INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT

Volume 3, Issue 1, 2012 pp.109-118
Journal homepage: www.IJEE.IEEFoundation.org

Unsteady hydromagnetic convective flow past an infinite vertical porous flat plate in a porous medium

S. S. Das[1], M. Maity[2], J. K. DAS[3]

[1] Department of Physics, KBDAV College, Nirakarpur, Khurda-752 019 (Orissa), India.
[2] Department of Physics, Suddhananda Residential Polytechnic, Bhatapatna, Phulnakhara, Cuttack-752 115 (Orissa), India.
[3] Department of Physics, Stewart Science College, Mission Road, Cuttack-753 001(Orissa), India.

Abstract
This paper theoretically investigates the unsteady free convective flow of a viscous incompressible electrically conducting fluid past an infinite vertical porous flat plate in a porous medium with constant suction in presence of a uniform transverse magnetic field. The governing equations of the flow field are solved using multi parameter perturbation technique and approximate solutions for velocity, temperature, skin friction and rate of heat transfer are obtained. The effects of the various flow parameters characterizing the flow field are analyzed with the help of figures and table. It is observed that a growing magnetic parameter M or permeability parameter K_p decelerates the transient velocity of the flow field at all points, while a growing Grashof number for heat transfer G_r accelerates the transient velocity at all points. Further, the effect of growing Prandtl number P_r is to diminish the transient temperature of the flow field at all points and on the other hand, the permeability parameter reverses the effect. The permeability parameter K_p enhances the skin friction as well as the rate of heat transfer at the wall and the magnetic parameter shows the reverse effect.

Keywords: Hydromagnetic flow; Unsteady; Free convection; Porous medium; Suction.

1. Introduction
The problem of unsteady hydromagnetic flow are very often observed in buoyancy induced motions in the atmosphere, in bodies of water, quasi-solid bodies such as earth, etc. Such problems through porous media over continuously moving flat surfaces are of great theoretical as well as practical interest due to their varied applications in 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 wide range of applications in diverse fields, Raptis [1] analyzed the unsteady free convection flow through a porous medium. Hossain and Begum [2] discussed the effect of mass transfer and free convection on the flow past a vertical plate.Vafai [3] reported the convective flow and heat transfer in variable porosity media. Bejan and Khair [4] have studied the heat and mass transfer by natural convection in a porous medium. Raptis and Perdikis [5] analyzed the unsteady flow through a porous medium in the presence of free convection. Singh and Dikshit [6] investigated the hydromagnetic flow past a continuously moving semi-infinite plate for large suction. Vajravelu and Hadjinicolaou [7] discussed the heat transfer in a viscous fluid over a stretching sheet with viscous dissipation and internal

heat generation. Deka *et al*. [8] explained the transient free convection flow past an infinite vertical plate with temperature-dependent heat source. Attia and Kotb [9] studied the MHD flow between two parallel plates with heat transfer. Raptis and Soundalgekar [10] investigated the steady laminar free convection flow of an electrically conducting fluid along a porous hot vertical plate in presence of heat source/sink. Sattar *et al*. [11] discussed the free convection flow and heat transfer through a porous vertical flat plate immersed in a porous medium.

Unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction has been studied by Kim [12]. Das *et al*. [13] approached numerically the effect of mass transfer on unsteady flow past an accelerated vertical porous plate with suction.Ogulu and Prakash [14] analyzed the heat transfer to unsteady magnetohydrodynamic flow past an infinite vertical moving plate with variable suction. Das and his team [15] discussed the effect of induced magnetic field on MHD flow and heat transfer in a conducting elastico-viscous fluid past a continuously moving porous flat surface. In a separate paper, they [16] analyzed 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. Sharma and Singh [17] reported the unsteady MHD free convective flow and heat transfer along a vertical porous plate with variable suction and internal heat generation. Das and his associates [18] analyzed the mass transfer effects on MHD flow and heat transfer past a vertical porous plate through a porous medium under oscillatory suction and heat source. Recently, Das and Tripathy [19] have investigated the effect of periodic suction on three dimensional flow and heat transfer past a vertical porous plate embedded in a porous medium.

