INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT

Volume 2, Issue 2, 2011 pp.375-382
Journal homepage: www.IJEE.IEEFoundation.org

Effect of heat source and variable suction on unsteady viscous stratified flow past a vertical porous flat moving plate in the slip flow regime

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 investigates the effect of heat source and variable suction on unsteady viscous stratified flow through a porous medium due to a moving porous plate under slip boundary condition for velocity field and jump in temperature field. The velocity of the porous plate decreases exponentially with time about a constant mean and a variable suction velocity is applied normal to the plate. The governing equations of the flow field are solved using perturbation technique and the expressions for velocity field, temperature distribution, skin-friction and heat flux are obtained. The effects of the pertinent parameters such as permeability parameter (K_p), velocity slip and temperature jump parameter (h_1, h_2), stratification parameter (α), suction velocity parameter (A), the heat source parameter (S) and Prandtl number (P_r) on velocity and temperature distribution of the flow field and also on skin-friction and the rate of heat transfer are analyzed and discussed with the aid of figures and table.

Keywords: Stratified flow, Unsteady, Porous medium, Slip flow regime, Variable suction, Heat source.

1. Introduction

Fluid motion influenced by the density and viscosity variations is characterized as stratified flow. These flows are of great theoretical and practical interest of many researchers because of their possible applications to engineering sciences particularly in the flow through porous media to provide a technique for studying the pore size in a porous medium.

In view of these applications, Gebhart and Pera [1] analyzed the nature of vertical natural convection flows resulting from the combined buoyancy effects of thermal and mass diffusion. Vafai and Tien [2] studied the boundary and inertia effects on flow and heat transfer in porous media. The unsteady stratified couette flow has been studied by Singh [3]. Jha and Ravindra [4] discussed the MHD free convection and mass transfer flow through a porous medium with heat source. Chauhan and Soni [5] reported the stratified coupled fluid flow due to an oscillating plate at the bottom of a highly permeated bed. Raptis and Soundalgekar [6] discussed the steady laminar free convection flow of an electrically conducting fluid along a porous hot vertical plate in presence of heat source/sink. Chamkha [7] studied the thermal radiation and buoyancy effects on hydromagnetic flow over an accelerating permeable surface with heat source and sink. Acharya *et al*. [8] analyzed the heat and mass transfer problem over an accelerating surface with heat source in presence of suction and blowing. Kamel [9] investigated the unsteady MHD convection through a porous medium with combined heat and mass transfer in presence of heat source/sink. Devi and Kandaswamy [10] estimated the effect of chemical reaction, heat and mass transfer on non-linear MHD flow past an accelerating surface with heat source and thermal stratification in the presence of suction or injection.

Raptis *et al*. [11] discussed the effect of thermal radiation on MHD Flow. Saha and Hossain [12] studied the natural convection flow with combined buoyancy effects due to thermal and mass diffusion in a thermally stratified media. Das *et al*. [13] estimated numerically the effect of mass transfer on unsteady flow past an accelerated vertical porous plate with suction. Mazumdar and Deka [14] analyzed the MHD flow past an impulsively started infinite vertical plate in presence of thermal radiation. Das and his co-workers [15] discussed the magnetohydrodynamic unsteady flow of a viscous stratified fluid through a porous medium past a porous flat moving plate in the slip flow regime with heat source. In a separate paper Das *et al*. [16] 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 his associates [17] reported the hydromagnetic convective flow past a vertical porous plate through a porous medium with suction and heat source. More recently, Das and Tripathy [18] estimated the effect of periodic suction on three dimensional flow and heat transfer past a vertical porous plate embedded in a porous medium.

The study reported herein is an attempt to analyze the effect of heat source and variable suction on unsteady viscous stratified flow through a porous medium due to a moving porous plate under slip boundary condition for velocity field and jump in temperature field. The velocity of the porous plate decreases exponentially with time about a constant mean and a variable suction velocity is applied normal to the plate. Using perturbation technique the governing equations of the flow field are solved and the expressions for fluid velocity, temperature, skin friction and Nusselt number are obtained. The effects of pertinent parameters on velocity, temperature, skin-friction and the rate of heat transfer are discussed with the aid of figures and table.

