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Finite difference analysis on an unsteady mixed convection flow past a semi-infinite vertical permeable moving plate with heat and mass transfer with radiation and viscous dissipation

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ABSTRACT

An unsteady, two-dimensional, hydro magnetic, laminar mixed convective boundary- layer flow of an incompressible, Newtonian, electrically-conducting and radiating fluid along a semi-infinite vertical permeable moving plate with heat and mass transfer is analyzed, by taking into account the effect of viscous dissipation. The plate moves with a constant velocity in the direction of fluid flow while the free stream velocity follows an exponentially increasing small perturbation law. The dimensionless governing equations for this investigation are solved numerically by using the implicit finite difference method. Numerical evolution of the analytical results is performed and graphical results for velocity, temperature and concentration profiles within the boundary layer and tabulated results for skin-friction coefficient, Nusselt number and Sherwood number are presented and discussed.

Keywords: Radiation, Viscous dissipation, mixed convection, MHD, finite difference method.

INTRODUCTION

The buoyancy force induced by density differences in a fluid cause's natural convection. Natural convection flows are frequently encountered in physics and engineering problems such as chemical catalytic reactors, nuclear waste material etc. Transient free convection is important in many practical applications such as thermal regulation process, security of energy systems etc. When a conductive fluid moves through a magnetic field, an ionized gas is electrically conductive, the fluid may be influenced by the magnetic field. Magneto hydrodynamic free convection heat transfer flow is considerable interest in the technical field due to its frequent occurrence in industrial technology and geothermal application, liquid metal fluid and MHD power generation systems etc. Transport processes in porous media are encountered in a broad range of scientific and engineering problems associated with the fiber and granular insulation materials, packed-bed chemical reactors and transpiration cooling. The change in wall temperature causing the free convection flow, could be a sudden or a periodic one, leading to a variation in the flow. In nuclear engineering, cooling of medium is more important from safety point of view and during this cooling process the plate temperature starts oscillating about a non-zero constant mean temperature. Further, oscillatory flow has applications in industrial and aerospace engineering. In literature, extensive research work performed to examine the effect of natural convection on flow past a plate. Gupta [7] studied free convection on flow past a linearly accelerated vertical plate in the presence of viscous dissipative heat using perturbation method. Das et al.[5] have analyzed radiation effects on flow past an impulsively started infinite isothermal vertical plate.

Combined buoyancy–generated heat and mass transfer, due to temperature and concentration variations, in fluid-saturated porous medium, have several important applications in variety of engineering processes including heat exchanger devices, petroleum reservoirs, chemical catalytic reactors, solar energy porous wafer collector systems, ceramic materials, migration of moisture through air contained in fibrous insulations and grain storage installations, and the dispersion of chemical contaminants through water-saturated soil, superconvectinggeothermics etc. The vertical free convection boundary layer flow in porous media owing to combined heat and mass transfer has been investigated by Nield[11], and Bejan [1], Dunn [6] and Kaviany [9]. Several researchers are attracted to the unsteady free convective flow past an infinite vertical porous media due to its important technological applications.In the last five years, many investigators dealing with heat flow and mass transfer over a vertical porous plate with variable suction, heat absorption or generation have been reported. Chamkha [2] presented thermal radiation and buoyancy effects on hydro-magnetic flow over an accelerating permeable surface with heat source or sink. Chen [3] studied heat and mass transfer with variable wall temperature and concentration. Unsteady MHD free convection flow and mass transfer near a moving vertical plate in the presence of thermal radiation is studied by Seethamahalakshmi et al [20]. Cookey et al [4] investigated the influence of viscous dissipation and radiation on unsteady MHD free-convection flow past an infinite heated vertical plate in a porous medium with time dependent suction.

Ogulu et al. [12] studied unsteady MHD free convective flow of a compressible fluid past a moving vertical plate in the presence of radiactive heat transfer. Ogulu and Mbeledogu[13]studied heat and mass transfer of an unsteady MHD natural convection flow of a rotating fluid past a vertical porous flat plate in the presence of radiative heat transfer. Pilani and Ganesan [14] presented finite difference analysis of unsteady natural convection MHD flow past an inclined plate with variable surface heat and mass flux.

Kishan and Srinivas [15] is investigated the effects of thermophoresis and viscous dissipation on MHD mixed convection, heat and mass transfer about an isothermal vertical flat plate embedded in a fluid saturated porous media. Singh [18] have been studied Transient free convection flow of a viscous incompressible fluid in a vertical parallel plate channel, when the walls are heated asymmetrically. Shanker, Prabhakar Reddy and AnandRao [17] have studied Radiation and mass transfer effects on unsteady MHD free convective fluid flow embedded in a porous medium with heat generation/ absorbtion. Ramachandra Prasad and Bhaskar Reddy [16] studied radiation and mass transfer effects on an unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate embedded in a porous media with viscous dissipation. They solved the problem by using the regular perturbation method.

The objective of the present paper is to analyze the radiation and mass transfer effects on an unsteady two-dimensional laminar mixed convective boundary layer flow of a viscous, incompressible, electrically conducting fluid along a vertical moving semi-infinite permeable plate with suction, embedded in a uniform porous medium, in presence of transverse magnetic field, by taking into account the effects of viscous dissipation. The equations of continuity, linear momentum, energy and diffusion, which govern the flow field, are solved by using a implicit finite difference method. The behavior of the velocity, temperature, concentration, skin-friction, Nusselt number and Sherwood number has been discussed for variations in the governing parameters.

