} \quad (21)$$

For $P_r \neq 1, S_c \neq 1$

$$\emptyset(y,t)=B_9\ \frac{1}{2}[\exp(-y\sqrt{N})erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{Nt}\right)$$
$$+\exp(y\sqrt{N})erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{Nt}\right)]$$
$$+B_8\frac{y}{2\sqrt{\pi t^3}}\exp\left(\frac{-y^2}{4t}-Nt\right)$$
$$-B_8\frac{y}{2\sqrt{\pi t^3}}\exp\left(\frac{-y^2}{4t}\right)+B_7 erfc\left(\frac{y}{2\sqrt{t}}\right)$$
$$+B_6\frac{1}{2}[\exp(-y\sqrt{F_1})erfc\left(\frac{y}{2\sqrt{t}}-\sqrt{F_1 t}\right)$$
$$+\exp(y\sqrt{F_1})erfc\left(\frac{y}{2\sqrt{t}}+\sqrt{F_1 t}\right)] \quad (22)$$

For P_r=1and S_c=1

Skin-friction

$$\tau=-\left(\frac{\partial u}{\partial y}\right)_{y=0}$$
$$=\frac{1}{2}[\frac{-2}{\sqrt{\pi t}}\exp(-Nt)+\sqrt{N}\ [erfc(\sqrt{Nt})-erfc(-\sqrt{Nt})]]$$
$$+\left(\frac{\partial\emptyset}{\partial y}\right)_{y=0} \quad (23)$$

Where

$$\left(\frac{\partial\emptyset}{\partial y}\right)_{y=0}=\frac{A_{29}}{2}\left[\frac{-2}{\sqrt{\pi t}}e^{-Nt}+\sqrt{N}\left(erfc(\sqrt{Nt})-erfc(-\sqrt{Nt})\right)\right]$$
$$+\frac{A_{10}}{2}e^{-A_9 t}\left[\frac{-2}{\sqrt{\pi t}}e^{-(N-A_9)t}+\sqrt{(N-A_9)}\ \left(erfc(\sqrt{(N-A_9)t})-erfc(-\sqrt{(N-A_9)t})\right)\right]$$
$$+\frac{A_{30}}{2}e^{A_{12}t}\left[\frac{-2}{\sqrt{\pi t}}e^{-(N+A_{12})t}+\sqrt{(N+A_{12})}\ \left(erfc\left(\sqrt{(N+A_{12})t}\right)-erfc\left(-\sqrt{(N+A_{12})t}\right)\right)\right]$$
$$+\frac{A_{31}}{2}e^{-A_3 t}\left[\frac{-2}{\sqrt{\pi t}}e^{-(N-A_3)t}+\sqrt{(N-A_3)}\ \left(erfc(\sqrt{(N-A_3)t})-erfc(-\sqrt{(N-A_3)t})\right)\right]$$
$$+\frac{A_{32}}{2}e^{-A_5 t}\left[\frac{-2}{\sqrt{\pi t}}e^{-(N-A_5)t}+\sqrt{(N-A_5)}\ \left(erfc(\sqrt{(N-A_5)t})-erfc(-\sqrt{(N-A_5)t})\right)\right]$$
$$+\frac{A_{33}}{2}e^{-A_{21}t}\left[\frac{-2}{\sqrt{\pi t}}e^{-(N-A_{21})t}+\sqrt{(N-A_{21})}\ \left(erfc\left(\sqrt{(N-A_{21})t}\right)-\ erfc\left(-\sqrt{(N-A_{21})t}\right)\right)\right]$$

$$+\frac{A_{34}}{2}\left[\frac{-2}{\sqrt{\pi t}}e^{-A_1 t}+\sqrt{(P_r A_1)}\ \left(erfc(\sqrt{A_1 t})-erfc(-\sqrt{A_1 t})\right)\right]$$
$$+\frac{A_{10}}{2}e^{-A_9 t}\left[\frac{-2}{\sqrt{\pi t}}e^{-(A_1-A_9)t}+\sqrt{(A_1-A_9)P_r}\ \left(erfc(\sqrt{(A_1-A_9)t})-erfc(-\sqrt{(A_1-A_9)t})\right)\right]$$

