INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT

Volume 2, Issue 4, 2011 pp.691-700
Journal homepage: www.IJEE.IEEFoundation.org

Magnetic field effects on unsteady convective flow along a vertical porous flat surface embedded in a porous medium with constant suction and heat sink

S. S. Das[1], J. Mohanty[2], P. Das[1]

[1] Department of Physics, K B D A V College, Nirakarpur, Khurda-752 019 (Orissa), India.
[2] Department of Physics, ABIT, CDA, Sector-I, Bidanasi, Cuttack-753 014, (Orissa), India.

Abstract
The magnetohydrodynamic unsteady convective flow of a viscous incompressible fluid along a vertical porous plate embedded in a porous medium with constant suction and heat sink is considered. Approximate solutions for velocity, temperature, skin friction and rate of heat transfer are obtained by solving the governing equations of the flow field using multi parameter perturbation technique. The effects of various flow parameters affecting the flow field are discussed with the help of figures and table. It is observed that a growing magnetic parameter or heat sink parameter retards the transient velocity of the flow field while the Grashof number or permeability parameter reverses the effect. Further, an increase in magnetic parameter or Prandtl number or heat sink parameter decreases the transient temperature of the flow field. A growing permeability parameter enhances the magnitude of skin friction and the rate of heat transfer at the wall, while the magnetic parameter reverses the effect.

Keywords: Convective flow; Heat sink; Magnetic field; Porous medium; Suction.

1. Introduction
The phenomenon of convective flow with heat transfer under the influence of magnetic field has received considerable attention of several workers because of its varied applications in different fields of science, technology and in industry. Such phenomena are observed in buoyancy induced motions in the atmosphere, in bodies of water, quasi-solid bodies such as earth, etc. Flow problems through porous media over flat surfaces are of great theoretical as well as practical interest in view of their applications in various fields such as aerodynamics, extraction of plastic sheets, cooling of infinite metallic plates in a cool bath, liquid film condensation process and in major fields of glass and polymer industries.
In view of their varied applications, Bejan and Khair [1] analyzed the heat and mass transfer by natural convection in a porous medium. Singh and Dikshit [2] discussed the hydromagnetic flow past a continuously moving semi-infinite plate at large suction. Kim and Vafai [3] analyzed the natural convection about vertical plate embedded in porous medium. Sahin [4] studied the transient heat conduction in semi-infinite solid with spatially decaying exponential heat generation. Crepeau and Clarksean [5] applied similarity solution to solve the problem of natural convection with internal heat generation. Chamkha and Khaled [6] explained the hydromagnetic combined heat and mass transfer by natural convection from a permeable surface embedded in a fluid saturated porous medium. Kim [7] presented the unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate

with variable suction. Geindrean and Auriault [8] investigated the magnetohydrodynamic flows in porous media. Sharma and Pareek [9] explained the behaviour of steady free convective MHD flow past a vertical porous moving surface.

The unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption has been studied by Chamkha [10]. Makinde [11] analyzed the free convection flow with thermal radiation and mass transfer past a moving vertical porous plate. Das and his associates [12] estimated the effect of heat source and variable magnetic field on unsteady hydromagnetic flow of a viscous stratified fluid past a porous flat moving plate in the slip flow regime. Recently, Sharma and Singh [13] discussed the unsteady MHD free convective flow and heat transfer along a vertical porous plate with variable suction and internal heat generation. More Recently, Das and his co-workers [14] estimated the effect of mass transfer on MHD flow and heat transfer past a vertical porous plate through a porous medium under oscillatory suction and heat source.

The objective of the present study is to analyze the effect of magnetic field on unsteady free convective flow of a viscous incompressible electrically conducting fluid past an infinite vertical porous flat plate embedded in a porous medium in presence of constant suction and heat sink. Approximate solutions are obtained for velocity field, temperature field, concentration distribution, skin friction and heat flux using multi parameter perturbation technique. The effects of the pertinent parameters on the flow field are discussed with the aid of figures and table.