2. Formulation of the problem

Consider a two dimensional unsteady flow of a viscous stratified fluid through a porous medium over a porous flat plate with slip boundary condition for velocity field and jump in temperature field in presence of a heat source. The plate is subjected to a variable suction velocity normal to it. Further, the plate is moving in its own plane with a velocity $U_0(1+\varepsilon e^{-\omega t})$. The *x*-axis is taken along the plate and the *y*-axis is normal to it. We assume

$$\rho = \rho_0 e^{-\beta y}, \quad \mu = \mu_0 e^{-\beta y} \quad \text{and} \quad k = k_0 e^{-\beta y} \quad \text{for } y \geq 0, \tag{1}$$

where β is a small positive number, ρ is the density of the fluid, μ is the viscosity of the fluid, k is the thermal conductivity and ρ_0, μ_0 and k_0 are the density, viscosity and thermal conductivity respectively at $y = 0$.

The pressure in the fluid is assumed to be constant. Under the above assumptions, the equations governing the flow are:

$$\frac{\partial v}{\partial y} = 0, \tag{2}$$

$$\frac{\partial u}{\partial t} + v\frac{\partial u}{\partial y} = \frac{1}{\rho}\frac{\partial}{\partial y}\left(\mu\frac{\partial u}{\partial y}\right) - \frac{\nu}{K}u, \tag{3}$$

$$\frac{\partial T}{\partial t} + v\frac{\partial T}{\partial y} = \frac{1}{\rho c_p}\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\mu}{\rho c_p}\left(\frac{\partial u}{\partial y}\right)^2 - S(T - T_\infty). \tag{4}$$

The initial and boundary conditions of the problem are

$$u = U_0\left(1 + \varepsilon e^{-\omega t}\right) + L_1\frac{\partial u}{\partial y}, \quad T = T_w + L_2\frac{\partial T}{\partial y} \quad \text{at} \quad y = 0, \tag{5}$$

$$u \to 0, \qquad T = T_w \qquad \text{as } y \to \infty,$$

where $L_1 = \left(\frac{2-m}{m}\right)L$, $L_2 = \left(\frac{2-a}{a}\right)\left(\frac{1.996\gamma}{\gamma+1}\right)\frac{L}{P_r}$,

L being the mean free path, m is the Maxwell's reflexion co-efficient and a is the thermal accommodation co-efficient.

The continuity equation (2) on integration gives

$$v = -v_0(1+A\varepsilon e^{-\omega t}), \tag{6}$$

where A is the suction velocity parameter.

We introduce the following non-dimensional quantities:

$$y^* = \frac{yv_0}{\nu}, t^* = \frac{v_0^2 t}{\nu}, \omega^* = \frac{\nu\omega}{v_0^2}, u^* = \frac{u}{U_0}, T^* = \frac{T-T_\infty}{T_w - T_\infty}, S^* = \frac{\nu S}{v_0^2}, \nu = \frac{\mu_0}{\rho_0}, K_p = \frac{v_0^2 K}{\nu^2}, h_1 = \frac{L_1 v_0}{\nu},$$

$$h_2 = \frac{L_2 v_0}{\nu}, E_c = \frac{U_0^2}{c_p(T_w - T_\infty)}, P_r = \frac{\rho_0 \nu c_p}{k_0}, \alpha = \frac{\beta\nu}{v_0}. \tag{7}$$

Using equations (1), (6) and (7) in equations (3) and (4) and dropping the asterisks, we have

$$\frac{\partial^2 u}{\partial y^2} + \left(1 - \alpha + A\varepsilon e^{-\omega t}\right)\frac{\partial u}{\partial y} - \frac{1}{K_p}u = \frac{\partial u}{\partial t}, \tag{8}$$

$$\frac{\partial^2 T}{\partial y^2} + P_r\left(1 - \frac{\alpha}{P_r} + A\varepsilon e^{-\omega t}\right)\frac{\partial T}{\partial y} - P_r\frac{\partial T}{\partial t} = -P_r E_c\left(\frac{\partial u}{\partial y}\right)^2 - P_r ST. \tag{9}$$