The proposed study we analyze the unsteady free convective flow of a viscous incompressible electrically conducting fluid past an infinite vertical porous flat plate in a porous medium with constant suction and in presence of a uniform magnetic field. Approximate solutions for velocity, temperature, skin friction and rate of heat transfer are obtained using multi parameter perturbation technique and the effects of the various flow parameters affecting the flow field are discussed with the help of figures and table.

2. Formulation of the problem

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

Continuity equation:

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

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:

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

where ρ is the density, g is the acceleration due to gravity, σ is the electrical conductivity, ν is the coefficient of kinematic viscosity, β is the volumetric coefficient of expansion for heat transfer, 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 and C_p is the specific heat at constant pressure.

The boundary conditions of the problem are:

$$u' = 0, v' = -v_0', T' = T_w' + \varepsilon(T_w' - T_\infty')e^{i\omega' t'} \quad \text{at} \quad y' = 0,$$
$$u' \to 0, \qquad T' \to T_\infty' \qquad \text{as} \quad y' \to \infty. \tag{4}$$

Introducing the following non-dimensional variables and parameters,

$$y = \frac{y' v_0'}{\nu}, t = \frac{t' v_0'^2}{4\nu}, \omega = \frac{4\nu\omega'}{v_0'^2}, u = \frac{u'}{v_0'}, \nu = \frac{\eta_0}{\rho}, T = \frac{T' - T_\infty'}{T_w' - T_\infty'}, M = \left(\frac{\sigma B_0^2}{\rho}\right)\frac{\nu}{v_0'^2}, K_p = \frac{v_0^2 K'}{\nu^2},$$
$$P_r = \frac{\nu}{k}, G_r = \frac{\nu g\beta(T_w' - T_\infty')}{v_0'^3}, E_c = \frac{v_0'^2}{C_p(T_w' - T_\infty')} \tag{5}$$

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

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

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

where M is the magnetic parameter, G_r is the Grashof number for heat transfer, P_r is the Prandtl number, K_p is the permeability parameter and E_c is the Eckert number.
The corresponding boundary conditions are:

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

3. Method of solution

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

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

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

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

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

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

First order:

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

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

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 taking 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), (12), (13) and (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:

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

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

$$T''_{00} + P_r T'_{00} = 0 \quad (22)$$

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

The corresponding boundary conditions are,

$$y = 0 : u_{00} = 0, T_{00} = 1, u_{10} = 0, T_{10} = 1$$
$$y \to \infty : u_{00} = 0, T_{00} = 0, u_{10} = 0, T_{10} = 0 \quad (24)$$

First order:

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

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

$$T''_{01} + P_r T'_{01} = -P_r \left(u'_{00} \right)^2 \quad (27)$$

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

The corresponding boundary conditions are,

$$y = 0 : u_{01} = 0, T_{01} = 0, u_{11} = 0, T_{11} = 0 ;$$
$$y \to \infty : u_{01} = 0, T_{01} = 0, u_{11} = 0, T_{11} = 0 . \quad (29)$$

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

$$u_{00} = A_1\left(e^{-P_r y} - e^{-m_3 y}\right) \tag{30}$$

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

$$u_{10} = A_2\left(e^{-m_1 y} - e^{-m_5 y}\right) \tag{32}$$

$$T_{10} = e^{-m_1 y} \tag{33}$$

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

$$T_{01} = B_1 e^{-2P_r y} + B_2 e^{-2m_1 y} \tag{34}$$

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

$$u_{01} = D_1 e^{-2P_r y} + D_2 e^{-2m_3 y} + D_3 e^{-P_r y} - D_4 e^{-m_3 y} \tag{36}$$

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

3.1 Skin friction

The skin friction at the wall is given by

$$\tau_w = \left(\frac{\partial u}{\partial y}\right)_{y=0} \tag{38}$$

Now, using equations (9), (16), (18), (30), (32), (36) and (37) in equation (38), we get

$$\tau_w = -P_r A_1 + m_3 A_1 - E_c\left[2P_r D_1 + 2m_3 D_2 + P_r D_3 - m_3 D_4\right] + \varepsilon e^{i\omega t}\{-m_1 A_2 + m_5 A_2 - E_c[(m_1 + P_r)E_1$$
$$+ (m_5 + P_r)E_2 + (m_1 + m_3)E_3 + (m_3 + m_5)E_4 + m_1 E_5 - m_5 E_6]\} \tag{39}$$