2. Formulation of the problem

Consider the unsteady free convective flow of a viscous incompressible electrically conducting fluid past an infinite vertical porous plate embedded in a porous medium in presence of constant suction and heat sink and a transverse magnetic field B_0. Let x'-axis be taken in vertically upward direction along the plate and y'-axis normal to it. Neglecting the induced magnetic field and the Joulean heat dissipation and applying Boussinesq's approximation the governing equations of the flow field are given by:

Continuity equation:

$$\frac{\partial v'}{\partial y'} = 0 \Rightarrow v' = v'_0 \,(\text{constant}), \tag{1}$$

Momentum equation:

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = g\beta\left(T' - T'_\infty\right) + \nu\frac{\partial^2 u'}{\partial y'^2} - \frac{\sigma B_0^2}{\rho}u' - \frac{\nu}{K'}u' \tag{2}$$

Energy equation:

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = k\frac{\partial^2 T'}{\partial y'^2} + \frac{\nu}{C_p}\left(\frac{\partial u'}{\partial y'}\right)^2 + S'\left(T - T_\infty{}'\right) \tag{3}$$

The initial and boundary conditions of the problem are:

$$u' = 0, v' = -v'_0, T' = T'_w + \varepsilon\left(T'_w - T'_\infty\right)e^{i\omega' t'} \text{ at } y' = 0,$$

$$u' \to 0,\ T' \to T'_\infty \text{ as } y' \to \infty. \tag{4}$$

Introducing the following non-dimensional variables and parameters,

$$y = \frac{y'v'_0}{\nu}, t = \frac{t'v_0'^2}{4\nu}, \omega = \frac{4\nu\omega'}{v_0'^2}, u = \frac{u'}{v'_0}, \nu = \frac{\eta_0}{\rho}, T = \frac{T' - T'_\infty}{T'_w - T'_\infty}, M = \left(\frac{\sigma B_0^2}{\rho}\right)\frac{\nu}{v_0'^2},$$

$$K_p = \frac{v_0^2 K'}{\nu^2}, P_r = \frac{\nu}{k}, G_r = \frac{\nu g\beta\left(T'_w - T'_\infty\right)}{v_0'^3}, S = \frac{4S'\nu}{v_0'^2}, E_c = \frac{v_0'^2}{C_p\left(T'_w - T'_\infty\right)} \tag{5}$$

in equations (2) and (3) under boundary conditions (4), we get:

$$\frac{1}{4}\frac{\partial u}{\partial t} - \frac{\partial u}{\partial y} = G_r T + \frac{\partial^2 u}{\partial y^2} - \left(M + \frac{1}{K_p}\right)u \tag{6}$$

$$\frac{1}{4}\frac{\partial T}{\partial t} - \frac{\partial T}{\partial y} = \frac{1}{P_r}\frac{\partial^2 T}{\partial y^2} + \frac{1}{4}ST + E_c\left(\frac{\partial u}{\partial y}\right)^2 \tag{7}$$

where g is the acceleration due to gravity, ρ is the density, σ is the electrical conductivity, β is the

volumetric coefficient of expansion for heat transfer, ν is the coefficient of kinematic viscosity, ω is the angular frequency, η_0 is the coefficient of viscosity, k is the thermal diffusivity, T is the temperature, T_w is the temperature at the plate, T_∞ is the temperature at infinity, C_p is the specific heat at constant pressure, P_r is the Prandtl number, M is the magnetic parameter, K_p is the permeability parameter, P_r is the Prandtl number, G_r is the Grashof number for heat transfer, S is the heat sink parameter and E_c is the Eckert number.
The corresponding boundary conditions are:

$$u = 0, T = 1 + \varepsilon e^{i\omega t}, \text{ at } y = 0,$$
$$u \to 0, T \to 0, \text{as } y \to \infty \quad (8)$$

3. Method of solution

In order to solve equations (6) and (7), we assume ε to be very small and the velocity and temperature of the flow field in the neighbourhood of the plate as

$$u(y,t) = u_0(y) + \varepsilon e^{i\omega t} u_1(y) \quad (9)$$

$$T(y,t) = T_0(y) + \varepsilon e^{i\omega t} T_1(y) \quad (10)$$

Substituting equations (9) and (10) in equations (6) and (7) respectively and equating the harmonic and non-harmonic terms and neglecting the coefficients of ε^2, we get
Zeroth order:

$$u_0'' + u_0' - \left(M + \frac{1}{K_p} \right) u_0 = -G_r T_0 \quad (11)$$

$$T_0'' + P_r T_0' + \frac{P_r S}{4} T_0 = -P_r E_c \left(\frac{\partial u_0}{\partial y} \right)^2 \quad (12)$$