2. Mathematical Analysis:

An unsteady two-dimensional hydromagnetic laminar mixed convective boundary layer flow of a viscous, incompressible, electrically conducting and radiation fluid in an optically thin environment, past a semi-infinite vertical permeable moving plate embedded in a uniform porous medium in the presence of thermal and concentration buoyancy effects has been considered. The x'-axis is taken in the upward direction along the plate and y'-axis normal to it. A uniform magnetic field is applied in the direction perpendicular to the plate. The transverse applied to the magnetic field and magnetic Reynolds number are assumed to be very small, so that the electric field is absent. The concentration of the diffusing species in the binary mixture is assumed to be very small in comparison with the other chemical species which are present, and hence the Soret and Dufour effects are negligible. Further, due to the semi-infinite plane surface assumption, the flow variables are functions of normal distance y' and t' only. Now under the usual Boussinesq's approximation the governing boundary layer equations are:

$$\frac{\partial v'}{\partial y'} = 0 \qquad \ldots(1)$$

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = -\frac{1}{\rho}\frac{\partial p'}{\partial x'} + \nu\frac{\partial^2 u'}{\partial y'^2} + g\beta(T' - T'_\infty) + g\beta^*(C' - C'_\infty) - \nu\frac{u'}{K'} - \frac{\sigma B_0^2 u'}{\rho} \qquad \ldots..(2)$$

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{1}{k}\frac{\partial q'}{\partial y'} + \frac{\nu}{C_p}\left(\frac{\partial u'}{\partial y'}\right)^2 \qquad \ldots(3)$$

$$\frac{\partial^2 q'}{\partial y'^2} - 3\alpha^2 q' - 16\sigma\alpha T_\infty'^3\frac{\partial T'}{\partial y'} = 0 \qquad \ldots(4)$$

$$\frac{\partial C'}{\partial t'} + v'\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'^2}{\partial y'^2} \qquad (5)$$

Where u', v' are the velocity components in x', y' directions respectively, t'-time, p'-the pressure, ρ- the fluid density, g-the acceleration due to gravity. β and β*- the thermal and concentration expansion coefficients respectively, k'-the permeability of the porous medium, T'- the of the fluid in the boundary layer, v-kinematic viscosity, σ- the electrical conductivity of the fluid, T'_∞ - the temperature of the fluid far away from the plate, C'- the species concentration in the boundary layer, C'_∞ – the species concentration in the fluid far away from the plate, B_o – the magnetic induction, α - the fluid thermal diffusivity, k-the thermal conductivity, q' –the radiative heat flux, σ* - the Stefan- Boltzmann constant and D- the mass diffusivity.

The third and the fourth terms of the right hand side of the momentum Eq. (2) denote the thermal and concentration buoyancy effects respectively. Also, the second and third terms on right hand side of Eq. (3) represent the radiative heat flux and viscous dissipation respectively.

It is assumed that the permeable plate moves with a constant velocity in the direction of the fluid flow and the free stream velocity follows the exponentially increasing small perturbation law. In addition, it is assumed that the temperature and concentration at the wall as well as the suction velocity are exponentially varying with time. Eq. (4) is differential approximation for radiation under fairly broad realistic assumptions. In one space coordinate y', the radiative heat flux q' satisfies this nonlinear differential equation.

The boundary conditions of the velocity, temperature and concentration fields are:

$u' = u'_p$; $T' = T'_\infty + \varepsilon(T'_w - T'_\infty)e^{n't'}$; $C' = C'_\infty + \varepsilon\,(C'_w - C'_\infty)\,e^{n't'}$ at $y' = 0$

$u' = U'_\infty = U_0(1 + \varepsilon\, e^{n't'})$; $T' \to T'_\infty$; $C' \to C'_\infty$ as $y' \to \infty$ …(6)

where u' is the plate velocity, T' and C'- the temperature and concentration respectively. U'- the free stream velocity, U_0 and n' –the constants

From equation (1), it is clear that the suction velocity of the plate is either a constant or function of time only. Hence, the suction velocity normal to the plate is assumed in the form:

$$v' = -v(1 + \varepsilon A\, e^{n't'}) \qquad \ldots(7)$$

Where A is a real positive constant and ε is small such that ε << 1, ε A<< 1, and V is a non – zero positive constant, the negative sign indicates that suction is towards the plate.

Outside the boundary layer, equation (2) gives:

$$-\frac{1}{\rho}\frac{\partial p'}{\partial x'} = \frac{dU'_\infty}{dt'} + \frac{\nu}{K'}U'_\infty + \frac{\sigma}{\rho}B_0^2\, U'_\infty \ldots(8)$$

Since the medium is optically thin with relatively low density and α<< 1, the radiative heat flux given by equqtion(3), becomes:

$$\frac{\partial q'}{\partial y'} = 4\alpha^2 (T' - T'_\infty) \qquad \ldots(9)$$

Where $\alpha^2 = \int_0^\infty \delta\lambda \frac{\partial B}{\partial T'}$, where B is Planck's function.

In order to write the governing equations and the boundary conditions in dimensionless form, the following non-dimensionless quantities are introduced:

$$u = \frac{u'}{U_0},\quad v = \frac{v'}{V_0},\quad y = \frac{V_0 y'}{v},\quad U_\infty = \frac{U'_\infty}{U_0},\ U_p = \frac{u'_p}{U_0},\quad t = \frac{t' V_0^2}{v},$$
$$\theta = \frac{T' - T'_\infty}{T'_w - T'_\infty},\quad C = \frac{C' - C'_\infty}{C'_w - C'_\infty},\quad n = \frac{n'v}{V_0^2},\quad K = \frac{K' V_0^2}{v^2},\ Pr = \frac{v\rho C_p}{k},\quad Sc = \frac{v}{D},\quad M = \frac{\sigma B_0^2 v}{\rho V_0^2},$$
$$Gr = \frac{v\beta g(T'_w - T'_\infty)}{U_0 V_0^2},\ Gm = \frac{v\beta^* g(C'_w - C'_\infty)}{U_0 V_0^2},\quad Ec = \frac{U_0^2}{C_p(T'_w - T'_\infty)},\quad R^2 = \frac{\alpha^2 (T'_w - T'_\infty)}{\rho C_p k U_0^2} \qquad \ldots(10)$$

In view of equations (4) and (7-10), the equations (2), (3) and (5) reduce to the following dimensionless forms:

$$\frac{\partial u}{\partial t} - (1+\varepsilon A e^{nt})\frac{\partial u}{\partial y} = \frac{dU_\infty}{dt} + \frac{\partial^2 u}{\partial y^2} + Gr\theta + GmC + N(U_\infty - u) \qquad \ldots(11)$$
$$\frac{\partial \theta}{\partial t} - (1+\varepsilon A e^{nt})\frac{\partial \theta}{\partial y} = \frac{1}{Pr}\left[\frac{\partial^2 \theta}{\partial y^2} - R^2\right] + Ec\left(\frac{\partial u}{\partial y}\right)^2 \qquad \ldots(12)$$
$$\frac{\partial C}{\partial t} - (1+\varepsilon A e^{nt})\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} \qquad \ldots(13)$$

Where N = M + (1/K) and Gr, Gm, Pr, R, Ec and Sc are thermal Groshof Number, solutalGroshof Number, Prandtl Number, Radiation parameter, Eckert Number and Schmidt Number respectively.

