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Research Article

Radiative Heat and Mass Transfer Effects on Natural Convection Couette Flow through a Porous Medium in the Slip flow Regime

S. S. Das [1], M. Mohanty [2], S. K. Panigrahi [3], R. K. Padhy [4], M. Sahu [5]

[1]Department of Physics, KBDAV College, Nirakarpur, Khordha-752 019 (Odisha), India
E-mail: *drssd2@yahoo.com*
[2]Department of Physics, Christ College, Mission Road, Cuttack-753 001 (Odisha), India
[3]Department of Mechanical Engineering, KIST, Techno Park, Jatni, Khordha-752 050 (Odisha), India
[4]Department of Physics, DAV Public School, Chandrasekharpur, Bhubaneswar-751 021(Odisha), India
[5]Department of Physics, Jupiter +2 Women's Sc. College, IRC Village, Bhubaneswar-751 015 (Odisha), India

Abstract

The objective of this paper is to analyze the effect of radiative heat and mass transfer on unsteady natural convection couette flow of a viscous incompressible fluid in the slip flow regime in presence of variable suction and radiative heat source. The governing equations of the flow field are solved employing perturbation technique and the expressions for the velocity, temperature, concentration distribution, skin friction and the rate of heat transfer i.e. the heat flux in terms of Nussels number N_u are obtained. The effects of the pertinent parameters such as suction parameters α_1, α_2 ; Grashof number for heat and mass transfer G_r, G_c; slip flow parameters h_1, h_2; radiation parameter F, permeability parameter K_p, Schmidt number S_c, Prandtl number P_r, etc. on the flow field have been studied and the results are presented graphically and discussed quantitatively.

Keywords: Radiative heat; Mass transfer; Natural convection; Couette flow; Variable suction; Permeability.

Introduction

In recent years the effect of radiation on flow problems with heat transfer has been given much importance in different fields of engineering and technology. Many engineering processes occur at high temperatures and the knowledge of radiation heat transfer has become very important for the design of pertinent equipments such as nuclear power plants, gas turbines and various propulsion devices for aircrafts, missiles, satellites and space vehicles. At high operating temperature, radiation effect is very significant. In view of the above interests a series of investigations have been made by different scholars.

Govindarajulu [1] discussed hydromagnetic couette flow with time-dependent suction. Sattar and Alam [2] analyzed thermal diffusion as well as transpiration effect on MHD free convection and mass transfer flow past an accelerated vertical porous plate. Sattar and Kalim [3] studied the unsteady free convection interaction with thermal radiation in a boundary layer flow past a vertical porous plate. Attia and Kotb [4] reported MHD flow between two parallel plates with heat transfer. Raptis and Perdikis [5] discussed radiation and free convection flow past a moving plate. Nagaraju *et al*. [6] investigated simultaneous radiative and convective heat transfer in a variable porosity medium. Sreekanth *et al*. [7] described transient MHD free convention flow of an incompressible viscous dissipative fluid. Chamkha [8] analyzed MHD flow of a uniformly stretched vertical permeable surface in presence of heat generation /absorption and chemical reaction.

Cookey *et al*. [9] discussed 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. Gokhale and Alsamman [10] estimated the effects of mass transfer on the transient free convection flow of a dissipative fluid along a semi-infinite vertical plate with constant heat flux. Singh and Gupta [11] investigated the MHD free convective flow of viscous fluid through a porous medium bounded by an oscillating porous plate in the slip flow regime with mass transfer. Das and his associates [12] estimated numerically the mass transfer effects on unsteady flow past an accelerated vertical porous plate with suction. Ibrahim *et al*. [13] analyzed the effect of chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate with heat source and suction. Das [14] investigated the effect of suction and injection on MHD three dimensional couette flow and heat transfer through a porous medium. Das and his co-workers [15] discussed the hydromagnetic convective flow past a vertical porous plate through a porous medium with suction and heat source.

The objective of this paper is to analyze the effect of radiative heat and mass transfer on unsteady natural convection couette flow of a viscous incompressible fluid in the slip flow regime in presence of variable suction and radiative heat source. The governing equations of the flow field are solved for the velocity, temperature, concentration distribution, skin friction and the rate of heat transfer and the effects of the various flow parameters on the flow field have been studied and the results are presented graphically and discussed quantitatively.