The corresponding boundary conditions are

$$u = 1 + \varepsilon e^{-\omega t} + h_1\frac{\partial u}{\partial y}, \quad T = 1 + h_2\frac{\partial T}{\partial y} \quad \text{at} \quad y = 0, \tag{10}$$

$$u \to 0, \qquad T \to 0 \qquad \text{as } y \to \infty.$$

3. Method of solution

In order to solve equations (8) and (9) for u and T, we assume the solutions of the following form:

$$u = 1 - u_1(y) + \varepsilon e^{-\omega t}\left[1 - u_2(y)\right] \tag{11}$$

$$T = T_1(y) + \varepsilon e^{-\omega t} T_2(y) \tag{12}$$

Substituting (11) and (12) in equations (8) and (9) and collecting the coefficients of like powers of ε and neglecting those of ε^2, we get

$$u_1'' + (1-\alpha)u_1' - \frac{1}{K_p}(1-u_1) = 0 \tag{13}$$

$$u_2'' + (1-\alpha)u_2' + \left(\frac{1}{K_p} - \omega\right)(1-u_2) + Au_1' = 0 \tag{14}$$

$$T_1'' + (P_r - \alpha)T_1' = -P_r E_c(1-u_1)^2 - P_r ST_1 \tag{15}$$

$$T_2'' + (P_r - \alpha)T_2' + \omega P_r T_2 + P_r AT_1' = -2P_r E_c(1-u_1)(1-u_2) - P_r ST_2 \tag{16}$$

The corresponding boundary conditions are

$$u_1 = -h_1\frac{\partial u}{\partial y}, \quad u_2 = 0, \quad T_1 = 1 + h_2\frac{\partial T}{\partial y}, \quad T_2 = 0 \quad \text{at} \quad y = 0, \tag{17}$$

$u_1 = 1, \quad u_2 = 1, \quad T_1 = 0, \quad T_2 = 0 \quad \text{as } y \to \infty.$

Solving equations (13)-(16) subject to boundary conditions (17), we get

$$u_1 = 1 + A_1 e^{-m_1 y}, \tag{18}$$

$$u_2 = 1 - e^{-m_3 y} + A_2\left(e^{-m_3 y} - e^{-m_1 y}\right), \tag{19}$$

$$T_1 = D_2 e^{m_4 y} - D_1 e^{-2m_1 y}, \tag{20}$$

$$T_2 = (B_3 - B_4)\left(e^{-(m_1+m_3)y} - e^{m_7 y}\right) + (B_5 - B_2)\left(e^{-2m_1 y} - e^{m_7 y}\right) - B_1\left(e^{-m_4 y} - e^{m_7 y}\right). \tag{21}$$

Substituting equations (18)-(21) in equations (11) and (12), the solutions for u and T are given by

$$u = -A_1 e^{-m_1 y} + \varepsilon e^{-\omega t}\left[\, e^{-m_3 y} - A_2\left(e^{-m_3 y} - e^{-m_1 y}\right)\right], \tag{22}$$

$$T = D_2 e^{m_4 y} - D_1 e^{-2m_1 y} + \varepsilon e^{-\omega t}\left[(B_3 - B_4)\left(e^{-(m_1+m_3)y} - e^{m_7 y}\right) + (B_5 - B_2)\left(e^{-2m_1 y} - e^{m_7 y}\right) - B_1\left(e^{-m_4 y} - e^{m_7 y}\right)\right] \tag{23}$$

where

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

$$m_4 = -\frac{1}{2}\left[P_r - \alpha + \sqrt{(P_r - \alpha)^2 - 4P_r S}\right], m_5 = \frac{1}{2}\left[\alpha - P_r + \sqrt{(P_r - \alpha)^2 - 4P_r S}\right],$$