The corresponding dimensionless boundary conditions are:

$$u = U,\ \theta = 1+\varepsilon e^{nt},\ C = 1+\varepsilon e^{nt} \qquad \text{at } y=0$$
$$U \to U_\infty = 1+\varepsilon e^{nt},\ \theta \to 0,\ C \to 0 \qquad \text{as } y \to \infty \qquad \ldots(14)$$

3. Method of Solution:

The equations (11-13) are coupled, non- linear partial differential equations and these cannot be solved in close-form. Applying finite difference formula for equations (11-13), the following system of equations are obtained

$$a_1 * u_{i-1}^{j+1} + b_1 * u_i^{j+1} + c_1 * u_{i+1}^{j+1} = d_1(i)$$
$$a_2 * \theta_{i-1}^{j+1} + b_2 * \theta_i^{j+1} + c_2 * \theta_{i+1}^{j+1} = d_2(i)$$
$$a_3 * C_{i-1}^{j+1} + b_3 * C_i^{j+1} + c_3 * C_{i+1}^{j+1} = d_3(i) \qquad \ldots(15)$$

where
$$d_1(i) = I\, u_{i-1}^j + H\, u_i^j + G\, u_{i+1}^j + D_1(i)$$
$$d_2(i) = J\, \theta_{i-1}^j + L\, \theta_i^j + O\theta_{i+1}^j + P + k\, Ec\, D_2(i)$$
$$d_3(i) = V\, C_{i-1}^j + S\, C_i^j + Q\, C_{i+1}^j$$

$$D_1(i) = B k + kGr\theta_i^j + kGmC_i^j + kN Z\,; \qquad D_2(i) = \left(\frac{u_{i+1}^j - u_i^j}{h}\right)^2$$

$$a_1 = \frac{-k}{2h^2},\quad b_1 = 1 + \frac{k}{h^2} + kN c_1 = \frac{-k}{2h^2}$$
$$a_2 = \frac{-k}{2Prh^2},\quad b_2 = 1 + \frac{k}{Prh^2},\quad c_2 = \frac{-k}{2Prh^2},$$
$$a_3 = \frac{-k}{2Sch^2},\quad b_3 = 1 + \frac{k}{Sch^2},\quad c_3 = \frac{-k}{2Sch^2}$$
$$E = 1+\varepsilon A e^{nt},\quad G = \frac{kE}{2h} + \frac{k}{2h^2},\ H = 1 - \frac{k}{h^2},\ I = \frac{-kE}{2h} + \frac{k}{2h^2},\ J = \frac{-kE}{2h} + \frac{k}{2Prh^2}$$
$$L = 1 - \frac{k}{Prh^2}, O = \frac{kE}{2h} + \frac{k}{2Prh^2}, P = -\frac{kR^2}{Pr},\quad Q = \frac{k}{2Sch^2} + \frac{kE}{2h},\quad B = \varepsilon n\, e^{nt},$$
$$S = 1 - \frac{k}{Sch^2},\quad V = \frac{k}{2Sch^2} + \frac{(-kE)}{2h} Z = 1 + \varepsilon e^{nt}$$

The boundary conditions (14) becomes
U_0^j=U_p; θ_0^j= 1+εA e^{nt} ; C_0^j= 1+εA e^{nt}
U_∞^j= 1+εA e^{nt}; θ_∞^j= 0; C_∞^j = 0 …(16)

Where h, k are mesh size along space direction and time direction respectively, Index i refers to space and j refers to time. The mesh system which consists of h = 0.01 and k =0.005, has been considered for computations. The solution of the equations (11-13) has been solved by using the finite difference scheme. The numerical values are obtained by solving the systemof equations (15) by using the Gauss-Siedel iterative method with the help of C-programming. In order to prove convergence of finite difference scheme, the computations is carried out for slightly changed values of h and k, by computing the same program, negligible change is observed.

RESULTS AND DISCUSSION

In order to get a physical insight of the problem, the above physical quantities are computed numerically for different values of the governing parameters viz., thermal Grashof number Gr, the SolutalGrashof number Gm , Prandtl number Pr, Schmidt number Sc, the plate velocity U_p, the radiation parameter R and the Eckert number Ec. In order to assess the accuracy of this method, we have compared our results with accepted data for the velocity and temperature profiles for a stationary vertical porous plate as computed by Helmy [8] and to the case of moving vertical porous plate as computed by Kim [10]. The results of these comparisons are found to be in very good agreement.

During the course of numerical calculations of velocity, temperature and species concentration functions the value of Prandtl number Pr is chosen to be 0.71 which represents air at 20^0 c. The values of Schmidt number Sc are chosen in such a way that they represent the diffusing chemical species of most common interest in air. For example, the values of Schmidt number for H_2, H_2O, NH_3 and propyl benzene in air are 0.22, 0.60, 0.78 and 2.62 respectively. Here,Grashof number for heat transfer Gr < 0 corresponding to an externally heated plate as the free convection currents are carried towards the plate. Gr > 0 corresponding to an externally cooled plate as the species concentration is assumed to be very low, thus only positive values are chosen.

Fig.1. exhibits the variation of velocity profiles for different values of Grashof number Gr, in case of corresponding to cooling of the plate (Gr >0). It is observed that from Fig.1(a). the velocity profiles increases with the increase of Gr. The rise in the values of velocity is due to enhancement in buoyancy force. In addition, it is noticed that the velocity increases rapidly near the wall of the porous plate as Grashof number increases and then decays to the free steam velocity. From Fig.1 (b). it can be seen that, increasing the values of SolutalGrashof number Gm is to increases the velocity profiles.

The radiation effects on velocity profiles are shown in Fig.2 it is observed that the velocity profiles decreases with the increase of Radiation parameter R. Fig.3 shows the effects of Schmidt Number on velocity profiles as the Schmidt number increases the velocity profiles decreases are noticed. In fig.4 it can be seen that the effect of Prandtl number Pr on velocity profiles. As Prandtl number increases the velocity profiles decreases. The effect of Eckert number Ec is shown in fig.5. Due to the effect of the Eckert number the fluid velocity is increases.