3.2 Heat flux

The rate of heat transfer i. e., heat flux at the wall in terms of Nusselt number is given by

$$N_u = \left(\frac{\partial T}{\partial y}\right)_{y=0} \tag{40}$$

Using equations (10), (17), (19), (31), (33)-(35) in equation (40), we get

$$N_u = -P_r - E_c\left[2P_r B_1 + 2m_1 B_2\right] + \varepsilon e^{i\omega t}\{-m_1 - E_c[(m_1 + P_r)C_1 + (m_5 + P_r)C_2$$
$$+ (m_1 + m_3)C_3 + (m_3 + m_5)C_4 - m_1 C_5]\} \tag{41}$$

where

$$m_1 = \frac{1}{2}\left[P_r + \sqrt{P_r^2 + i\omega P_r}\right],\ m_2 = \frac{1}{2}\left[-P_r + \sqrt{P_r^2 + i\omega P_r}\right],\ m_3 = \frac{1}{2}\left[1 + \sqrt{1 + 4\left(M + \frac{1}{K_p}\right)}\right],\ m_4 = \frac{1}{2}\left[-1 + \sqrt{1 + 4\left(M + \frac{1}{K_p}\right)}\right],$$

$$m_5 = \frac{1}{2}\left[1 + \sqrt{1 + 4\left(M + \frac{1}{K_p} + \frac{i\omega}{4}\right)}\right],\ m_6 = \frac{1}{2}\left[-1 + \sqrt{1 + 4\left(M + \frac{1}{K_p} + \frac{i\omega}{4}\right)}\right],\ A_1 = \frac{G_r}{(m_3 - P_r)(m_4 + P_r)},$$

$$A_2 = \frac{G_r}{(m_5 - m_1)(m_6 + m_1)},\ B_1 = \frac{-P_r A_1^2}{2},\ B_2 = \frac{P_r m_3 A_1^2}{2(P_r - 2m_3)},\ B_3 = B_1 + B_2,\ C_1 = -\frac{2P_r A_1 A_2}{(m_1 + m_2 + P_r)},$$

$$C_2 = \frac{2P_r^2 A_1 A_2 m_5}{(m_5 - m_1 + P_r)(m_5 + m_2 + P_r)},\ C_3 = \frac{2P_r A_1 A_2 m_1}{(m_3 + m_2 + m_1)},\ C_4 = \frac{2P_r A_1 A_2 m_3 m_5}{(m_5 + m_3 + m_1)(m_5 + m_3 + m_2)},$$

$$C_5 = C_1 + C_2 + C_3 + C_4,\; D_1 = \frac{G_r B_1}{(m_3 - 2P_r)(m_4 + 2P_r)},\; D_2 = \frac{-G_r B_2}{m_3(m_4 + 2m_3)},\; D_3 = \frac{G_r B_3}{(P_r - m_3)(m_4 + P_r)},\; D_4 = D_1 + D_2 + D_3$$
$$,\; E_1 = \frac{G_r C_1}{(m_5 - m_1 - P_r)(m_6 + m_1 + P_r)},\; E_2 = \frac{-G_r C_2}{P_r(m_6 + m_5 + P_r)},\; E_3 = \frac{G_r C_3}{(m_5 - m_3 - m_1)(m_6 + m_3 + m_1)},$$
$$E_4 = \frac{-G_r C_4}{m_3(m_6 + m_5 + m_3)},\; E_5 = \frac{G_r C_5}{(m_5 - m_1)(m_6 + m_1)},\; E_6 = E_1 + E_2 + E_3 + E_4 + E_5 \qquad (42)$$

4. Results and discussions

The problem of unsteady free convective flow of a viscous incompressible electrically conducting fluid past an infinite vertical porous flat plate in a porous medium with constant suction in presence of a uniform transverse magnetic field has been studied. Approximate solutions for velocity, temperature, skin friction and rate of heat transfer are obtained using multi parameter perturbation technique and the effects of the various flow parameters affecting the flow field are discussed with the help of velocity profiles shown in Figures 1-3, temperature profiles shown in Figures 4, 5 and Table1.