$$m_6 = \frac{1}{2}\left[\alpha - P_r + \sqrt{(P_r - \alpha)^2 - 4P_r (S + \omega)}\right],$$

$$m_7 = -\frac{1}{2}\left[P_r - \alpha + \sqrt{(P_r - \alpha)^2 - 4P_r (S + \omega)}\right], A_1 = \frac{-e^{\omega t} - h_1 m_3 \varepsilon}{(1 + h_1 m_1)e^{\omega t} + \dfrac{\varepsilon A m_1}{m_1 + m_2}}, \; A_2 = \frac{m_1 A A_1}{(m_3 - m_1)(m_1 + m_2)},$$

$$B_1 = \frac{A D_2 P_r m_4}{(m_4 - m_7)(m_4 - m_6)}, B_2 = \frac{2AA_1^2 E_c P_r^{\,2} m_1}{(2m_1 + m_4)(2m_1 + m_5)(2m_1 + m_6)(2m_1 + m_7)},$$

$$B_3 = \frac{2A_1 E_c P_r}{(m_1 + m_3 + m_7)(m_1 + m_3 + m_6)}, B_4 = \frac{2AA_1^2 E_c P_r m_1}{(m_1 + m_3 + m_6)(m_1 + m_3 + m_7)(m_3 - m_1)(m_1 + m_2)},$$

$$B_5 = \frac{2AA_1^2 E_c P_r m_1}{(2m_1 + m_6)(2m_1 + m_7)(m_3 - m_1)(m_1 + m_2)}, \; D_1 = \frac{A_1^2 E_c P_r}{(2m_1 + m_4)(2m_1 + m_5)},$$

$$D_2 = \frac{1}{1 - h_2 m_4}\left\{1 + D_1 + 2h_2 m_1 D_1 + h_2 \varepsilon e^{-\omega t}\left[(B_4 - B_3)(m_1 + m_3 + m_7) + (B_2 - B_5)(2m_1 + m_7) - B_1(m_4 - m_7)\right]\right\}.$$

3.1 Skin friction

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

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} \tag{24}$$

Substituting the value of u from equation (22) in equation (24), we obtain the skin friction at the wall as

$$\tau = A_1 m_1 + \varepsilon e^{-\omega t}\left[-m_3 + \frac{m_1 A A_1}{(m_1 + m_2)}\right]. \tag{25}$$

3.2 Heat flux

The rate of heat transfer i.e. the local heat flux at the wall in terms of Nusselt number (N_u) is given by

$$N_u = -\left(\frac{\partial T}{\partial y}\right)_{y=0} \tag{26}$$

Using equation (23) in equation (26), we get

$$N_u = 2m_1D_1 - m_4D_2 - \varepsilon e^{-\omega t}\left[(B_3 - B_4)(m_1 + m_3 + m_7) + (B_5 - B_2)(2m_1 + m_7) - B_1(m_4 - m_7)\right]. \tag{27}$$

4. Results and discussions

The two dimensional unsteady viscous stratified flow through a porous medium due to a moving porous plate under slip boundary condition for velocity field and jump in temperature field in presence of a heat source has been considered. Using perturbation technique, the governing equations of the flow field are solved and the expressions for velocity field, temperature, skin-friction and Nusselt number are obtained. The effects of the pertinent parameters such as permeability parameter (K_p), velocity slip and temperature jump parameter (h_1, h_2), stratification parameter (α), suction velocity parameter (A) and the heat source parameter (S) on velocity and temperature distribution of the flow field are analyzed and discussed with the aid of velocity profiles (1)-(4) and temperature profiles (5)-(8) respectively and their effect on skin friction and heat flux are also studied with the help of Table 1.

4.1 Velocity field (u)

The velocity of the flow field changes substantially with the variation of permeability parameter (K_p), suction velocity parameter (A), stratification parameter (α) and the velocity slip parameter (h_1). These variations are shown in Figures 1-4.