The Fig.6 is shown for the velocity profiles for the different values of permeable parameter K, with the increasing values of K the velocity profiles decreases. Fig.7 shows that the effects of magnetic field parameter M on the velocity profiles. It is obvious that an existence of the magnetic field decreases the velocity.

Figs. 8-10 is drawn for the temperature profiles for the different parameters Pr, R, Ec. The Prandtl number effects on temperature profiles are shown in fig.8. It is observed that an increase in Prandtl number Pr results a decrease of the thermal boundary layer thickness and in general lower average temperature within the boundary layer. The reason is that smaller values of Pr are equivalent to increase in the thermal conductivity of the fluid and therefore, heat is able to diffuse away from the heated surface more rapidly for higher values of Pr. Hence, in case of smaller Prandtl numbers as the thermal boundary layer is thicker and the rate of heated transfer is reduced.

From fig.9it can be seen that an increase in the radiation parameter results a decrease in the temperature profiles within the boundary layer, as well as decreased temperature boundary layer. The effect of Eckert number is shown in fig.10 it can be seen that the temperature increases with the increase of Eckert number.

The concentration profiles are shown in fig.11 for different values of Schmidt number Sc. The concentration profiles decreases with the increase in the values of Sc. From fig. 12 it is observed that concentration profiles increases with increases in Soret number Sr.