2. Formulation of the problem

We consider a two dimensional unsteady free convective flow of a viscous incompressible fluid between two vertical parallel porous plates placed at a distance *h* apart in the slip flow regime in presence of variable suction and radiative heat source. Let the medium between the plates be filed with a porous material of permeability

$$K'(t') = K'_0\left(1 + \varepsilon B e^{-\omega' t'}\right), \tag{1}$$

and a time dependent suction

$$v'(t') = -v'_0\left(1 + \varepsilon A e^{-\omega' t'}\right) \tag{2}$$

be applied at the plate y=0 and the same injection velocity be applied at the pate y=1. We choose x-axis along the plate and y-axis normal to it. Under the above conditions the equations governing the flow are:

Momentum equation:

$$\frac{\partial u'}{\partial t'} - v'_0\left(1 + \varepsilon A e^{-\omega' t'}\right)\frac{\partial u'}{\partial y'} = g\beta\left(T' - T'_h\right) + g\beta^*\left(C' - C'_h\right) + \nu\frac{\partial^2 u'}{\partial y'^2} - \frac{\nu}{K'(t')}u', \tag{3}$$

Energy equation:

$$\frac{\partial T'}{\partial t'} - v_0'\left(1+\varepsilon A e^{-\omega' t'}\right)\frac{\partial T'}{\partial y'} = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y'}, \tag{4}$$

Concentration equation:

$$\frac{\partial C'}{\partial t'} - v_0'\left(1+\varepsilon A e^{-\omega' t'}\right)\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2}. \tag{5}$$

The boundary conditions of the problem are:

$$u' - U_1 = L_1\frac{\partial u'}{\partial y'}, \frac{\partial T'}{\partial y'} = -\frac{q}{k}, \frac{\partial C'}{\partial y'} = -\frac{m}{D} \text{ at } y' = 0,$$

$$u' - U_2 = L_2\frac{\partial u'}{\partial y'}, T' = T_h', C' = C_h' \qquad at\ \ y' = h, \tag{6}$$

where $L_1 = \frac{(2-\mu_1)}{\mu_1}L$, L being the mean free path and □$_1$, the Maxwell's reflection coefficient.

The radiative heat flux q_r is given by

$$\frac{\partial q_r}{\partial y'} = 4\left(T' - T_h'\right)I \ , \tag{7}$$

where $I = \int k_{\lambda w}\frac{\partial e_{b\lambda}}{\partial T}d\lambda$, $k_{\lambda w}$ is the absorption coefficient at the wall, $e_{b\lambda}$ is Planck's function and λ is the frequency, u' is the velocity, T' is the temperature, C' is the concentration, β is the volumetric coefficient of expansion for heat transfer, β^* is the volumetric coefficient of expansion for mass transfer, k is the thermal conductivity, ν is the kinematic viscosity, C_p is the specific heat at constant pressure, D is the molecular diffusivity, g is the acceleration due to gravity, A and B are the real positive constants, t is the time and ε is a small positive number such that $\varepsilon A \ll 1$ and $\varepsilon B \ll 1$.

Introducing the following non-dimensional variables and parameters,

$$y = \frac{y' v_0'}{\nu}, t = \frac{t' v_0'^2}{\nu}, \omega = \frac{\nu\omega'}{v_0'^2}, u = \frac{u'}{v_0'}, \nu = \frac{\eta_0}{\rho}, K_p = \frac{v_0^2 K_0'}{\nu^2},\ \ \theta = \frac{k v_0'\left(T' - T_h'\right)}{\nu q'}, C = \frac{D v_0'\left(C' - C_h'\right)}{\nu m},$$

$$P_r = \frac{\rho\nu C_p}{k}, G_r = \frac{\nu^2 g\beta q}{k v_0'^4}, G_c = \frac{\nu^2 g\beta^* m}{D v_0'^4}, F = \frac{4\nu I}{\rho C_p v_0'^2},\ S_c = \frac{\nu}{D},\ \alpha_1 = \frac{U_1}{v_0},\ \alpha_2 = \frac{U_2}{v_0},\ R = \frac{v_0' h}{\nu},$$

$$h_1 = \frac{L_1 v_0'}{\nu},\ \ h_2 = \frac{L_2 v_0'}{\nu} \tag{8}$$

in Equations (3)-(5), we get the following non-dimensional equations

$$\frac{\partial u}{\partial t} - \left(1+\varepsilon A e^{-\omega t}\right)\frac{\partial u}{\partial y} = G_r\theta + G_c C + \frac{\partial^2 u}{\partial y^2} - \frac{u}{K_p\left(1+\varepsilon B e^{-\omega t}\right)}, \tag{9}$$