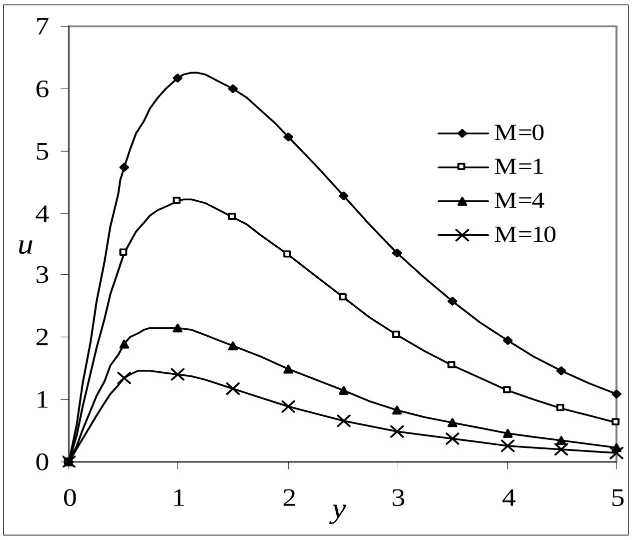

Figure 1. Transient velocity profiles against *y* for different values of *M* with G_r=4, K_p=1, P_r=0.71, E_c=0.002, ω=5.0, ε=0.2, ωt=π/2

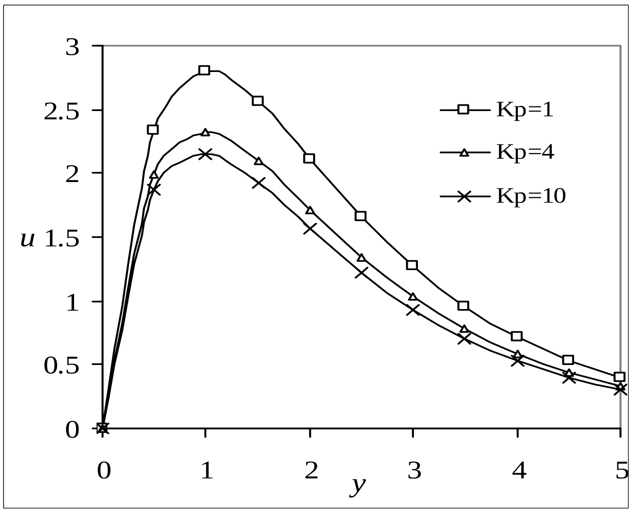

Figure 2. Transient velocity profiles against y for different values of Kp with Gr=4, Ec=0.002, Pr=0.71, M=1, ω=5.0, ε=0.2, ωt=π/2

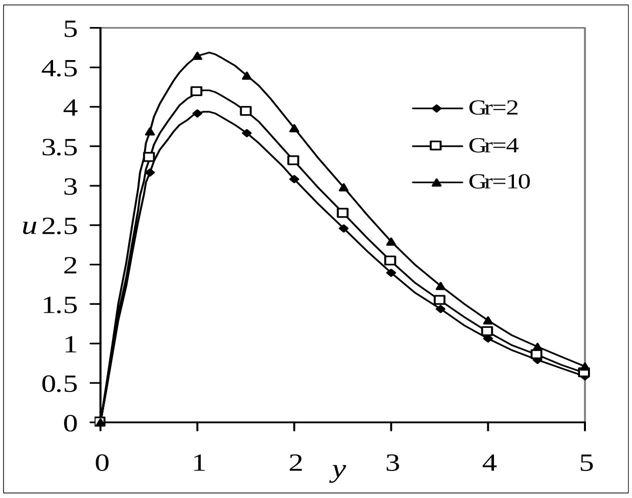

Figure 3. Transient velocity profiles against *y* for different values of G_r with K_p=1, E_c=0.002, P_r=0.71, *M*=1, ω=5.0, ε=0.2, ωt=π/2