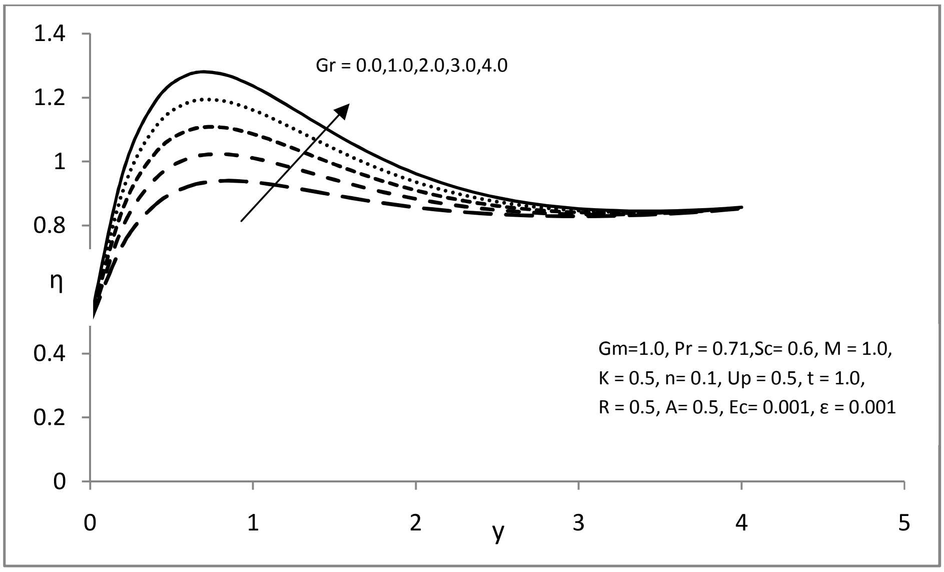

Fig.1(a). Effect of Gr on velocity

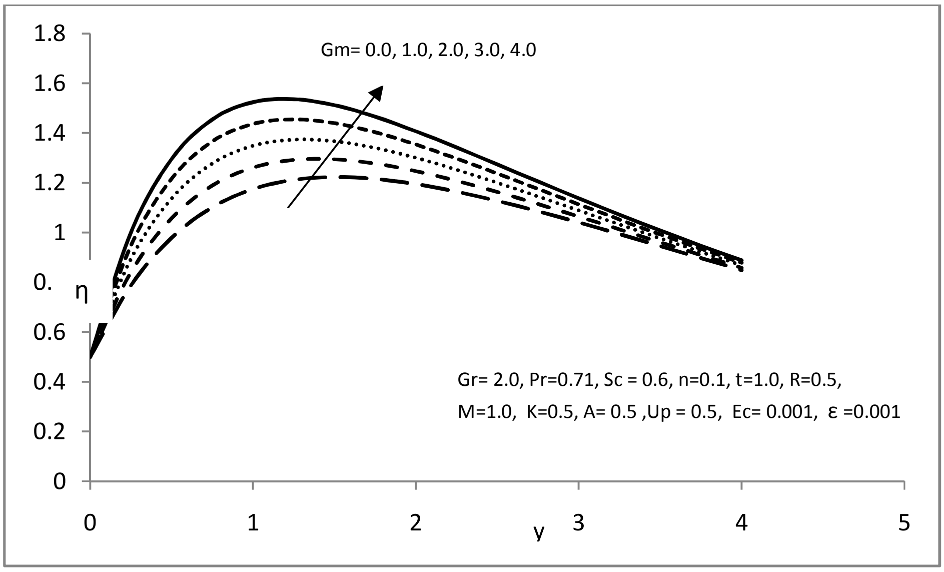

Fig.1 (b). Effect ofGm on velocity

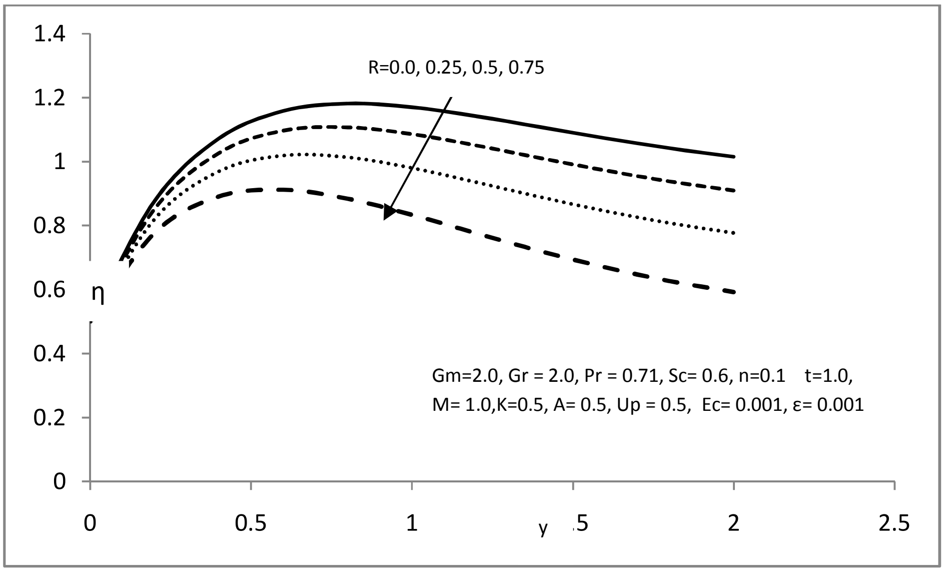

Fig.2. Effect of radiation on velocity

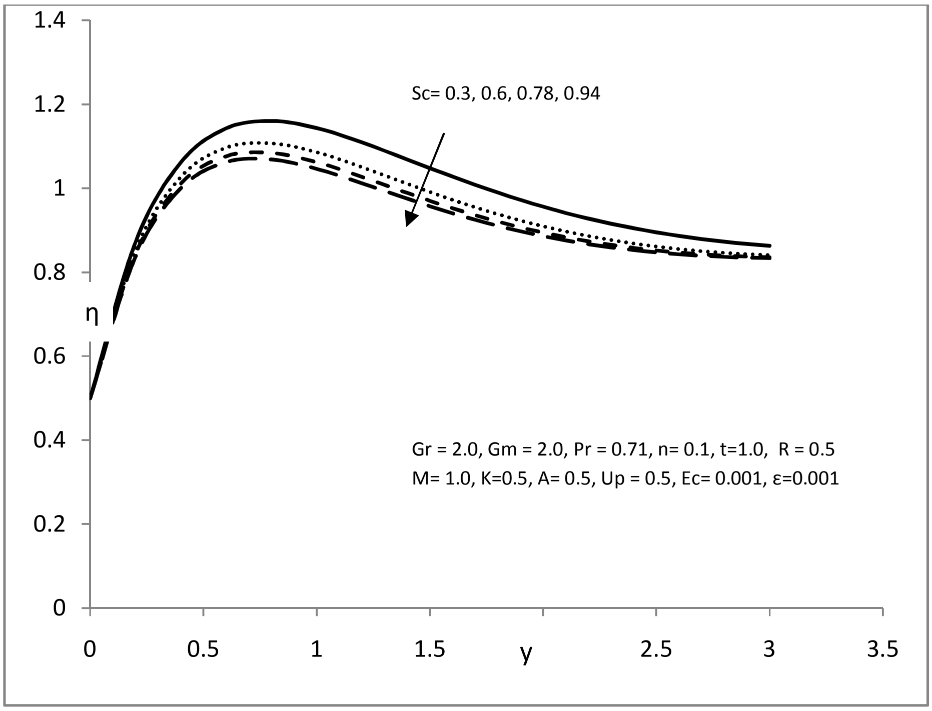

Fig.3 . Effect of Sc on velocity

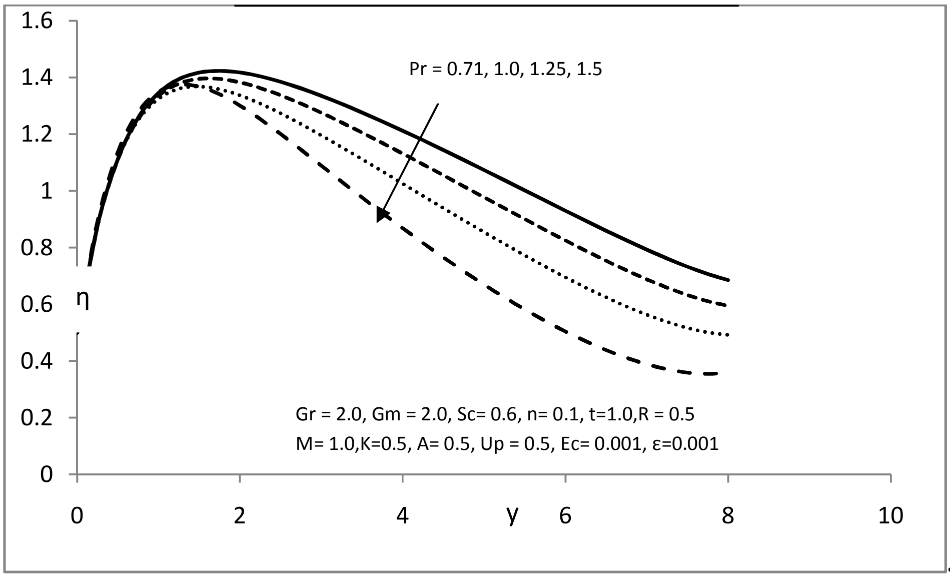