$$\frac{\partial\theta}{\partial t}-\left(1+\varepsilon Ae^{-\omega t}\right)\frac{\partial\theta}{\partial y}=\frac{1}{P_r}\frac{\partial^2\theta}{\partial y}-F\theta\ , \tag{10}$$

$$\frac{\partial C}{\partial t}-\left(1+\varepsilon Ae^{-\omega t}\right)\frac{\partial C}{\partial y}=\frac{1}{S_c}\frac{\partial^2 C}{\partial y^2}\ , \tag{11}$$

where G_r and G_c respectively are the Grashof number for heat and mass transfer, K_p is the permeability parameter, P_r is the Prandtl number, F is the radiation parameter, S_c is the Schmidt number, α_1 and α_2 are the suction parameters and h_1 and h_2 are the slip flow parameters.

The corresponding boundary conditions now reduce to:

$$u=\alpha_1+h_1\frac{\partial u}{\partial y},\ \ \frac{\partial\theta}{\partial y}=-1,\ \ \frac{\partial C'}{\partial y'}=-1\ \ at\ \ y=0\ \ ,$$

$$u=\alpha_2+\frac{\partial u}{\partial y},\ \ \theta=0,\ \ C=0\ \ \ \ at\ \ y=h\ . \tag{12}$$

3. Method of Solution

We now wish to seek the solutions for Equations (9)-(11) under boundary condition (12) for a particular case R=1, which is valid for an incompressible fluid. In order to solve Equations (9)-(11), we assume

$$u\,(y,\,t)=u_0\,(y)+\varepsilon u_1\,(y)\,e^{-\omega t}+O\,(\varepsilon^2), \tag{13}$$

$$\theta\,(y,\,t)=\theta_0\,(y)+\varepsilon\theta_1\,(y)\,e^{-\omega t}+O\,(\varepsilon^2), \tag{14}$$

$$C(y,\,t)=C_0\,(y)+\varepsilon\,C_1\,(y)\,e^{-\omega t}+O\,(\varepsilon^2). \tag{15}$$

Using Equations (13)-(15) in Equations (9)-(11), we get the following zeroth order and first order equations:

Zeroth order:

$$-\frac{\partial u_0}{\partial y}=G_r\theta_0+G_cC_0+\frac{\partial^2u_0}{\partial y^2}-\frac{u_0}{K_p}\ , \tag{16}$$

$$-\frac{\partial\theta_0}{\partial y}=\frac{1}{P_r}\frac{\partial^2\theta_0}{\partial y}-F\theta_0\,, \tag{17}$$

$$-\frac{\partial C_0}{\partial y}=\frac{1}{S_c}\frac{\partial^2C_0}{\partial y^2}\,, \tag{18}$$

First order:

$$-\omega u_1-A\frac{\partial u_0}{\partial y}-\frac{\partial u_1}{\partial y}=G_r\theta_1+G_cC_1+\frac{\partial^2u_1}{\partial y^2}-\frac{u_1}{K_p}+\frac{Bu_0}{K_p}\ \ , \tag{19}$$

$$-\omega\theta_1-A\frac{\partial\theta_0}{\partial y}-\frac{\partial\theta_1}{\partial y}=\frac{1}{P_r}\frac{\partial^2\theta_1}{\partial y}-F\theta_1\,, \tag{20}$$

$$-\omega C_1 - A\frac{\partial C_0}{\partial y} - \frac{\partial C_1}{\partial y} = \frac{1}{S_c}\frac{\partial^2 C_1}{\partial y^2}. \tag{21}$$

The corresponding boundary conditions are

$$u_0 = \alpha_1 + h_1\frac{\partial u_0}{\partial y}, u_1 = h_1\frac{\partial u_1}{\partial y}, \ \frac{\partial \theta_0}{\partial y} = -1, \ \frac{\partial \theta_1}{\partial y} = 0, \ \frac{\partial C_0}{\partial y} = -1, \ \frac{\partial C_1}{\partial y} = 0 \quad at \ \ y = 0 \ ,$$

$$u_0 = \alpha_2 + h_2\frac{\partial u_0}{\partial y}, u_1 = h_2\frac{\partial u_1}{\partial y}, \ \theta_0 = 0, \ \theta_1 = 0, \ C_0 = 0, \ C_1 = 0 \quad at \ \ y = 1. \tag{22}$$