$$+A_{13}\left[\frac{\sqrt{S_c}}{\sqrt{\pi t}}\right]$$
$$+\frac{A_{35}}{2}e^{-A_{12}t}\left[\frac{-2\sqrt{S_c}}{\sqrt{\pi t}}e^{-A_{12}t}+\sqrt{(S_c A_{12})}\ \left(erfc(\sqrt{A_{12}t})-erfc(-\sqrt{A_{12}t})\right)\right]$$
$$+\frac{A_{15}}{2}e^{-A_3 t}\left[\frac{-2\sqrt{S_c}}{\sqrt{\pi t}}e^{A_3 t}+\sqrt{(-A_3 S_c)}\ \left(erfc(\sqrt{-A_3 t})-erfc(-\sqrt{-A_3 t})\right)\right]$$
$$+\frac{A_{18}}{2}e^{A_{12}t}\left[\frac{-2\sqrt{S_c}}{\sqrt{\pi t}}e^{-A_{12}t}+\sqrt{(A_{12}S_c)}\ \left(erfc(\sqrt{A_{12}t})-erfc(-\sqrt{A_{12}t})\right)\right]$$
$$+\frac{A_{19}}{2}e^{-A_5 t}\left[\frac{-2\sqrt{S_c}}{\sqrt{\pi t}}e^{A_5 t}+\sqrt{(-A_5 S_c)}\ \left(erfc(\sqrt{(-A_5)t})-erfc(-\sqrt{(-A_5)t})\right)\right]$$

$$+\frac{A_{36}}{2}e^{-A_{21}t}\left[\frac{-2P_r}{\sqrt{\pi t}}e^{-(A_1-A_{25})t}+\sqrt{(A_1-A_{25})P_r}\left(erfc\left(\sqrt{(A_1-A_{25})t}\right)-erfc\left(-\sqrt{(A_1-A_{25})t}\right)\right)\right]$$

$$+\frac{A_{28}}{2}e^{-A_3t}\left[\frac{-2P_r}{\sqrt{\pi t}}e^{-(A_1-A_3)t}+\sqrt{(A_1-A_3)P_r}\left(erfc\left(\sqrt{(A_1-A_3)t}\right)-erfc\left(-\sqrt{(A_1-A_3)t}\right)\right)\right]$$

$$+\frac{A_{28}}{2}e^{-A_5t}\left[\frac{-2P_r}{\sqrt{\pi t}}e^{-(A_1-A_5)t}+\sqrt{(A_1-A_5)P_r}\left(erfc\left(\sqrt{(A_1-A_5)t}\right)-erfc\left(-\sqrt{(A_1-A_5)t}\right)\right)\right]$$

for $P_r \neq 1, S_c \neq 1$ (24)

$$\left(\frac{\partial \emptyset}{\partial y}\right)_{y=0}=\frac{B_9}{2}\left[\frac{-2}{\sqrt{\pi t}}e^{-Nt}+\sqrt{N}\left(erfc\left(\sqrt{Nt}\right)-erfc\left(-\sqrt{Nt}\right)\right)\right]$$
$$+\frac{B_8}{2\sqrt{\pi t^3}}e^{-Nt}-\frac{B_8}{2\sqrt{\pi t^3}}-\frac{B_7}{\sqrt{\pi t}}$$
$$-\frac{B_6}{2}\left[\frac{-2}{\sqrt{\pi t}}e^{-F_1t}+\sqrt{F_1}\left(erfc\left(\sqrt{F_1t}\right)-erfc\left(-\sqrt{F_1t}\right)\right)\right]$$

for $P_r = 1$ and $S_c = 1$ (25)

Nusselt number

In non dimensional form, the rate of heat transfer is given by

$$N_u=-\left(\frac{\partial\theta}{\partial y}\right)_{y=0}$$
$$=\frac{1}{2}\left[\frac{-2}{\sqrt{\pi t}}e^{-A_1t}+\sqrt{(P_rA_1)}\left(erfc\left(\sqrt{A_1t}\right)-erfc\left(-\sqrt{A_1t}\right)\right)\right]$$

for $P_r \neq 1$ (26)

$$=\frac{1}{2}\left[\frac{-2}{\sqrt{\pi t}}e^{-A_1t}+\sqrt{(A_1)}\left(erfc\left(\sqrt{A_1t}\right)-erfc\left(-\sqrt{A_1t}\right)\right)\right]$$

for $P_r=1$ (27)