Fig.4. Effect of Pr on velocity

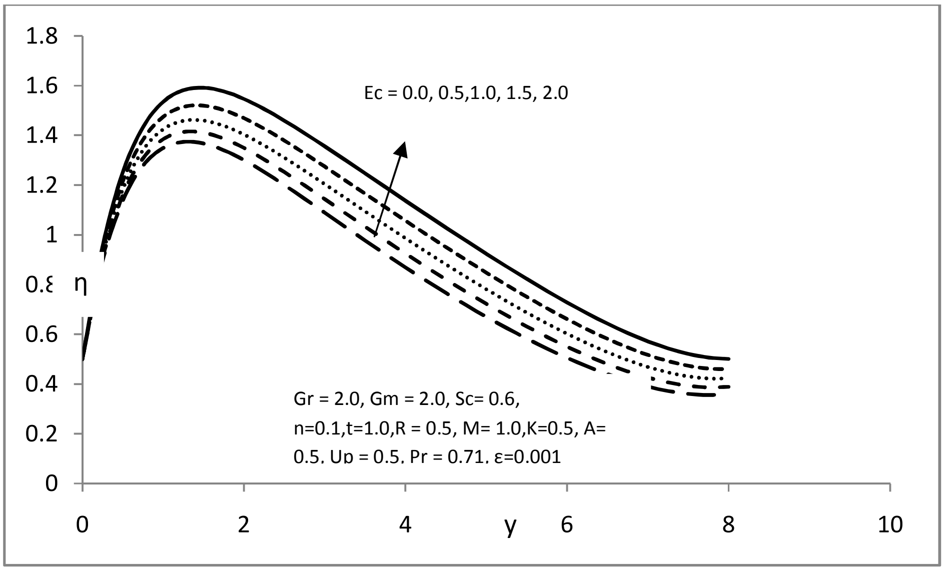

Fig.5Effect of Ec on velocity

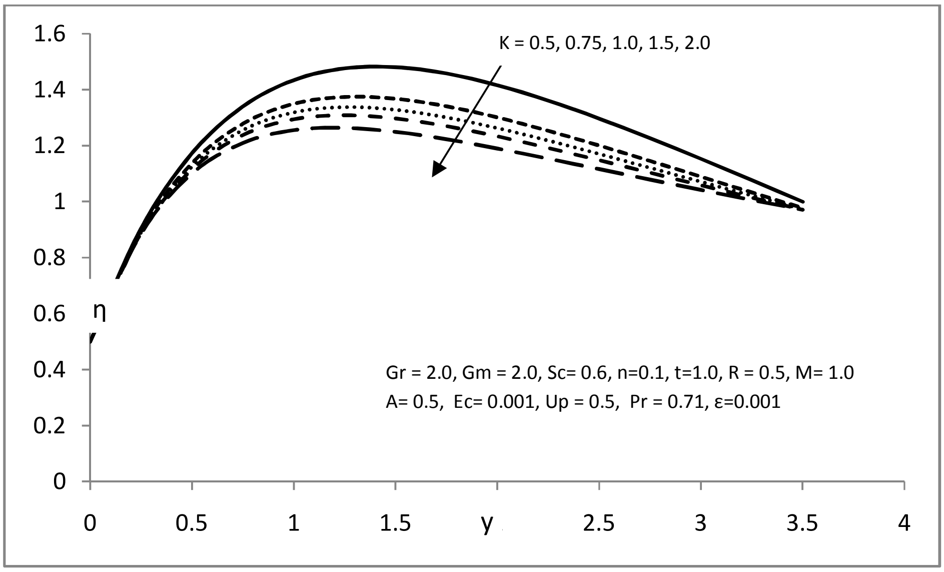

Fig.6 Effect of K on velocity

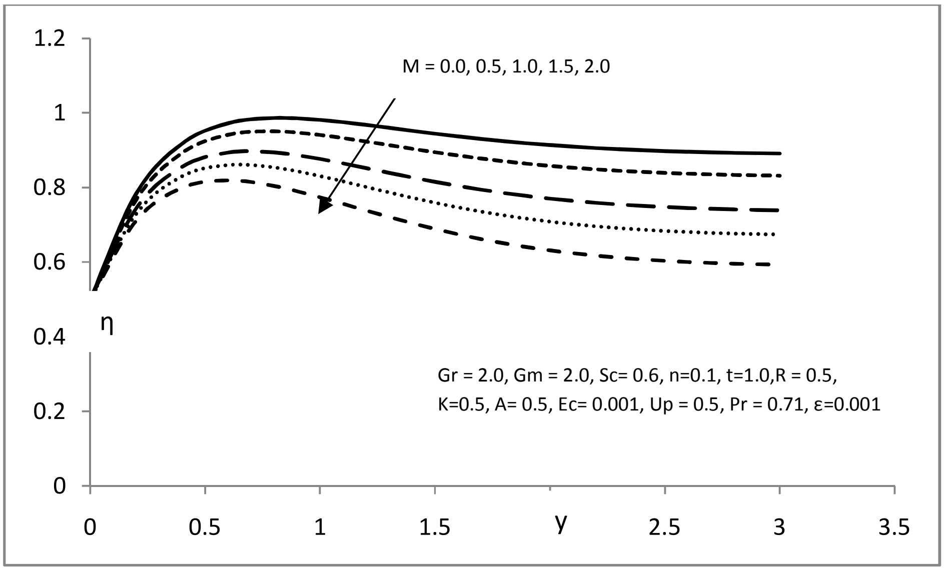

Fig.7. Effect of M on velocity

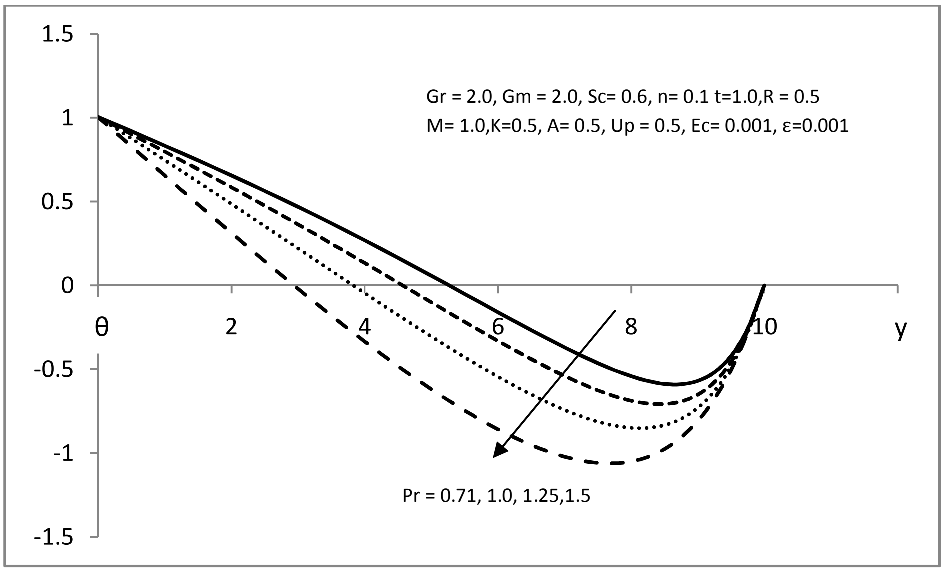

Fig. 8. Effect of Pr on Temperature

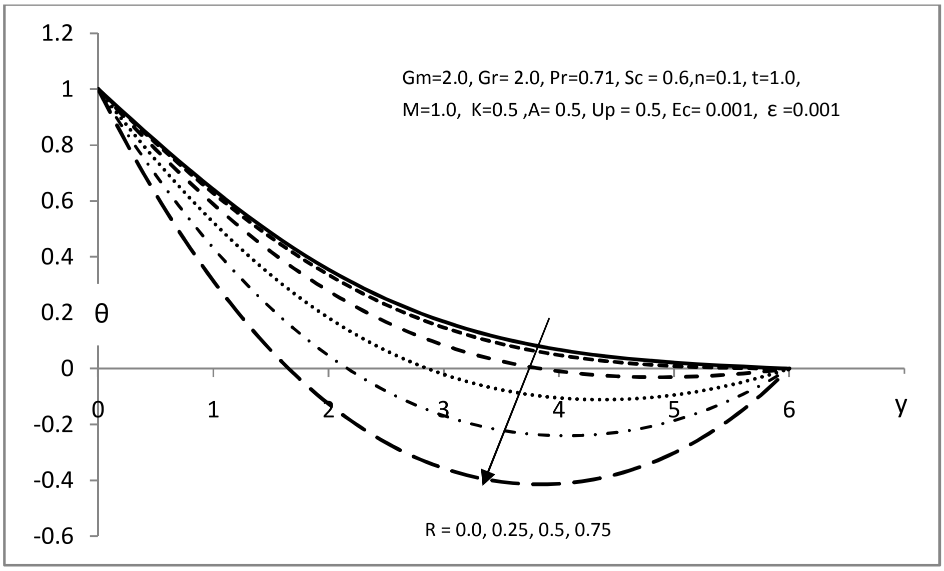