The solutions of Equations (16)-(21) under boundary condition (22) are given by

$$u(y,t) = \left(B_1 e^{m_1 y} + B_2 e^{m_2 y} - B_8 e^{\lambda_3 y} - B_9 e^{\lambda_4 y} - B_{10} e^{-S_c y} + B_{11}\right) + \varepsilon e^{-\omega t}\left(B_3 e^{m_3 y} + B_4 e^{m_4 y} - B_{12} e^{\lambda_1 y} - B_{13} e^{\lambda_2 y} + D_0 e^{\lambda_3 y} + D_1 e^{\lambda_4 y} - D_2 e^{\lambda_5 y} - D_3 e^{\lambda_6 y} - D_4 e^{m_1 y} - D_5 e^{m_2 y} - D_6 e^{-S_c y}\right), \tag{23}$$

$$\theta(y,t) = \left(A_2 e^{\lambda_3 y} + A_3 e^{\lambda_4 y}\right) + \varepsilon e^{-\omega t}\left(A_4 e^{\lambda_5 y} + B_0 e^{\lambda_6 y} - B_6 e^{\lambda_3 y} - B_7 e^{\lambda_4 y}\right), \tag{24}$$

$$C(y,t) = \frac{1}{S_c}\left(e^{-S_c y} + e^{S_c}\right) + \varepsilon e^{-\omega t}\left(A_0 e^{\lambda_1 y} + A_1 e^{\lambda_2 y} + B_5 e^{-S_c y}\right). \tag{25}$$

The wall shear stress i.e. the skin friction at the wall is given by

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} = \left(\frac{\partial u_0}{\partial y}\right)_{y=0} + \varepsilon e^{-\omega t}\left(\frac{\partial u_1}{\partial y}\right)_{y=0}. \tag{26}$$

Using Equation (23) in Equation (26), it is given by

$$\tau = \left(m_1 B_1 + m_2 B_2 - \lambda_3 B_8 - \lambda_4 B_9 + S_c B_{10}\right) + \varepsilon e^{-\omega t}\left(m_3 B_3 + m_4 B_4 - \lambda_1 B_{12} - \lambda_2 B_{13} + \lambda_3 D_0 + \lambda_4 D_1 - \lambda_5 D_2 - \lambda_6 D_3 - m_1 D_4 - m_2 D_5 + S_c D_6\right). \tag{27}$$

The rate of heat transfer i.e. the heat flux at the wall is given by

$$N_u = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} = \left(\frac{\partial \theta_0}{\partial y}\right)_{y=0} + \varepsilon e^{-\omega t}\left(\frac{\partial \theta_1}{\partial y}\right)_{y=0}. \tag{28}$$

Using Equation (24) in Equation (28), it is given by

$$N_u = \left(\lambda_3 A_2 + \lambda_4 A_3\right) + \varepsilon e^{-\omega t}\left(\lambda_5 A_4 + \lambda_6 B_0 - \lambda_3 B_6 - \lambda_4 B_7\right), \tag{29}$$

where

$$\lambda_1 = -\frac{S_c}{2} + \frac{1}{2}\sqrt{S_c^2 - 4\omega S_c}, \ \lambda_2 = -\frac{S_c}{2} - \frac{1}{2}\sqrt{S_c^2 - 4\omega S_c}, \ \lambda_3 = -\frac{P_r}{2} + \frac{1}{2}\sqrt{P_r^2 + 4P_r F},$$

$$\lambda_4 = -\frac{P_r}{2} - \frac{1}{2}\sqrt{P_r^2 + 4P_r F}, \ \lambda_5 = -\frac{P_r}{2} + \frac{1}{2}\sqrt{P_r^2 - 4P_r(\omega - F)}, \ \lambda_6 = -\frac{P_r}{2} - \frac{1}{2}\sqrt{P_r^2 - 4P_r(\omega - F)},$$