Sherwood Number

Another important physical quantities of interest is the Sherwood number which in non-dimensional form is $S_h=-\left(\frac{\partial c}{\partial y}\right)_{y=0}$

$$=-\sqrt{\frac{S_c}{\pi t}}-\frac{A_2}{2}e^{-A_3t}\left[\frac{-2}{\sqrt{\pi t}}e^{A_3t}+\sqrt{(-A_3S_c)}\left(erfc\left(\sqrt{-A_3t}\right)-erfc\left(-\sqrt{-A_3t}\right)\right)\right]$$
$$+A_6\left[\frac{\sqrt{S_c}}{\sqrt{\pi t}}\right]$$
$$-\frac{A_6}{2}e^{-A_5t}\left[\frac{-2}{\sqrt{\pi t}}e^{A_5t}+\sqrt{(-A_5S_c)}\left(erfc\left(\sqrt{-A_5t}\right)-erfc\left(-\sqrt{-A_5t}\right)\right)\right]$$
$$+\frac{A_2}{2}e^{-A_3t}\left[\frac{-2}{\sqrt{\pi t}}e^{-(A_1-A_3)t}+\sqrt{(A_1-A_3)P_r}\left(erfc\left(\sqrt{(A_1-A_3)t}\right)-erfc\left(-\sqrt{(A_1-A_3)t}\right)\right)\right]$$
$$+\frac{A_6}{2}\left[\frac{-2}{\sqrt{\pi t}}e^{-A_1t}+\sqrt{(P_rA_1)}\left(erfc\left(\sqrt{A_1t}\right)-erfc\left(-\sqrt{A_1t}\right)\right)\right]$$
$$-\frac{A_6}{2}e^{-A_5t}\left[\frac{-2}{\sqrt{\pi t}}e^{-(A_1-A_5)t}+\sqrt{(A_1-A_5)P_r}\left(erfc\left(\sqrt{(A_1-A_5)t}\right)-erfc\left(-\sqrt{(A_1-A_5)t}\right)\right)\right]$$

for $P_r \neq 1, S_c \neq 1$ (28)

$$=\frac{B_1}{2\sqrt{\pi t^3}}e^{-F_1t}-\frac{B_1}{2\sqrt{\pi t^3}}-\frac{B_2}{\sqrt{\pi t}}$$
$$-\frac{S_0}{2}\left[\frac{-2}{\sqrt{\pi t}}e^{-F_1t}+\sqrt{F_1}\left(erfc\left(\sqrt{F_1t}\right)-erfc\left(-\sqrt{F_1t}\right)\right)\right]$$

for $P_r=1$ and $S_c=1$ (29)

IV. Results And Discussions

The present study deals with an Unsteady MHD free convective Heat and Mass transfer flow over an inclined plate embedded in porous medium, which moves with time dependent velocity in a viscous, electrically conducting incompressible fluid, under the influence of uniform magnetic field, applied normal to the plate. The presence of thermal radiation, heat source and Soret effect are considered. The dimensionless governing equations i.e. momentum equation which is coupled with the energy and mass diffusion equations are analytically solved in closed form by Laplace transform technique. The expressions for velocity, temperature, concentration, skin friction, rate of heat and mass transfer are derived and discussed through graphs and tables for different physical parameters.

The velocity profile for the different values of Magnetic parameter (M), thermal Grashof number (G_r), mass Grashof number (Gm), Radiation parameter (F), Prandtl number (Pr), Schmidt number (Sc), Soret number (S_0) and Heat source parameter (Q_0) are shown in the figures 2 -10 respectively. From these figures it is observed that the velocity increases as Pr and G_r increases. While velocity decreases as F, Sc, So, M, $\propto$, Gm and Q_0 increases.

Figure 11 - figure 13 shows that the temperature profile for the different values of the Prandtl number (Pr), the Radiation parameter (F) and the Heat source parameter (Q_0). It is noticed that temperature decreases as Pr, F and Q_0 increases.