First order:

$$u_1'' + u_1' - \frac{i\omega}{4} u_1 - \left(M + \frac{1}{K_p} \right) u_1 = -G_r T_1 \quad (13)$$

$$T_1'' + P_r T_1' - \frac{P_r}{4} (i\omega - S) T_1 = -2 P_r E_c \left(\frac{\partial u_0}{\partial y} \right) \left(\frac{\partial u_1}{\partial y} \right) \quad (14)$$

The corresponding boundary conditions are

$$y = 0 : u_0 = 0, T_0 = 1, u_1 = 0, T_1 = 1,$$
$$y \to \infty : u_0 = 0, T_0 = 0,, u_1 = 0, T_1 = 0. \quad (15)$$

Using multi parameter perturbation technique and choosing E_c <<1, we assume

$$u_0 = u_{00} + E_c u_{01} \quad (16)$$
$$T_0 = T_{00} + E_c T_{01} \quad (17)$$
$$u_1 = u_{10} + E_c u_{11} \quad (18)$$
$$T_1 = T_{10} + E_c T_{11} \quad (19)$$

Now using equations (16)-(19) in equations (11)-(14) and equating the coefficients of like powers of E_c neglecting those of E_c^2, we get the following set of differential equations:
Zeroth order:

$$u_{00}'' + u_{00}' - \left(M + \frac{1}{K_p} \right) u_{00} = -G_r T_{00} \quad (20)$$

$$u_{10}'' + u_{10}' - \left(M + \frac{1}{K_p} + \frac{i\omega}{4} \right) u_{10} = -G_r T_{10} \quad (21)$$

$$T''_{00} + P_r T'_{00} + \frac{P_r S}{4} T_{00} = 0 \tag{22}$$

$$T''_{10} + P_r T'_{10} - \frac{P_r}{4}(i\omega - S)T_{10} = 0 \tag{23}$$

The corresponding boundary conditions are

$$y = 0 : u_{00} = 0, T_{00} = 1, u_{10} = 0, T_{10} = 1$$

$$y \to \infty : u_{00} = 0, T_{00} = 0, u_{10} = 0, T_{10} = 0 \tag{24}$$

First order:

$$u''_{01} + u'_{01} - \left(M + \frac{1}{K_p}\right)u_{01} = -G_r T_{01} \tag{25}$$

$$u''_{11} + u'_{11} - \left(M + \frac{1}{K_p} + \frac{i\omega}{4}\right)u_{11} = -G_r T_{11} \tag{26}$$

$$T''_{01} + P_r T'_{01} + \frac{P_r S}{4} T_{01} = -P_r \left(u'_{00}\right)^2 \tag{27}$$

$$T''_{11} + P_r T'_{11} - \frac{P_r}{4}(i\omega - S)T_{11} = -2P_r \left(\frac{\partial u_{00}}{\partial y}\right)\left(\frac{\partial u_{10}}{\partial y}\right) \tag{28}$$

The corresponding boundary conditions are,

$$y = 0 : u_{01} = 0, T_{01} = 0, u_{11} = 0, T_{11} = 0 ;$$

$$y \to \infty : u_{01} = 0, T_{01} = 0, u_{11} = 0, T_{11} = 0 \tag{29}$$

Solving equations (20) - (23) subject to boundary condition (24) we get,

$$u_{00} = A_1\left(e^{-m_1 y} - e^{-m_5 y}\right) \tag{30}$$

$$T_{00} = e^{-m_1 y} \tag{31}$$

$$u_{10} = A_2\left(e^{-m_3 y} - e^{-m_7 y}\right) \tag{32}$$

$$T_{10} = e^{-m_3 y} \tag{33}$$

Solving equations (25)- (28) subject to boundary condition (29) we get,

$$T_{01} = B_1 e^{-2m_1 y} + B_2 e^{-2m_3 y} + B_3 e^{-(m_1+m_5)y} - B_4 e^{-m_1 y} \tag{34}$$

$$T_{11} = C_1 e^{-(m_1+m_3)y} + C_2 e^{-(m_1+m_7)y} + C_3 e^{-(m_3+m_5)y} + C_4 e^{-(m_5+m_7)y} - C_5 e^{-m_3 y} \tag{35}$$

$$u_{01} = D_1 e^{-2m_1 y} + D_2 e^{-2m_5 y} + D_3 e^{-(m_1+m_5)y} + D_4 e^{-m_1 y} - D_5 e^{-m_5 y} \tag{36}$$

$$u_{11} = E_1 e^{-(m_1+m_3)y} + E_2 e^{-(m_1+m_7)y} + E_3 e^{-(m_3+m_5)y} + E_4 e^{-(m_5+m_7)y} + E_5 e^{-m_3 y} - E_6 e^{-m_7 y} \tag{37}$$