$$m_1 = -\frac{1}{2}+\frac{1}{2}\sqrt{1+\frac{4}{K_p}}\,,\ m_2 = -\frac{1}{2}-\frac{1}{2}\sqrt{1+\frac{4}{K_p}}\,,\ m_3 = -\frac{1}{2}+\frac{1}{2}\sqrt{1+4\left(\frac{1}{K_p}-\omega\right)}\,,\ m_4 = -\frac{1}{2}-\frac{1}{2}\sqrt{1+4\left(\frac{1}{K_p}-\omega\right)}\,,$$

$$A_0 = \frac{\left(B_5 S_c e^{\lambda_2} + B_5\lambda_2 e^{-S_c}\right)}{\left(\lambda_1 e^{\lambda_2} - \lambda_2 e^{\lambda_1}\right)}\,,\ A_1 = \frac{\left(B_5 S_c - A_0\lambda_1\right)}{\lambda_2}\,,\ A_2 = \frac{e^{\lambda_4}}{\left(\lambda_4 e^{\lambda_3} - \lambda_3 e^{\lambda_4}\right)}\,,\ A_3 = -\frac{A_2 e^{\lambda_3}}{e^{\lambda_4}}\,,$$

$$A_4 = \frac{e^{\lambda_6}\left(B_6\lambda_3 + B_7\lambda_4\right) - \lambda_6\left(B_6 e^{\lambda_3} + B_7 e^{\lambda_4}\right)}{\left(\lambda_5 e^{\lambda_6} - \lambda_6 e^{\lambda_5}\right)}\,,\ B_0 = \frac{B_6\lambda_3 + B_7\lambda_4 - A_4\lambda_5}{\lambda_6}\,,\ B_1 = \frac{E_3E_5 - E_2E_6}{E_1E_5 - E_2E_4}\,,$$

$$B_2 = \frac{E_3 - B_1E_1}{E_2}\,,\ B_3 = \frac{E_9E_{11} - E_8E_{12}}{E_7E_{11} - E_8E_{10}}\,,\ B_4 = \frac{E_9 - B_3E_7}{E_8}\,,\ B_5 = -\frac{A}{\omega S_c}\,,\ B_6 = \frac{AP_r A_2\lambda_3}{\lambda_3^2 + \lambda_3 P_r + P_r\left(\omega - F\right)}\,,$$

$$B_7 = \frac{AP_r A_3\lambda_4}{\lambda_4^2 + \lambda_4 P_r + P_r\left(\omega - F\right)}\,,\ B_8 = \frac{G_r A_2}{\lambda_3^2 + \lambda_3 - \frac{1}{K_p}}\,,\ B_9 = \frac{G_r A_3}{\lambda_4^2 + \lambda_4 - \frac{1}{K_p}}\,,\ B_{10} = \frac{G_c}{S_c\left(S_c^2 - S_c - \frac{1}{K_p}\right)}\,,$$

$$B_{11} = \frac{G_c K_p e^{-S_c}}{S_c}\,,\quad B_{12} = \frac{G_c A_0}{\lambda_1^2 + \lambda_1 - \left(\frac{1}{K_p} - \omega\right)}\,,\ B_{13} = \frac{G_c A_1}{\lambda_2^2 + \lambda_2 - \left(\frac{1}{K_p} - \omega\right)}\,,\ D_0 = \frac{G_r B_6 + AB_8\lambda_3 + \frac{BB_8}{K_p}}{\lambda_3^2 + \lambda_3 - \left(\frac{1}{K_p} - \omega\right)}\,,$$

$$D_1 = \frac{G_r B_7 + AB_9\lambda_4 + \frac{BB_9}{K_p}}{\lambda_4^2 + \lambda_4 - \left(\frac{1}{K_p} - \omega\right)}\,,\ D_2 = \frac{G_r A_4}{\lambda_5^2 + \lambda_5 - \left(\frac{1}{K_p} - \omega\right)}\,,\ D_3 = \frac{G_r B_0}{\lambda_6^2 + \lambda_6 - \left(\frac{1}{K_p} - \omega\right)}\,,$$

$$D_4 = \frac{AB_1 m_1 + \frac{BB_1}{K_p}}{m_1^2 + m_1 - \left(\frac{1}{K_p} - \omega\right)}\,,\ D_5 = \frac{AB_2 m_2 + \frac{BB_2}{K_p}}{m_2^2 + m_2 - \left(\frac{1}{K_p} - \omega\right)}\,,\ D_6 = \frac{\frac{BB_{10}}{K_p} - AB_{10}S_c - G_c B_5}{S_c^2 - S_c - \left(\frac{1}{K_p} - \omega\right)}\,,\ D_7 = \frac{BB_{11}}{K_p\left(\frac{1}{K_p} - \omega\right)}\,,$$