The concentration profile for different values of the Schmidt number (Sc), Prandtl number (Pr), the Soret number (S_0), Heat source parameter (Q_0) and Radiation parameter (F) are shown in figures 14-18 respectively. It is noticed that the concentration decreases as Sc, So, Pr, F and Q_0 increases.

From table 1 it is noticed that an increasing the mass Grashof number (Gm), Prandtl number (Pr), the Magnetic parameter (M), the Heat source parameter (Q_0), the Radiation parameter (F), the Soret number (S_0) results an increasing Skin friction. While it decreases with increase of the thermal Grashoff number (G_r) and the Schmidt number (Sc) respectively.

Table 2 discusses the effects of Prandtl number (Pr), the Radiation parameter (F) and the Heat source parameter (Q_0) numerically on rate of heat transfer (Nu). It is noticed that the rate of heat transfer increases with increasing of Pr, F and Q_0.

Table 3 shows the effects of Prandtl number (Pr), the Radiation parameter (F), the Schmidt number (Sc), the Soret number (S_0) and the Heat source parameter (Q_0) on rate of mass transfer (S_h) numerically. It is observed that the rate of mass transfer increases with increasing Pr, F, S_c So and Q_0.

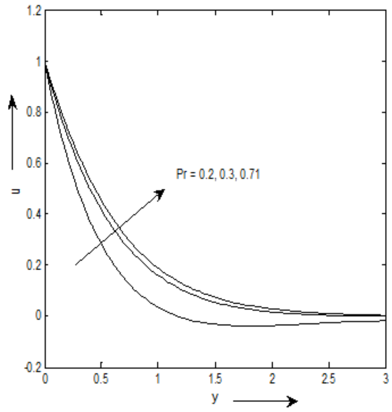

Fig. 2: Velocity profile for Pr

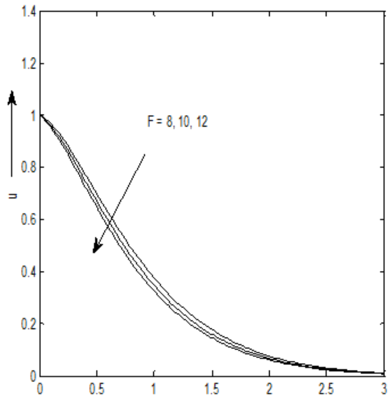

Fig. 3: Velocity profile for F

Fig. 2: Velocity profile for Pr

Fig. 3: Velocity profile for F

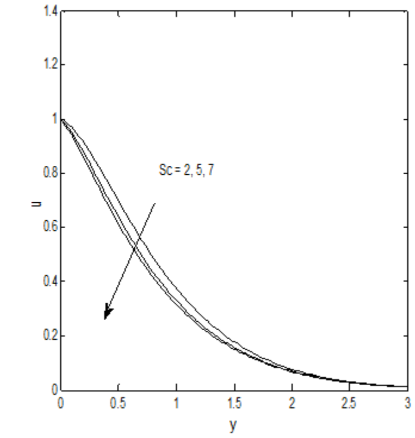

Fig.4: Velocity profile for Sc

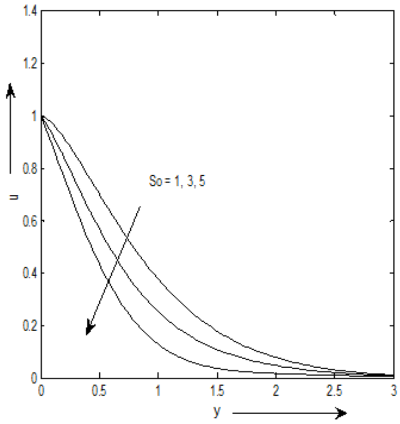

Fig.5: Velocity profile for S_0

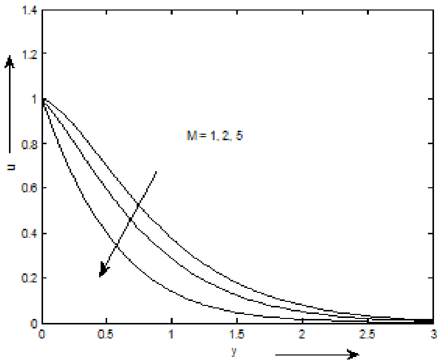

Fig.6: Velocity profile for M

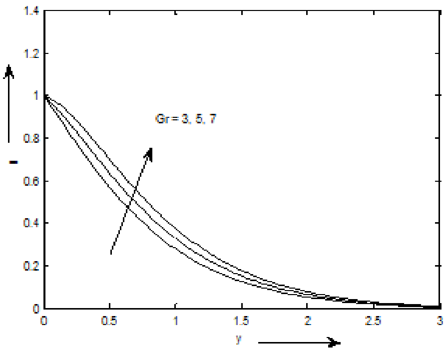

Fig.7: Velocity profile for G_r

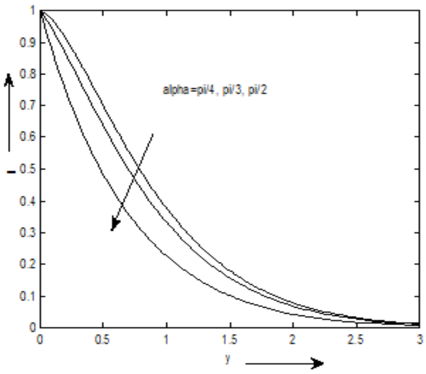

Fig.8: Velocity profile for ∝

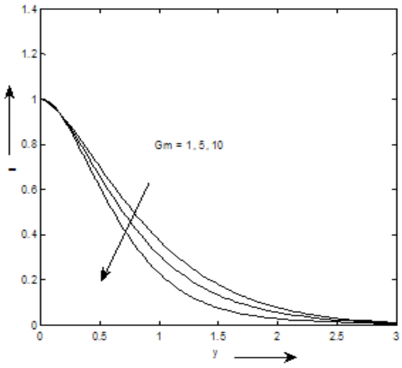

Fig.9: Velocity profile for Gm

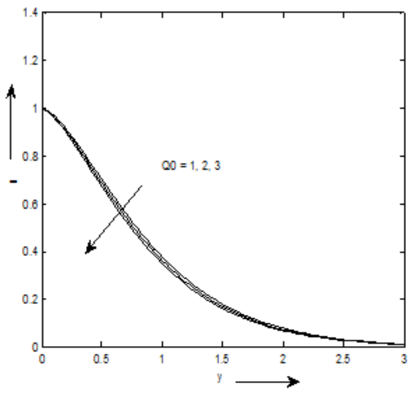

Fig.10: Velocity profile for Q_0

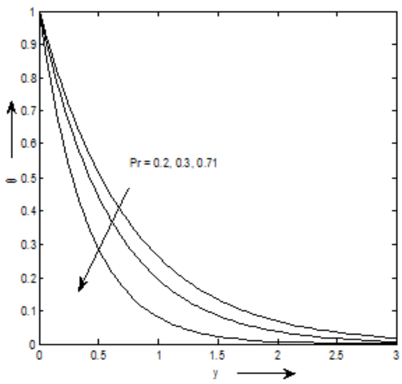

Fig.11: Temperature profile for Pr

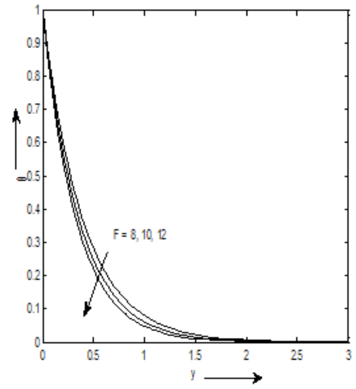

Fig.12: Temperature profile for F

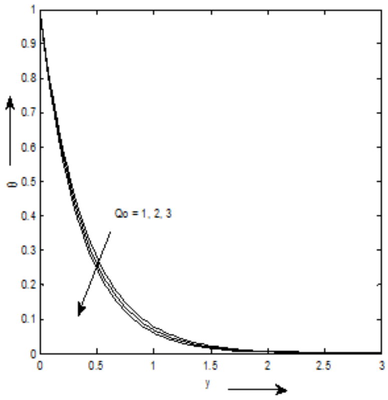

Fig.13: Temperature profile for Q_0

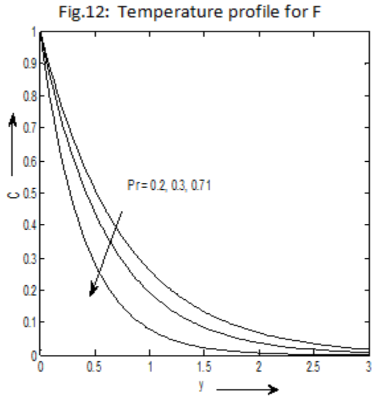

Fig.14: Concentration profile for Pr