3.1 Skin friction

Using equations (9), (16), (18), (30), (32), (36) and (37), the skin friction at the wall is given by

$$\begin{aligned}\tau_w &= \left(\frac{\partial u}{\partial y}\right)_{y=0} \\ &= -m_1 A_1 + m_5 A_1 - E_c\left[2m_1 D_1 + 2m_5 D_2 + \right. \\ &\quad \left.(m_1 + m_5)D_3 + m_1 D_4 - m_5 D_5\right] + \varepsilon e^{i\omega t}\left\{A_2(m_7 - m_3) - E_c\left[(m_1 + m_3)E_1\right.\right. \\ &\quad \left.\left. + (m_1 + m_7)E_2 + (m_3 + m_5)E_3 + (m_5 + m_7)E_4 + m_3 E_5 - m_7 E_6\right]\right\}\end{aligned} \tag{38}$$

3.2 Heat flux

Using equations (10), (17), (19), (31), (33) - (35), the heat flux i.e. the rate of heat transfer at the wall in terms of Nusselt number is given by

$$\begin{aligned}N_u &= \left(\frac{\partial T}{\partial y}\right)_{y=0} \\ &= -m_1 - E_c\left[2m_1 B_1 + 2m_3 B_2 + (m_1 + m_5)B_3 - m_1 B_4\right]\end{aligned}$$

$$+\varepsilon e^{i\omega t}\{-m_3 - E_c[(m_1+m_3)C_1+(m_1+m_7)C_2$$
$$+(m_3+m_5)C_3+(m_5+m_7)C_4-m_3C_5]\} \tag{39}$$

where,

$$m_1=\frac{1}{2}\left[P_r+\sqrt{P_r^2-SP_r}\right],\ m_2=\frac{1}{2}\left[-P_r+\sqrt{P_r^2-SP_r}\right],\ m_3=\frac{1}{2}\left[P_r+\sqrt{P_r^2-P_r(S-i\omega)}\right],\ m_4=\frac{1}{2}\left[-P_r+\sqrt{P_r^2-P_r(S-i\omega)}\right],$$

$$m_5=\frac{1}{2}\left[1+\sqrt{1+4\left(M+\frac{1}{K_p}\right)}\right],\ m_6=\frac{1}{2}\left[-1+\sqrt{1+4\left(M+\frac{1}{K_p}\right)}\right],\ m_7=\frac{1}{2}\left[1+\sqrt{1+4\left(M+\frac{1}{K_p}+\frac{i\omega}{4}\right)}\right],$$

$$m_8=\frac{1}{2}\left[-1+\sqrt{1+4\left(M+\frac{1}{K_p}+\frac{i\omega}{4}\right)}\right],\ A_1=\frac{G_r}{(m_5-m_1)(m_6+m_1)},\ A_2=\frac{G_r}{(m_7-m_3)(m_8+m_3)},\ B_1=\frac{-P_rm_1A_1^2}{(m_2+2m_1)},$$

$$B_2=\frac{P_rm_5^2A_1^2}{(m_1-2m_5)(m_2+2m_5)}\ B_3=\frac{2P_rA_1{}^{2}{}_{1}m_1}{(m_1+m_2+m_5)},\ B_4=B_1+B_2+B_3,\ C_1=-\frac{2P_rA_1A_3}{(m_1+m_3+m_4)},$$

$$C_2=\frac{2P_rA_1A_2m_1m_7}{(m_7-m_3+m_1)(m_7+m_4+m_1)},\ C_3=\frac{2P_rA_1A_2m_3}{(m_5+m_4+m_3)},\ C_4=\frac{2P_rA_1A_2m_5m_7}{(m_7+m_5+m_3)(m_7+m_5+m_4)},$$

$$C_5=C_1+C_2+C_3+C_4\ D_1=\frac{G_rB_1}{(m_5-2m_1)(m_6+2m_1)},\ D_2=\frac{-G_rB_2}{m_5(m_6+2m_5)},\ D_3=\frac{-G_rB_3}{m_1(m_6+m_5+m_1)},$$