$$E_1 = 1 - h_1 m_1\,,\ E_2 = 1 - h_1 m_2\,,\ E_3 = \alpha_1 + B_8\left(1 - h_1\lambda_3\right) + B_9\left(1 - h_1\lambda_4\right) + B_{10}\left(1 + h_1 S_c\right) - B_{11}\,,$$
$$E_4 = e^{m1}\left(1 - h_2 m_1\right),\ E_5 = e^{m2}\left(1 - h_2 m_2\right),$$

$$E_6 = \alpha_2 + B_8 e^{\lambda_5}\left(1 - h_2\lambda_3\right) + B_9 e^{\lambda_4}\left(1 - h_2\lambda_4\right) + B_{10} e^{-S_c}\left(1 - h_2 S_c\right) - B_{11}\,,\ E_7 = 1 - h_1 m_3\,,\ E_8 = 1 - h_1 m_4\,,$$

$$E_9 = B_{12}\left(1 - h_1\lambda_1\right) + B_{13}\left(1 - h_1\lambda_2\right) - D_0\left(1 - h_1\lambda_3\right) - D_1\left(1 - h_1\lambda_4\right) + D_2\left(1 - h_1\lambda_5\right)$$
$$+ D_3\left(1 - h_1\lambda_6\right) + D_4\left(1 - h_1 m_1\right) + D_5\left(1 - h_1 m_2\right) + D_6\left(1 + h_1 S_c\right) + D_7\,,\ E_{10} = e^{m3}\left(1 - h_2 m_3\right),$$
$$E_{11} = e^{m4}\left(1 - h_2 m_4\right),$$
$$E_{12} = B_{12} e^{\lambda_1}\left(1 - h_2\lambda_1\right) + B_{13} e^{\lambda_2}\left(1 - h_2\lambda_2\right) - D_0 e^{\lambda_3}\left(1 - h_2\lambda_3\right) - D_1 e^{\lambda_4}\left(1 - h_2\lambda_4\right) + D_2 e^{\lambda_5}\left(1 - h_2\lambda_5\right)$$

$$+ D_3 e^{\lambda_6}\left(1 - h_2\lambda_6\right) + D_4 e^{m1}\left(1 - h_2 m_1\right) + D_5 e^{m2}\left(1 - h_2 m_2\right) + D_6 e^{-S_c}\left(1 + h_2 S_c\right) + D_7\,. \qquad (30)$$

4. Discussions and Results

This paper discusses the effect of variable suction and mass transfer on unsteady free convective couette flow of a viscous incompressible fluid in the slip flow regime in presence of variable suction and radiative heat source. The governing equations of the flow field are solved for the velocity, temperature, concentration distribution, skin friction and the rate of heat transfer and the effects of the various flow parameters on the flow field have been studied and the results are presented graphically and discussed quantitatively with the aid of velocity profiles 1-9, temperature profiles 10-11 and concentration distribution shown in Figure 12.

4.1. Velocity field

The velocity of the flow field varies to a great extent with the variation of the flow parameters. The main factors affecting the velocity of the flow field are suction parameters α_1, α_2, Grashof number for heat and mass transfer G_r, G_c; slip flow parameters h_1, h_2, radiation parameter F, permeability parameter K_p and Schmidt number S_c. The effects of these parameters on the velocity of the flow field are analyzed in Figures 1-9.