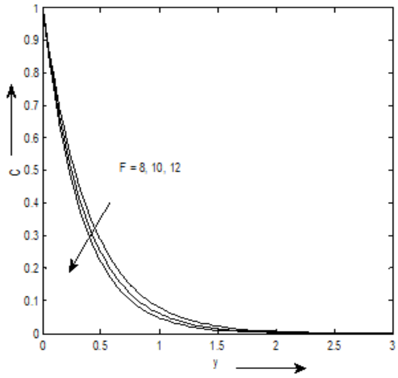

Fig.15: Concentration profile for F

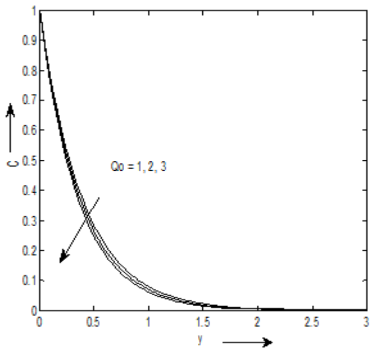

Fig. 16: Concentration profile for Q_0

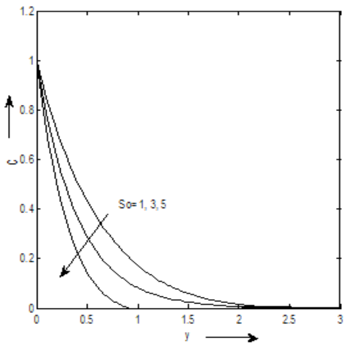

Fig. 17: Concentration profile for S_0

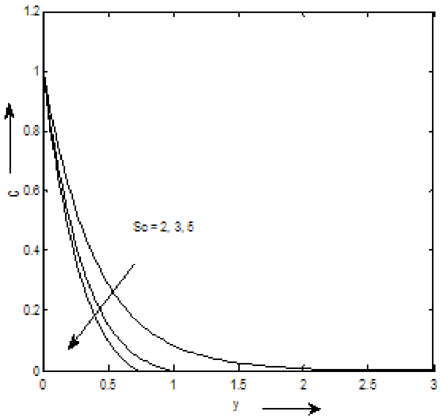

Fig. 18: Concentration profile for Sc

Table 1: Skin-friction

Pr	**F**	**Sc**	**S0**	**M**	**G_r**	**Gm**	**Q_0**	**∝**	**S_f**
0.20	8.00	2.00	5.00	1.00	7.00	1.00	1.00	0.79	**-2.40**
0.30	8.00	2.00	5.00	1.00	7.00	1.00	1.00	0.79	**190.55**
0.20	**10.00**	2.00	5.00	1.00	7.00	1.00	1.00	0.79	**161.75**
0.20	8.00	**5.00**	5.00	1.00	7.00	1.00	1.00	0.79	**-60.51**
0.20	8.00	2.00	**7.00**	1.00	7.00	1.00	1.00	0.79	**15.89**
0.20	8.00	2.00	5.00	**3.00**	7.00	1.00	1.00	0.79	**133.95**
0.20	8.00	2.00	5.00	1.00	**10.00**	1.00	1.00	0.79	**-24.66**
0.20	8.00	2.00	5.00	1.00	7.00	**2.00**	1.00	0.79	**41.39**
0.20	8.00	2.00	5.00	1.00	7.00	1.00	**5.00**	0.79	**120.71**
0.20	8.00	2.00	5.00	1.00	7.00	1.00	1.00	**1.05**	**-1.20**

Table 2: Nusselt number

Pr	**F**	**Q_0**	**N_u**
0.20	8.00	1.00	**2.68**
0.30	8.00	1.00	**3.29**
0.20	**10.00**	1.00	**2.97**
0.20	8.00	**5.00**	**3.22**