$$D_4=\frac{G_rB_4}{(m_1-m_5)(m_6+m_1)},\ D_5=D_1+D_2+D_3+D_4,\ E_1=\frac{G_rC_1}{(m_7-m_3-m_{31})(m_8+m_3+m_1)},\ E_2=\frac{-G_rC_2}{m_1(m_8+m_7+m_1)},$$

$$E_3=\frac{G_rC_3}{(m_7-m_5-m_3)(m_8+m_5+m_3)},\ E_4=\frac{-G_rC_4}{m_5(m_8+m_7+m_5)},\ E_5=\frac{G_rC_5}{(m_7-m_3)(m_8+m_3)},\ E_6=E_1+E_2+E_3+E_4+E_5.$$

4. Results and discussions

The problem presents the effect of magnetic field on unsteady free convective flow of a viscous incompressible electrically conducting fluid past an infinite vertical porous plate embedded in a porous medium. The governing equations of the flow field are solved employing multi parameter perturbation technique and approximate solutions are obtained for velocity field, temperature field, skin friction and rate of heat transfer. The effects of the pertinent parameters on the flow field are analyzed and discussed with the help of velocity profiles 1-4, temperature profiles 5-7 and Table1.

4.1 Velocity field

The velocity of the flow field suffers a substantial change with the variation of magnetic parameter M, Grashof number for heat transfer G_r, permeability parameter K_p and heat sink parameter S. The effects of these parameters on the velocity field are analyzed with the aid of Figures 1-4.

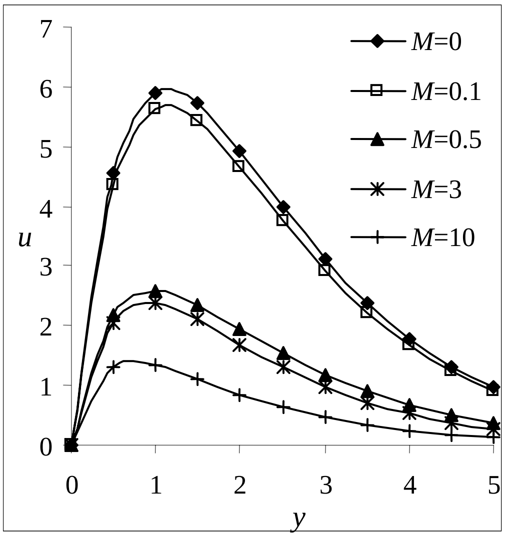

Figure 1. Transient velocity profiles against y for different values of M with G_r=5, K_p=1, S= -0.1, P_r=0.71, E_c=0.002, ω=5.0, ε=0.2, ωt=π/2

Figure 1 depicts the effect of magnetic parameter M on the velocity field. Curve with M=0 corresponds to non-MHD flow. A study of the curves of the said figure shows that a growing magnetic parameter retards the velocity of the flow field at all points due to the dominating action of Lorentz force on the flow field.

In Figure 2, we discuss the effect of permeability parameter K_p on the velocity field. The permeability parameter K_p increases the transient velocity of the flow field at all points. In Figure 3, we present the effect of Grashof number for heat transfer G_r on the velocity field. Curves with G_r >0 correspond to cooling of the plate, while G_r <0 correspond to heating of the plate. Comparing the curves of Figure 3, we observe that G_r has an accelerating effect on the velocity field. Figure 4, presents the effect of heat sink/source parameter S on the velocity profiles of the flow field. Curve with S<0 and S>0 corresponds to the presence of heat sink and heat source respectively in the flow field. The effect of heat sink parameter (S<0) is to retard the velocity of the flow field at all points while the effect reverses in presence of heat source(S>0).