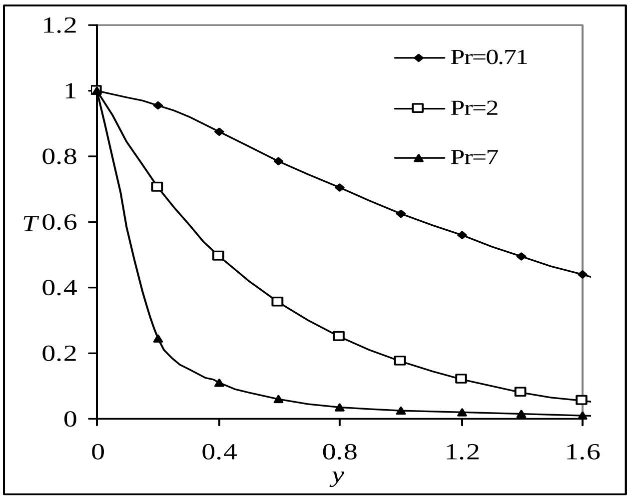

Figure 4. Temperature profiles against y for different values of Pr with Gr=4, M=1, Kp=1, Ec=0.002, ω=5.0, ε=0.2, ωt=π/2

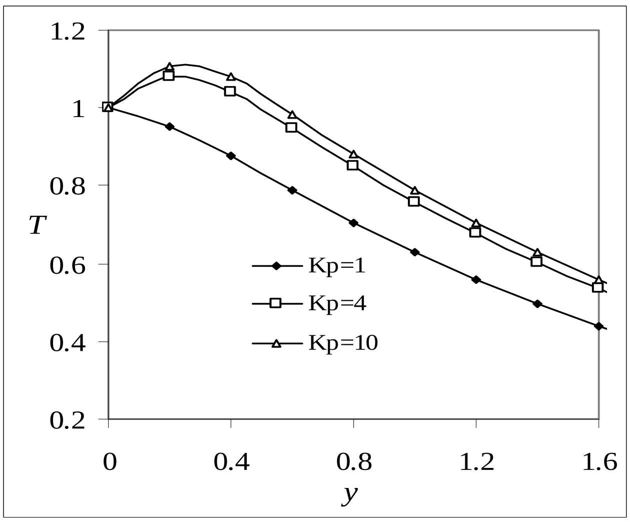

Figure 5. Temperature profiles against y for different values of Kp with Gr=4, M=1, Pr =0.71, Ec=0.002, ω=5.0, ε=0.2, ωt=π/2

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 Gr=4, Pr=0.71, Ec=0.002, ε =0.2, ω=5.0, ωt=π/2

K_p	M =0		M =2		M = 4		M =10	
	τ	N_u	τ	N_u	τ	N_u	τ	N_u
0.2	7.27274	-0.05907	5.94654	-0.11571	5.42523	-0.20227	4.56435	-0.23462
1.0	11.67684	1.75293	9.20107	0.58764	6.67837	-0.11364	5.18634	-0.22107
5.0	13.67578	5.52476	10.40892	1.32563	7.08325	-0.07347	5.38026	-0.213356
10.0	14.18236	6.87351	10.74237	1.54786	7.20147	-0.06494	5.43273	-0.20943

4.1 Velocity field

The velocity of the flow field suffers a change in magnitude due to the variation of the flow parameters. The flow parameters affecting the velocity field are mainly magnetic parameter M, Grashof number for heat transfer G_r and permeability parameter K_p. The effects of these parameters on the velocity of the flow field have been discussed with the aid of velocity profiles shown in Figures 1-3.

Figure 1 depicts the effect of magnetic parameter M on the velocity of the flow field. In the above figure curve with M=0 corresponds to the case of non-MHD flow. A close observation of the curves of the figure shows that a growing magnetic parameter decelerates velocity of the flow field at all points due to the action of the Lorentz force in the flow field. Figure 2 elucidates the effect of permeability parameter K_p on the velocity field. The permeability parameter K_p retards 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. For cooling of the plate $G_r>0$, a growing Grashof number for heat transfer accelerates the velocity of the flow field at all points due to the action of free convection current in the flow field.

4.2 Temperature field

The variation in the value of temperature of the flow field is mainly due to change in Prandtl number P_r and the permeability parameter K_p. The effects of these parameters are shown in Figures 4 and 5 respectively. The effect of growing Prandtl number P_r is to decrease the transient temperature of the flow field at all points in the flow field while a growing permeability parameter reverses the effect.

4.3 Skin friction and rate of heat transfer

The value of skin friction τ and the rate of heat transfer N_u at the plate against permeability parameter K_p for different values of magnetic parameter M are entered in Table1 keeping other parameters of the flow field constant. The permeability parameter K_p is found to enhance the skin friction at the wall while a growing magnetic parameter M shows the reverse effect. The rate of heat transfer at the plate increases as the permeability parameter K_p grows in the flow field. On the other hand, the effect of increasing magnetic parameter M is to decrease the rate of heat transfer at the wall.