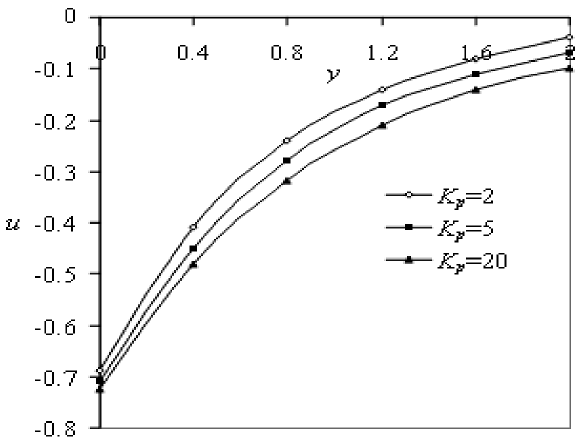

Figure1. Velocity profiles against y for different values of K_p with P_r=0.71, E_c=0.01, A=1, h_1=0.1, h_2=1, α=0.1, ω=0.1, t=1, ε=0.2

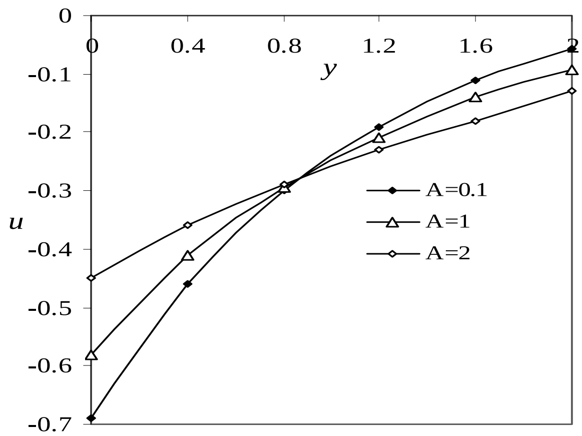

Figure2. Velocity profiles against y for different values of A with P_r=0.71, K_p=10, A=1, h_1=0.1, h_2=1, α=0.1, ω=0.1, t=1, E_c=0.01, ε=0.2

4.1.1 Effect of permeability parameter (K_p)

The effect of permeability parameter (K_p) on the velocity profiles of the flow field is shown in Figure 1 for small (2), moderate (5) and large (20) values of the permeability parameter taking other parameters of the flow field constant. The permeability parameter is found to enhance the velocity (absolute value) of the flow field at all points.

4.1.2 Effect of suction velocity parameter (A)

Figure 2 elucidates the effect of suction velocity parameter (A) on the velocity profiles of the flow field. One remarkable feature of this finding is that the magnitude of the velocity of the flow field decreases near the plate upto a certain point ($y \leq 0.88$) and thereafter the flow behaviour reverses as the suction velocity parameter increases.

4.1.3 Effect of stratification parameter (α)

Figure 3 depicts the effect of stratification parameter (α) on the velocity of the flow field. In the figure, curve with α =0 corresponds to the absence of stratification in the flow field. A study of the curves of the figure shows that the stratification parameter (α) accelerates the velocity (magnitude) of the flow field at all points.

4.1.4 Effect of velocity slip parameter (h_1)

The effect of velocity slip parameter (h_1) on the velocity of the flow field is shown in Figure 4. A comparison of the curves of the figure shows that the velocity slip parameter (h_1) reduces the absolute value of the velocity of the flow field at all points.

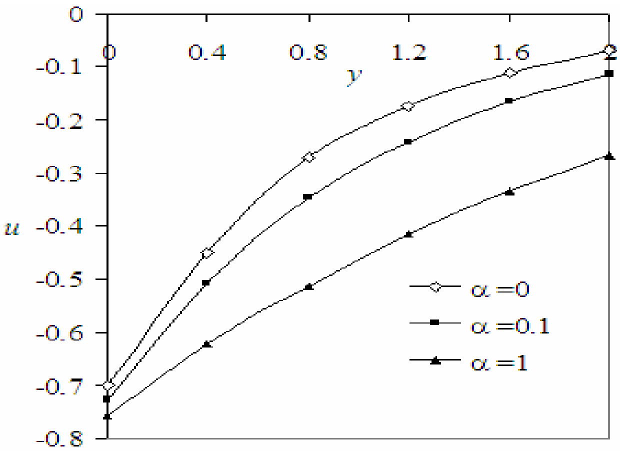

Figure3. Velocity profiles against y for different values of α with P_r=0.71, K_p=10, A=1, h_1=0.1, h_2=1, ω=0.1, t=1, Ec=0.01, ε=0.2