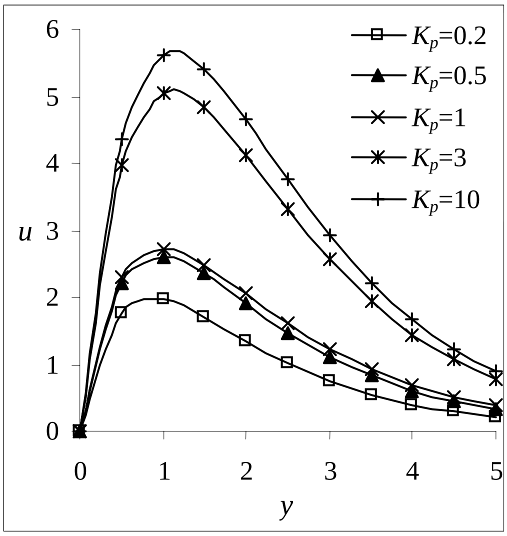

Figure 2. Transient velocity profiles against y for different values of K_p with G_r=5, E_c=0.002, S= -0.1, P_r=0.71, M=1, ω=5.0, ε=0.2, ωt=π/2

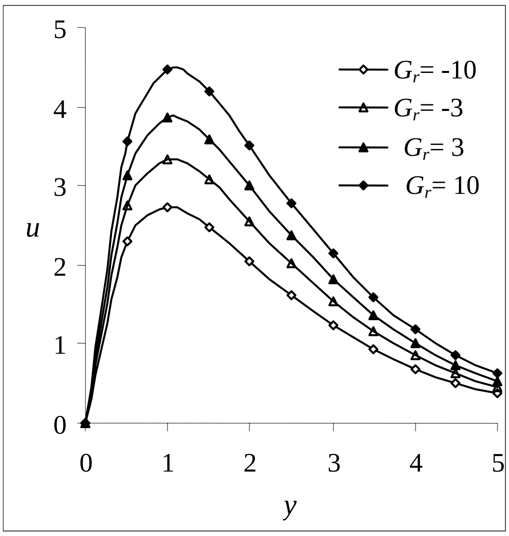

Figure 3. Transient velocity profiles against y for different values of G_r with M=1, K_p=1, S= -0.1, Pr=0.71, E_c=0.002, ω=5.0, ε=0.2, ωt=π/2

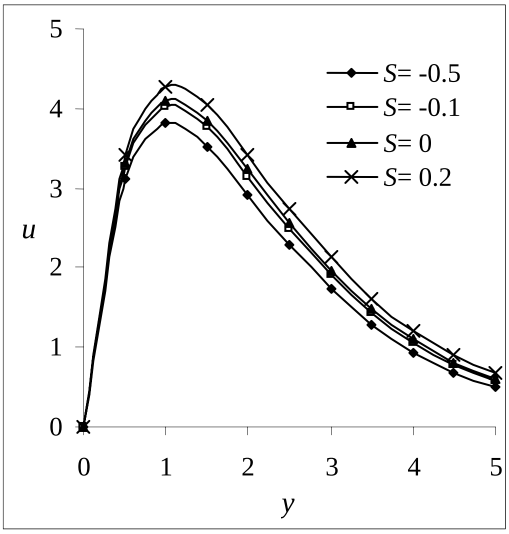

Figure 4. Transient velocity profiles against *y* for different values of *S* with G_r=5, E_c=0.002, *M*=1, K_p=1, P_r=0.71, ω=5.0, ε=0.2, ωt=π/2

4.2 Temperature field

The temperature of the flow field is found to change more or less with the variation of magnetic parameter *M*, Prandtl number P_r and heat sink parameter S. These are shown in Figures 5, 6 and 7 respectively. Comparing the curves of the said figures, we notice that the effect of increasing the magnitude of magnetic parameter or Prandtl number or heat sink parameter is to decrease the temperature of the flow field at all points with some discrepancy near the pate for lower value of P_r (P_r <1).

4.3 Skin friction and rate of heat transfer

In Table1 we present the variation in the value of skin friction τ and the rate of heat transfer N_u against permeability parameter K_p for different values of magnetic parameter *M* keeping other parameters of the flow field constant. It is observed that the permeability parameter K_p leads to enhance the magnitude of skin friction and the rate of heat transfer at the wall while a growing magnetic parameter *M* shows the reverse effect. Further, for higher value of *M* the heat flux assumes negative value due to the dominating action of the Lorentz force on the temperature field.