Fig.9. Effect of R on Temperature.

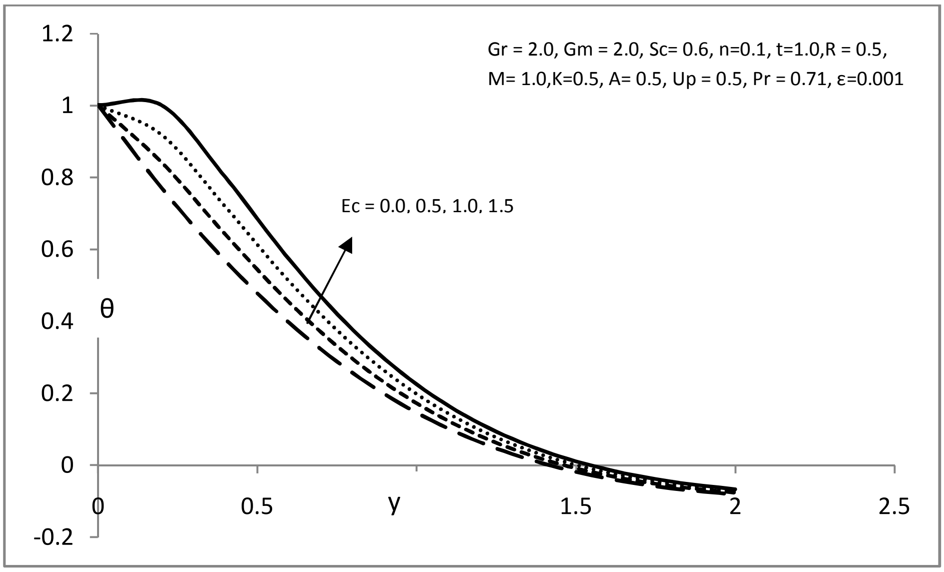

Fig.10. Effect ofEc on temperature

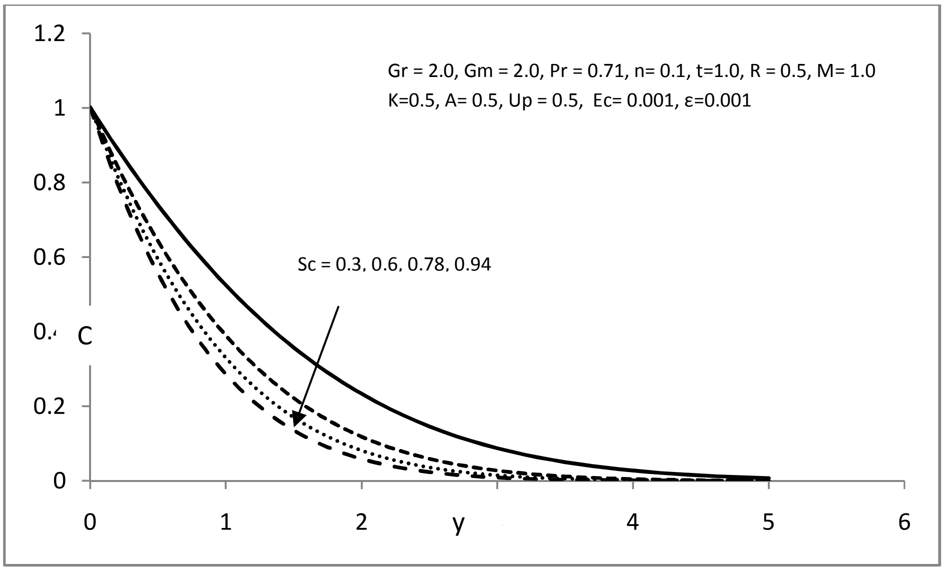

Fig.11. Effect of Sc on concentration

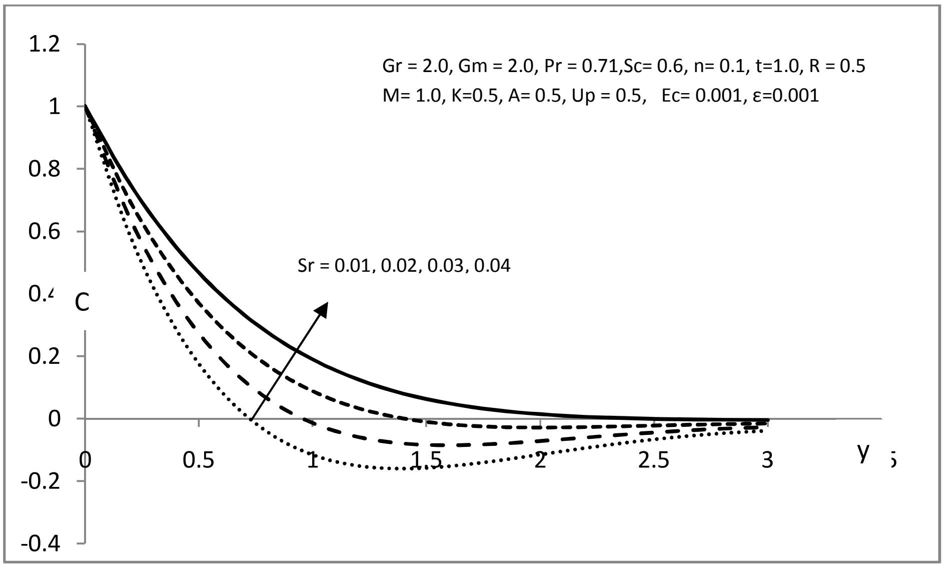

Fig.12. Effect of Sr on concentration

Table 1 – Effect of Gr and Gmon C_f. Reference values as in Fig.1 (a).& 1(b)