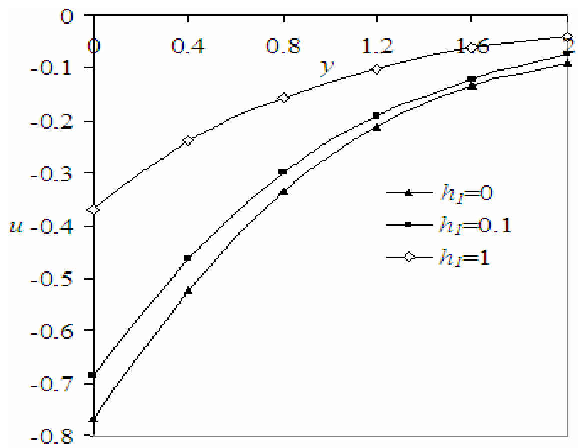

Figure4. Velocity profiles against y for different values of h_1 with P_r=0.71, E_c=0.01, A=1, h_2=1, α=0.1, ω=0.1, t=1, ε=0.2

4.2 Temperature field (T)

The temperature field suffers a change in magnitude with the variation of the pertinent parameters of the flow field. There is a major change in the temperature field due to the variation of Prandtl number (P_r), heat source parameter (S), stratification parameter (α) and temperature jump parameter (h_2). These variations are analyzed in Figures 5-8.

4.2.1 Effect of Prandtl number (P_r)

Figure 5 depicts the effect of Prandtl number (P_r) on the temperature field for small (0.71), moderate (1) and large (5) values of the Prandtl number. The Prandtl number is found to decrease the temperature of the flow field at all points.

4.2.2 Effect of heat source parameter (S)

The effect of heat source parameter (S) on the temperature profiles of the flow field has been shown in Figure 6. Curve with S = 0 corresponds to no heat source case. A comparison of the curves of the said figure shows that the heat source parameter has an accelerating effect on the temperature profiles of the flow field at all points.

4.2.3 Effect of stratification parameter (α)

Figure 7 depicts the effect of stratification parameter (α) on the temperature profiles of the flow field. Curve with α =0 corresponds to the absence of stratification in the flow field. The stratification parameter (α) is observed to enhance the temperature of the flow field at all points.

4.2.4 Effect of temperature jump parameter (h_2)

Figure 8 analyzes the effect of temperature jump parameter in the flow field. It plays a dominant role on the temperature profiles of the flow field. The temperature jump parameter (h_2) is varied in steps and the behaviour of the temperature field is analyzed. It is found to decrease the temperature of the flow field at all points.

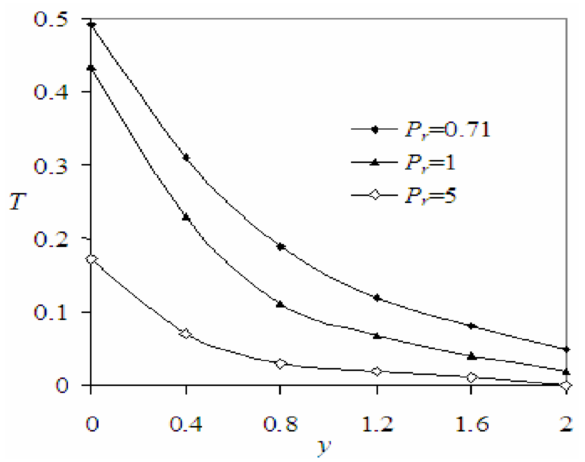

Figure 5. Temperature profiles against *y* for different values of *Pr* with *S*=1, K_p=10, *A*=1, h_1=0.1, h_2=1, α=0.1, ω=0.1, *t*=1, E_c=0.01, ε=0.2