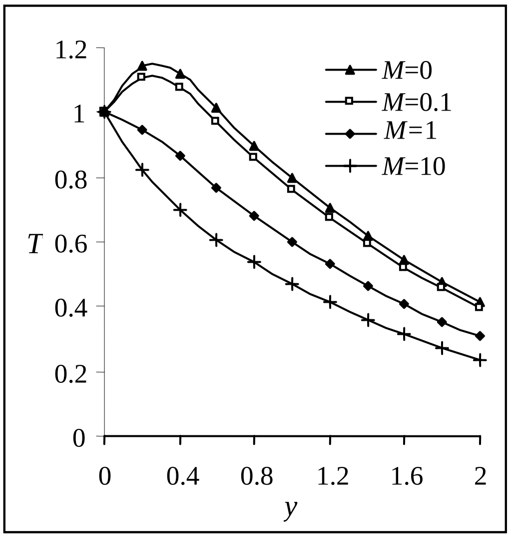

Figure 5. Temperature profiles against *y* for different values of *M* with G_r=5, *S* = -0.1, K_p=1, P_r=0.71, E_c=0.002, ω=5.0, ε=0.2, ωt=π/2

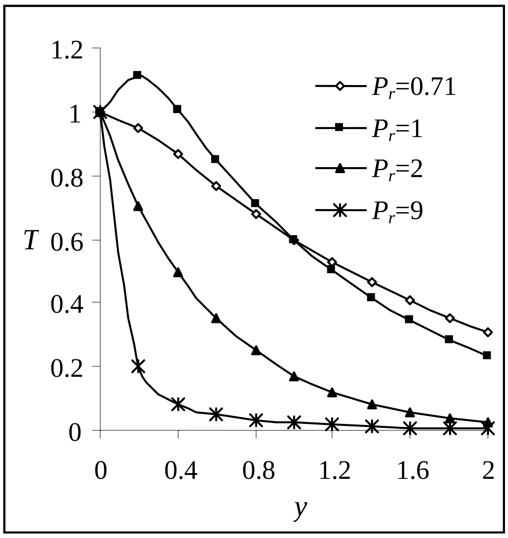

Figure 6. Temperature profiles against y for different values of P_r with G_r=5, M=1, K_p=1, S= -0.1, E_c=0.002, ω=5.0, ε=0.2, ωt=π/2

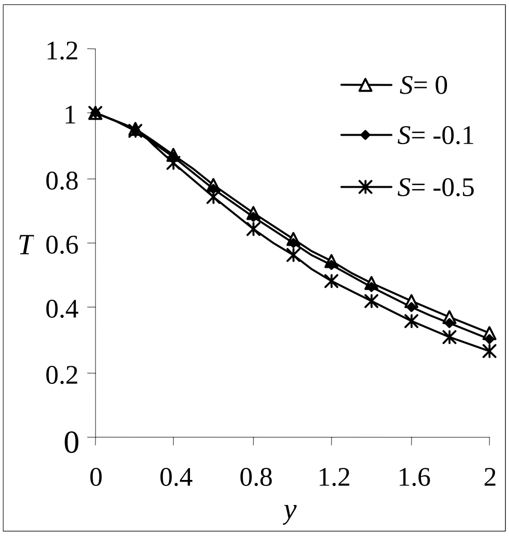

Figure 7. Temperature profiles against y for different values of S with G_r=5, M=1, K_p=1, P_r=0.71, E_c=0.002, ω=5.0, ε=0.2, ωt=π/2

Table 1. Variation in the value of skin friction τ and the rate of heat transfer N_u against K_p for different values of M with S =0.1, G_r=5, E_c=0.002, ω=5.0, ε =0.2, ωt=π/2

K_P	M = 0.1		M = 0.5		M = 1.0		M = 5.0	
	τ	N_u	τ	N_u	τ	N_u	τ	N_u
0.5	9.55757	0.51907	9.07377	0.32180	8.56529	0.15812	6.35630	-0.21884
1	11.2559	1.67942	10.4675	1.03267	9.76371	0.58221	6.74621	-0.18249
3	13.1484	4.47417	11.9023	2.39942	10.8232	1.25813	7.05215	-0.14755
10	14.1088	6.97182	12.5795	3.39462	11.3046	1.48072	7.17001	-0.13238

ISSN 2076-2895 (Print), ISSN 2076-2909 (Online)

5. Conclusion

From the above study, we present below the following results of physical interest on the velocity, temperature, skin friction and rate of heat transfer at the wall of the flow field.