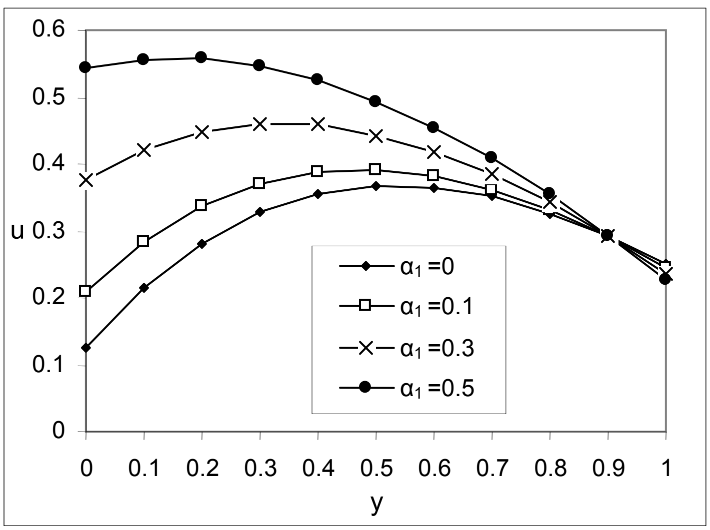

Figure 1: Velocity profiles against y for different values of α_1 with P_r=0.71, ω=0.1, t=0.1, ∈=0.02, G_c= 2, G_r=2, S_c=0.6, K_p=1, F=0.1, A=0.5, B=0.5, h_1=0.1, h_2=0.1 and α_2=0.2

Figures 1 and 2 discuss the effect of suction parameters α_1 and α_2 respectively on the flow field. Analyzing the curves of both the figures, it is observed that both the parameters have accelerating effect on the velocity of the flow field at all points. Figures 3 and 4 respectively depict the effect of Grashof number for heat transfer G_r and mass transfer G_c on the flow field. The Grashof number for heat transfer is found to retard the velocity of the flow field at all points. The effect of a growing Grashof number for mass transfer is to accelerate the magnitude of velocity of the flow field at all points. The effects of slip flow parameters h_1, h_2; on the velocity of the flow field are shown in Figures 5 and 6 respectively. Comparing the curves of both the figures, it is observed that both the parameters enhance the velocity of the flow field at all points in a different manner. The parameter h_1 tends to converge the velocity profiles at a point and there after the effect reverses while the parameter h_2 tends to diverge the velocity profiles from a point.

Figure 7 shows the effect of radiation parameter F on the flow field. A growing radiation parameter is found to accelerate the velocity of the flow field at all points. In Figure 8, we present the effect of permeability parameter K_p on the velocity field .The effect of increasing permeability parameter is to accelerate the velocity of the flow field at all points. Figure 9 elucidates the effect of Schmidt number S_c on the velocity field. The effect of growing S_c is to decrease the velocity at all points of the flow field.

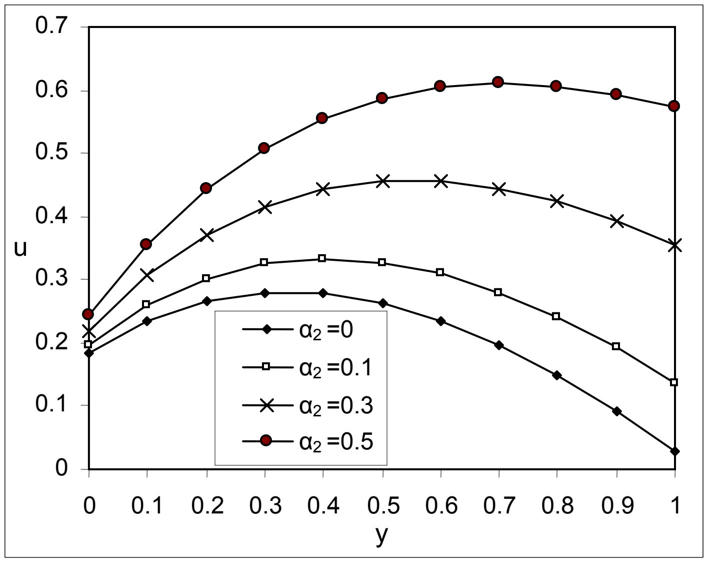

Figure 2: Velocity profiles against y for different values of α_2 with P_r=0.71, ω=0.1, t=0.1, $\in$=0.02, G_c= 2, G_r=2, S_c=0.6, K_p=1, F=0.1, A=0.5, B=0.5, h_1=0.1, h_2=0.1 and α_1=0.1