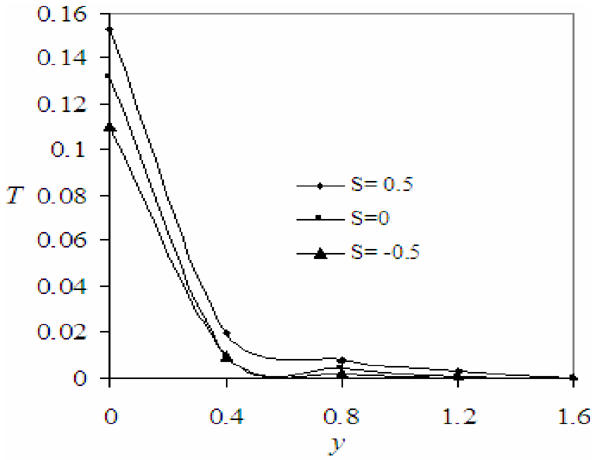

Figure 6. Temperature profiles against *y* for different values of *S* with P_r=0.71, K_p=10, *A*=1, h_1=0.1, h_2=1, α=0.3, ω=0.1, *t*=1, E_c=0.01, ε=0.2

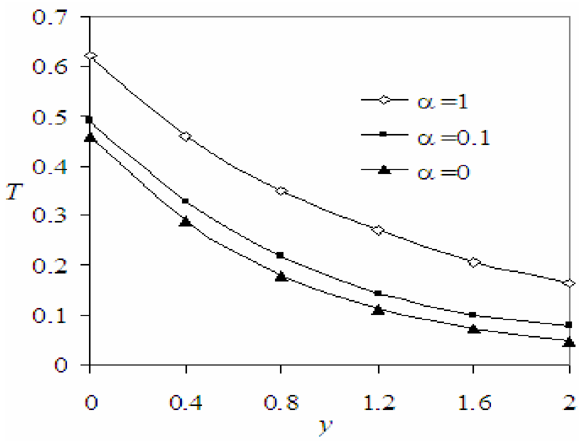

Figure 7. Temperature profiles against *y* for different values of α with P_r=0.71, *S*=1, K_p=10, *A*=1, h_1=0.1, h_2=1, ω=0.1, *t*=1, E_c=0.01, ε=0.2

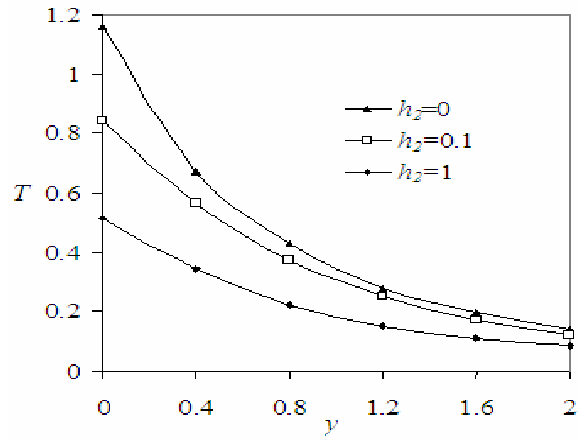

Figure 8. Temperature profiles against *y* for different values of h_2 with P_r=0.71, *S*=1, K_p=10, *A*=1, h_1=0.1, α=0.3, ω=0.1, *t*=1, E_c=0.01, ε=0.2

4.3 Skin friction (τ) and heat flux (N_u)

In Table 1, we enter the values of skin friction at the wall (τ) and the rate of heat transfer in terms of Nusselt number (N_u) with the variation of stratification parameter (α). The stratification parameter (α) reduces the magnitude of both skin friction and heat flux at the wall.