1. A growing magnetic parameter M or heat sink parameter ($S<0$) retards the transient velocity of the flow field at all points.
2. The effect of increasing Grashof number for heat transfer G_r or heat source($S>0$) parameter is to enhance the transient velocity of the flow field at all points.
3. The permeability parameter K_p increases the transient velocity of the flow field at all points.
4. The effect of increasing the magnitude of magnetic parameter or Prandtl number or heat sink parameter is to decrease the temperature of the flow field at all points with some discrepancy near the pate for lower value of P_r (P_r <1).
5. The permeability parameter K_p leads to enhance the magnitude of skin friction and the rate of heat transfer at the wall while a growing magnetic parameter M shows the reverse effect.

References

[1] Bejan A., Khair K. R. Heat and mass transfer by natural convection in a porous medium. Int. J. Heat Mass Transfer. 1985, 28, 909-918.
[2] Singh A. K., Dikshit C.K. Hydromagnetic flow past a continuously moving semi-infinite plate at large suction, Astrophys. Space Sci. 1988, 248, 249-256.
[3] Kim S. J., Vafai K. Analysis of natural convection about vertical plate embedded in porous medium. Int. J. Heat Mass Transfer. 1989, 32, 665-677.
[4] Sahin A.Z. Transient heat conduction in semi-infinite solid with spatially decaying exponential heat generation. Int.Commun. Heat Mass Transfer. 1992. 19, 349-358.
[5] Crepeau J. C., Clarksean R. Similarity solution of natural convection with internal heat generation. ASME Journal of Heat Transfer. 1997, 119, 183-185.
[6] Chamkha A. J., Khaled A. A. R. Hydromagnetic combined heat and mass transfer by natural convection from a permeable surface embedded in a fluid saturated porous medium. Int. J. Numer. Meth. Heat Fluid Flow. 2000, 10, 5, 455-476.
[7] Kim Y. J. Unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction. Int. J. Engng. Sci. 2000, 38, 833-845.
[8] Geindrean C., Auriault J. L. Magnetohydrodynamic flows in porous media, J. Fluid Mech. 2002, 466, 343-363.
[9] Sharma P. R.., Pareek D. Steady free convection MHD flow past a vertical porous moving surface. Ind. J. Theo. Phys. 2002, 50, 5-13.
[10] Chamkha A. J. Unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption, Int. J. Eng. Sci. 2004, 24, 217-230.
[11] Makinde O. D. Free convection flow with thermal radiation and mass transfer past a moving vertical porous plate, Int. Commun. Heat Mass Trans. 2005, 32, 1411-1419.
[12] Das S. S., Mohanty S. K., Panda J. P., Mishra S. Effect of heat source and variable magnetic field on unsteady hydromagnetic flow of a viscous stratified fluid past a porous flat moving plate in the slip flow regime. Advances Appl. Fluid Mech. 2008, 4, 2, 187-203.
[13] Sharma P. R., Singh G. Unsteady MHD free convective flow and heat transfer along a vertical porous plate with variable suction and internal heat generation. Int. J. Appl. Math. Mech. 2008, 4, 5, 1-8.
[14] Das S. S., Satapathy A., Das J. K., Panda J. P. Mass transfer effects on MHD flow and heat transfer past a vertical porous plate through a porous medium under oscillatory suction and heat source. Int. J. Heat Mass Trans. 2009, 52, 5962-5969.

S. S. Das did his M. Sc. degree in Physics from Utkal University, Orissa (India) in 1982 and obtained his Ph. D degree in Physics from the same University in 2002. He served as a Faculty of Physics in Nayagarh (Autonomous) College, Orissa (India) from 1982-2004 and presently working as the Head of the faculty of Physics in KBDAV College, Nirakarpur, Orissa (India) since 2004. He has 28 years of teaching experience and 11 years of research experience. He has produced 2 Ph. D scholars and presently guiding 15 Ph. D scholars. Now he is carrying on his Post Doc. Research in MHD flow through Porous Media. His major fields of study are MHD flow, Heat and Mass Transfer Flow through Porous Media, Polar fluid, Stratified flow etc. He has 50 papers in the related area, 40 of which are published in Journals of International repute. Also he has reviewed a good number of research papers of some International Journals. Dr. Das is currently acting as the Honorary Member of Editorial Board of Indian Journal of Science and Technology and as Referee of AMSE Journal, France; Central European Journal of Physics; International Journal of Medicine and Medical Sciences, Chemical Engineering Communications, International Journal of Energy and Technology, Progress in Computational Fluid Dynamics etc.
E-mail address: drssd2@yahoo.com