Table 3: Sherwood number

Pr	**F**	**S_c**	**S_0**	**Q_0**	**S_h**
0.20	8.00	2.00	5.00	1.00	**0.38**
0.30	8.00	2.00	5.00	1.00	**0.73**
0.20	**10.00**	2.00	5.00	1.00	**0.52**
0.20	8.00	**5.00**	5.00	1.00	**0.67**
0.20	8.00	2.00	**7.00**	1.00	**0.54**
0.20	8.00	2.00	5.00	**5.00**	**0.39**

V. Conclusion

The present study deals with an Unsteady MHD free convective Heat and Mass transfer flow over an inclined plate embedded in porous medium, which moves with time dependent velocity in a viscous, electrically conducting incompressible fluid, under the influence of uniform magnetic field, applied normal to the plate. The presence of thermal radiation, heat source and Soret effect are considered. The dimensionless governing equations i.e. momentum equation which is coupled with the energy and mass diffusion equations are analytically solved in closed form by Laplace transform technique. The expressions for velocity, temperature, concentration, skin friction, rate of heat and mass transfer are derived and discussed through graphs and tables for different physical parameters. From the study the following conclusions can be drawn:

- The velocity profile increases with increase in Pr and G_r while it decreases with increase in F, Sc, So , M, Gm, Q_0 and α.
- The temperature decreases with increase in values of Pr, Q_0 and F.
- The Concentration decreases with increase in Pr, F, Q_0, Sc and So.
- Velocity on skin friction increases with increase in Pr, F, So, M, Gm, Q_0 and ∝, while it decreases with increase in Sc and Gr.
- The rate of heat transfer expressed in terms of Nusselt number increases with increase in Pr, F and Q_0.
- The rate of mass transfer expressed in terms of Sherwood number increases with increase in Pr, F, Sc, S_0 and Q_0.

Appendix:

$$A_1 = F_1 = F + Q \quad A_2 = \frac{-S_c S_0 P_r}{P_r - S_c}, \quad A_3 = \frac{A_1 P_r}{P_r - S_c}, \quad A_4 = \frac{-S_c S_0 F P_r}{P_r - S_c},$$

$$A_5 = A_3 = \frac{A_1 P_r}{P_r - S_c}, \ A_6 = \frac{A_4}{A_5}, \ A_7 = 1 - A_6, \ A_8 = \frac{-G_r}{P_r - 1},$$

$$A_9 = \frac{P_r A_1 - N}{P_r - 1}, \ A_{10} = \frac{A_8}{A_9}, \quad A_{11} = \frac{-G_m A_7}{S_c - 1}, \quad A_{12} = \frac{N}{S_c - 1},$$

$$A_{13} = \frac{-G_m A_7}{N}, \ A_{14} = \frac{G_m A_2}{S_c - 1}, \ A_{15} = \frac{A_{14}}{-(A_8 + A_{12})}, \ A_{16} = -A_{15},$$

$$A_{17} = \frac{-G_m A_6}{S_c - 1}, \ A_{18} = \frac{A_{17}}{A_8 + A_{12}}, \ A_{19} = -A_{18}, \ A_{20} = \frac{-G_m A_2 - N}{P_r - 1},$$

$$A_{21} = A_9 = \frac{P_r A_1 - N}{P_r - 1}, \ A_{22} = \frac{A_{20}}{A_8 - A_{21}}, \ A_{23} = -A_{22} = \frac{A_{20}}{A_{21} - A_8}$$

$$A_{24} = \frac{-G_m A_6}{P_r - 1}, \ A_{25} = \frac{-G_m A_6}{P_r A_1 - N}, \ A_{26} = \frac{G_m A_6}{P_r - 1}, \ A_{27} = \frac{A_{26}}{A_5 - A_{21}},$$

$$A_{28} = -A_{27} = \frac{A_{26}}{A_{21} - A_5}\,,\ A_{29} = -(A_{10} - A_{13} + A_{25})\ ,$$
$$A_{30} = -(A_{13} + A_{16} + A_{18})\,, A_{31} = -(A_{15} + A_{23})$$
$$A_{32} = -(A_{19} + A_{28})\ ,\ A_{33} = -(A_{22} - A_{25} + A_{27})\ ,$$
$$A_{34} = (A_{10} + A_{25})\,,\ A_{35} = (A_{13} + A_{16})\ ,$$
$$A_{36} = -A_{33} = (A_{22} - A_{25} + A_{27})$$

References

[1]. Soundalgekar .1979, free convection effects on the flow past a vertical oscillating plate. Astrophysics and Space Science 64, 165- 172.