Table 1. Values of skin friction (τ) and heat flux (N_u) for different values of stratification parameter (α)

α	τ	N_u
0	-1.2436	0.5436
0.5	-1.1134	0.4739
1.0	-0.9021	0.3994
2.0	-0.8869	0.2078

5. Conclusion

We conclude below 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. (1) A growing permeability parameter (K_p) accelerates the velocity of the flow field at all points. (2) The effect of stratification parameter (α) is to increase the magnitude of the velocity and temperature of the flow field at all points, while it reduces the magnitude of both skin friction and the rate of heat transfer at the wall. (3) The suction velocity parameter (*A*) reduces the magnitude of the velocity of the flow field near the plate up to a certain point

(y≤0.88) and thereafter the flow behaviour reverses. (4) A growing velocity slip parameter (h_1) decreases the magnitude of the velocity of the flow field at all points. (5) The effect of increasing Prandtl number (P_r) is to diminish the temperature of the flow field at all points. (6) An increase in heat source parameter (S) enhances the temperature of the flow field at all points while the temperature jump parameter (h_2) reverses the effect..

References

[1] Gebhart B., Pera L.The nature of vertical natural convection flows resulting from the combined buoyancy effects of thermal and mass diffusion. Int. J. Heat and Mass Trans. 1971, 14, 2025-2050.
[2] Vafai K., Tien C. L. Boundary and inertia effects on flow and heat transfer in porous media. Int. J. Heat Mass Trans. 1981, 24, 195-203.
[3] Singh A. K. Unsteady stratified couette flow. Ind. J. Theo. Phys. 1986, 34(4), 291.
[4] Jha B.K., Ravindra P. MHD free convection and mass transfer flow through a porous medium with heat source. Astro Phys. Space Sci. 1991, 181, 117-123.
[5] Chauhan D. S., Soni V. Stratified coupled fluid flow due to an oscillating plate at the bottom of a highly permeated bed. AMSE J. Mod. Meas. Cont. B. 1994, 53, 1.
[6] 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. ZAMM. 1996, 10, 59-62.
[7] Acharya M., Singh L.P., Dash G. C. Heat and mass transfer over an accelerating surface with heat source in presence of suction and blowing, Int. J. Engng. Sci. 1999, 37, 1-18.
[8] Chamkha A. J. Thermal radiation and buoyancy effects on hydromagnetic flow over an accelerating permeable surface with heat source and sink. Int. J. Engng. Sci. 2000, 38, 1699-1712.
[9] Kamel M.H. Unsteady MHD convection through porous medium with combined heat and mass transfer with heat source/sink. Energy Conversion and Management. 2001, 42, 393-405.
[10] Devi S. P. A., Kandaswamy R. Effect of chemical reaction, heat and mass transfer on non-linear MHD flow past an accelerating surface with heat source and thermal stratification in the presence of suction or injection. Communication in Numerical Methods in Engineering. 2003, 19, 513-520.
[11] Raptis A., Perdikis C., Takhar H. S. Effect of thermal radiation on MHD Flow. Appl. Math. Compute. 2004, 153, 645-649.
[12] Saha S.C., Hossain M.A. Natural Convection flow with combined buoyancy effects due to thermal and mass diffusion in a thermally stratified media. Int. J. Thermal Sci. 2004, 44(5), 89-102.
[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] Mazumdar M. K., Deka R. K. MHD flow past an impulsively started infinite vertical plate in presence of thermal radiation. Romanian J. Phys. 2007, 52(5-6), 529-535.
[15] Das S. S., Tripathy U. K., Das J. K., Sahoo S. K., Mishra S. Magnetohydrodynamic unsteady flow of a viscous stratified fluid through a porous medium past a porous flat moving plate in the slip flow regime with heat source. Far East J. Math. Sci. 2008, 29(1), 71-88.
[16] 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. Heat Mass Trans. 2009, 52(25-26), 5962-5969.
[17] Das S. S., Tripathy U. K., Das J. K. Hydromagnetic convective flow past a vertical porous plate through a porous medium with suction and heat source, Int. J. Ener. Env. 2010, 1(3), 467-478.
[18] 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. Ener. Env. 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 etc. E-mail address: drssd2@yahoo.com