GrC_f
01.2780
11.4591
21.6403
31.8214
42.0026
GmC_f
01.1179
11.3791
21.6403
31.9014
4 2.1626

Table 3 – Effects of radiation on C_f and Nu Re_x^{-1}. Reference value as in Fig.2 and 9

R	C_f	NuRe_x^{-1}
0	1.7721	0.8248
0.25	1.7391	0.9085
0.5	1.6403	1.1595
0.75	1.4755	1.5779

Table 4 – Effects of Sc on C_f and Sh Re_x^{-1}. Reference values as in Fig. 3 and 11

Sc	C_f	Sh Re_x^{-1}
0.3	1.7422	0.5171
0.6	1.6403	0.7491
0.78	1.5958	0.8711
0.94	1.5628	0.9712

Table 5 – Effect of Ec on C_f and Nu Re_x^{-1}. Reference values as in Fig. 5 and 10.

Ec	**C_f**	**Nu Re_x^{-1}**
0	1.6403	1.1596
0.5	1.6457	1.1251
1.0	1.6512	1.0902
1.5	1.6568	1.0549

From the Table 1,it is observed that an increase in Grashof number Gr leads to increases the skin-friction value. Table 2,shows that an increase in the solutalGrashof numberGm is to increases the skin-friction value. From Table 3,it observes as radiation increases the skin friction decreases, where as it increases the Nusselt number. From Table4, it is noticed that an increase in the Schmidt number reduces the skin-friction and increases the Sherwood number. Finally, it is observed from Table5, that as Eckert number increases the skin-friction increases, and the Nusselt number decreases.

CONCLUSION

The governing equations for unsteady MHD convective heat and mass transfer flow past a semi- infinite vertical permeable moving plate embedded in a porous medium with radiation was formulated. Viscous dissipation effects were also included in the present work. The plate velocity is maintained at constant value and the flow was subjected to a transverse magnetic field. The resulting partial differential equations were solved in finite difference method. Numerical evaluations solutions were performed and graphical results were obtained to illustrate the details of the flow and heat and mass transfer characteristics and their dependence on some physical parameters. It was found that when thermal and solutalGrashof numbers were increased, the thermal and concentration buoyancy effects were enhanced and thus, the fluid velocity increased. However, the presence of radiation effects caused reductions in the fluid velocity. Also, when the Schmidt number was increased, the concentration level was decreased resulting in decreased fluid velocity. In addition, it was found that the skin-friction coefficient increased due to increase in thermal and concentration buoyancy effects while it decreased due to increase in either radiation parameter or the Schmidt number. However, the Nusselt number increased as parameter increased and the Sherwood number also increased as Schmidt number increased. Increase in Eckert number leads to an increase skin-friction and decrease in Nusselt number.

REFERENCES

[1] Adrian Bejan, Khairy R. Khair; *Int Journal of Heat Mass Transfer*, 28, **1985**, 909-918.
[2] Chamkha A J, *Int J Heat Mass Transfer*, 38,**2000**, 1699.
[3] Chen.:*Acta Mechanica*, 172,**2004**, 219.
[4] Cookey C I, Ogulu A &Ombu-Pepple V B.: *Int J Heat Mass Transfer*, 46, **2003**, 2305-2311.
[5] Das U.N, Deka R.K &soundalgekar V.M.: *J. Theo. Mech*.1: **1996**, 111-115.
[6] Dunn J C & Hardee H C.: *J. Volcanology and Geothermal Res*, 11,**1981**, 189.
[7] Gupta A.S, Pop I. &Soundalgekar V.M.: *Rev. Roum. Sci. Techn-Mec.* Apl.24: **1979**, 561-568.
[8] Helmy K A.: *ZAMM*, 78(4), **1998**, 255-270.
[9] Kavinany M.: Principles of heat transfer in porous media, (McGraw-Hill, New York), **1992**.
[10] Kim Y J, *Int J EnggSci*, 38, **2000**, 833.
[11] Nield D A &Bejan A.: Convection in porous media, 3rdEdn (Springer, New York), **2006**.
[12] Mbeledogua.I.U, A.R.C. Amakirib, A. Oguluc, *Int J Heat Mass Transfer*,50, **2007**, 1668-1674.
[13] Mbeledogua.I.U, A. Ogulub; , *Int J Heat Mass Transfer*, 50, **2007**, 1902-1908.
[14] Ganesan P &Pilani G.: *Int J Heat Mass Transfer*, 47, **2004**, 4449-4457.
[15] Kishan,N and Srinivasmaripala; *Advances in Appled Science Research*, Vol.3(1), **2012** pp. 60-74.
[16] Ramachandra Prasad V, Bhaskar Reddy N.: *Indian journal of pure & Applied Physics*, Vol.46, Feb **2008**. Pp.81-92.
[17] Shanker B, Prabhakar Reddy B &AnandRao J.: *Indian Journal of Pure & Applied Physics* Vol. 48, March **2010**, pp. 157-165.
[18] Singh A.K., Gholami H. R. &Soundalgekar V.M.: *Heat and Mass Transfer*. 31,**1996**, 329-331.

[19] Anjali Devi, S andDavic Maxim Gururaj; *Advances in Appled Science Research*, Vol.3(1),**2012**, pp. 319-334.
[20] Seethamahalakshmi, Ramana Reddy G.V, andPrasad,B.D.C.N; *Advances in Appled Science Research*, Vol.2(6), 2011, pp. 261-269.