[2]. Revankar.2000, Free convection effect on the flow past an impulsively started or oscillating infinite vertical plate., Mechanics Research Comm.27, 241-246.

[3]. Soundalgekar et al.1995, Mass Transfer effects on flow past a vertical oscillating plate with variable temperature. , Heat and Mass transfer 30(5), 309-312.

[4]. Das et al.1996, Mass transfer effects on flow past an impulsively started infinite vertical plate with constant mass flux – an exact solution. , Heat and mass transfer 31, 163-167.

[5]. Muthukumaraswamy 2003, Effects of chemical reaction on moving isothermal plate with variable mass diffusion. Theory Appl. Mech. 30(3), 209-220.

[6]. Panda et al. 2003, Unsteady Free convection flow and Mass Transfer past a vertical porous plate. AMSE Modeling B 72(3), 47-58.

[7]. Takhar et al. 2006, Unsteady free convection flow over an infinite vertical porous plate due to the combined effects of thermal and mass diffusion, magnetic field and hall current,. Heat Mass Transfer 39, 823-834.

[8]. Hossain &Mondal .1985, Mass transfer effects on the unsteady hydro magnetic free convection flow past an accelerated vertical porous plate,. J. Phys. D: Appl. Phys 18,163-169.

[9]. Israel-Cookey .& Sigalo .2003, Unsteady MHD free convection and Mass Transfer flow past an infinite heated porous vertical plate with time suction., ASME Modeling B 72(3), 25.

[10]. Sahoo et al.2003, Magneto hydrodynamic unsteady free convection flow past an infinite vertical plate with constant suction and heat sink,. Ind. J. Pure and Appl. Math 34(1), 145-155.

[11]. Ali . et al., 2000, Hydro magnetic combined heat and Mass Transfer by natural convection from a permeable surface embedded in a fluid saturated porous medium, International Journal of Numerical Methods for Heat & Fluid flow 10(5) ,455-476.

[12]. Chaudhary &Jain 2006., Combined heat and mass transfer effects on MHD free convection flow past an oscillating plate embedded in porous medium,.Rom. Jour. Phys. 52(5-7), 505-524.

[13]. Das 2010, Exact solution of MHD free convection flow and mass transfer near a moving vertical plate in presence of thermal radiation. AJMP 8(1), 29-41.

[14]. Viskanta, R., The forced convection flow in a horizontal channel permeated by uniform vertical magnetic fluid in the presence of radiation, ZAMP, vol. 14. pp. 353-361 (1963).

[15]. Takhar, H.S., Goria, R.S.R. and Soundalgekar, V.M., The effects of radiation on the MHD free convection flow past a semi-infinite vertical plate. Int. J. Num

[16]. Chaudhary, R. C., Arpita Jain, Combined heat and mass transfer effects on MHD free convection flow past an oscillating plate embedded in porous medium, Rom. Journ. Phys., Vol. 52, Nos. 5–7, 2007, 505–524, Bucharest.

[17]. Das, U.N., Deka, R.K., and Soundalgekar, V.M., The radiation effects on flow past an impulsively started infinite isothermal vertical plate, J. Theo. Mech.Vol.1.pp.111-115 (1996).

[18]. Ramana Reddy, G.V., Ramana Murthy, Ch. V. and Bhaskar Reddy, N., Mass transfer and radiation effects of unsteady MHD free convective fluid flow embedded in porous medium with heat generation/absorption, Journal of Applied Mathematics and Fluid Mechanics, vol.2, No.1, pp. 85—98 (2010).

[19]. Sivaiah, M.,Nagarajan, A.S. and Reddy, P.S., Radiation effects on MHD free convection flow over a vertical plate with heat and mass flux, Emirates Journal for Engg. Research, vol.15 (1), pp. 35-40 (2010).