5. Conclusion

We bring out the following results of physical interest on the velocity, temperature, skin friction and the rate of heat transfer at the wall in the flow field from the above study.

1. A growing magnetic parameter M or permeability parameter K_p retards the transient velocity of the flow field at all points.
2. The Grashof number for heat transfer G_r enhances the transient velocity of the flow field at all points.
3. The effect of growing Prandtl number P_r is to decrease the transient temperature of the flow field at all points in the flow field while a growing permeability parameter reverses the effect.
4. The permeability parameter K_p enhances the skin friction and the rate of heat transfer at the wall.
5. The effect of increasing magnetic parameter is to decrease the skin friction and the rate of heat transfer at the wall in the flow field.

References

[1] Raptis A. Unsteady free convection flow through porous medium. Int. J. Engng. Sci.1983, 21 (4), 345-349.

[2] Hossain M. A., Begum R. A. Effect of mass transfer and free convection on the flow past a vertical plate. ASME J. Heat Transfer. 1984, 106, 664-668.

[3] Vafai K. Convective flow and heat transfer in variable porosity media. J. Fluid Mechanics. 1984, 147, 233-259.
[4] 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.
[5] Raptis A., Perdikis P.C. Unsteady flow thrpugh a porous medium in the presence of free convection. Int. Comm. Heat and Mass Trans. 1985, 12, 697-704.
[6] Singh A.K., Dikshit C.K. Hydromagnetic flow past a continuously moving semi-infinite plate for large suction. Astrophys. Space Sci. 1988, 148, 249-256.
[7] Vajravelu K.R., Hadjinicolaou A. Heat transfer in a viscous fluid over a stretching sheet with viscous dissipation and internal heat generation. Int. Comm. Heat Mass Transfer. 1993, 20, 417-430.
[8] Deka R. K., Das U. N., Soundalgekar V. M. Transient free convection flow past an infinite vertical plate with temperature-dependent heat source. Proc. Math. Soc. BHU. 1995, 11, 105-110.
[9] Attia H.A., Kotb N. A. MHD flow between two parallel plates with heat transfer. Acta Mechanica. 1996, 117, 215-220.
[10] Raptis A. A., Soundalgekar V.M. Steady laminar free convection flow of an electrically conducting fluid along a porous hot vertical plate in presence of heat source/sink. Z. Angew. Math. Mech. 1996, 10, 59-62.
[11] Sattar M.A., Rahman M.M., Alam M. Free convection flow and Heat transfer through a porous vertical flat plate immersed in a porous medium. J. Energy Res. 2000, 22 (1), 17-21.
[12] 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.
[13] Das S. S., Sahoo S. K., Dash G. C. Numerical solution of mass transfer effects on unsteady flow past an accelerated vertical porous plate with suction. Bull. Malays. Math. Sci. Soc. 2006, 29(1), 33-42.
[14] Ogulu A., Prakash J. Heat transfer to unsteady magneto-hydrodynamic flow past an infinite vertical moving plate with variable suction. Physica Scripta. 2006, 74(2), 232-238.
[15] Das S. S., Satapathy A., Panda J. P., Patnaik A. B. Effect of induced magnetic field on MHD flow and heat transfer in a conducting elastico-viscous fluid past a continuously moving porous flat surface. AMSE J. Mod. Meas. Cont. B. 2007, 76 (5), 81-92.
[16] 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 and Applications in Fluid Mechanics. 2008, 4(2), 187-203.
[17] 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.
[18] 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 Transfer. 2009, 52 (25-26), 5962-5969.
[19] Das S. S., Tripathy., U. K. Effect of periodic suction on three dimensional flow and heat transfer past a vertical porous plate embedded in a porous medium. Int. J. Energy Environment. 2010, 1 (5), 757-768.

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. Dr. Das is the recipient of prestigious honour of being selected for inclusion in Marquis Who's Who in Science and Engineering of New Jersey, USA for the year 2011-2012 (11th Edition) for his outstanding contribution to research in Science and Engineering.
E-mail address: drssd2@yahoo.com