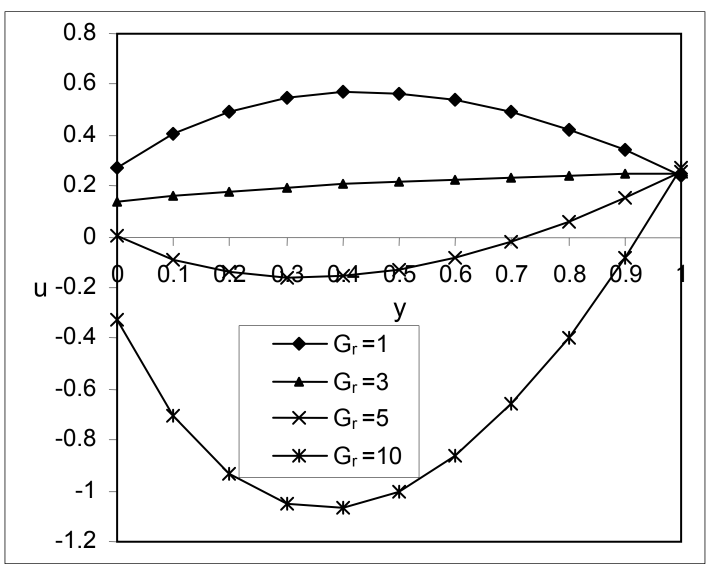

Figure 3: Velocity profiles against y for different values of G_r□ with P_r=0.71, ω=0.1, t=0.1, ∈=0.02, G_c= 2, S_c=0.6, K_p=1, F=0.1, A=0.5, B=0.5, h_1=0.1, h_2=0.1, α_1=0.1 and α_2=0.2

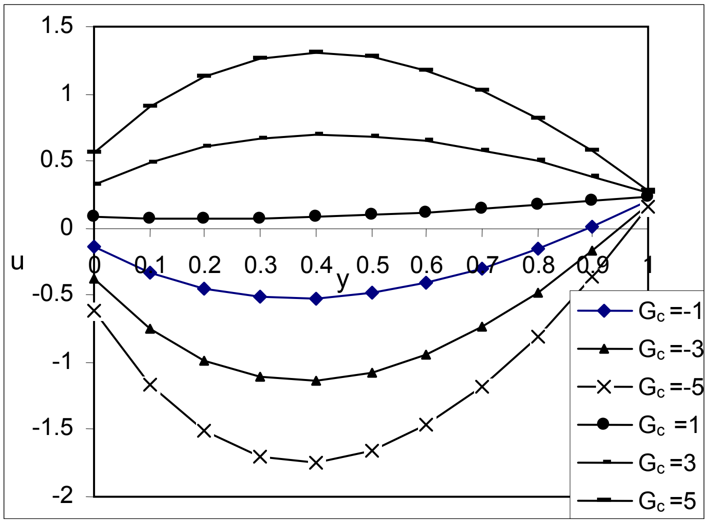

Figure 4: Velocity profiles against y for different values of □ G_c with P_r=0.71, ω=0.1, t=0.1, ∈=0.02, G_r=2, S_c=0.6, K_p=1, F=0.1, A=0.5, B=0.5, h_1=0.1, h_2=0.1, α_1=0.1 and α_2=0.2

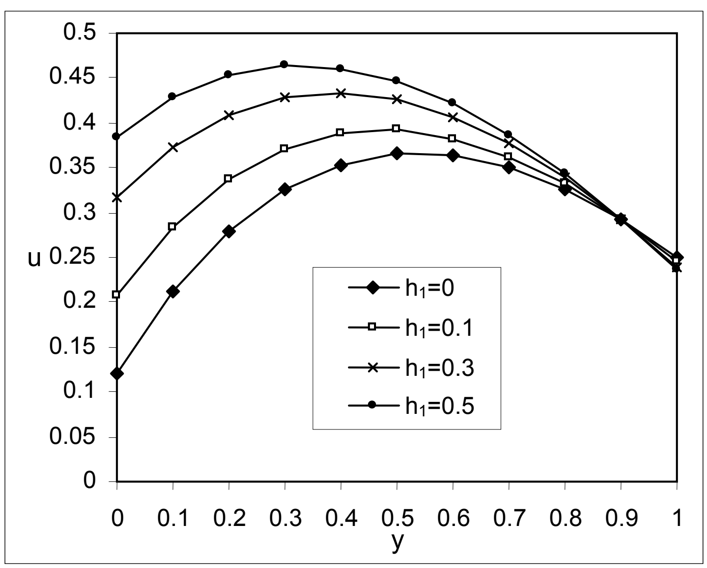

Figure 5: Velocity profiles against y for different values of h□□ with P_r=0.71, ω=0.1, t=0.1, ∈=0.02, G_c= 2, G_r=2, S_c=0.6, K_p=1, F=0.1, A=0.5, B=0.5, h_2=0.1, α_1=0.1 and α_2=0.2

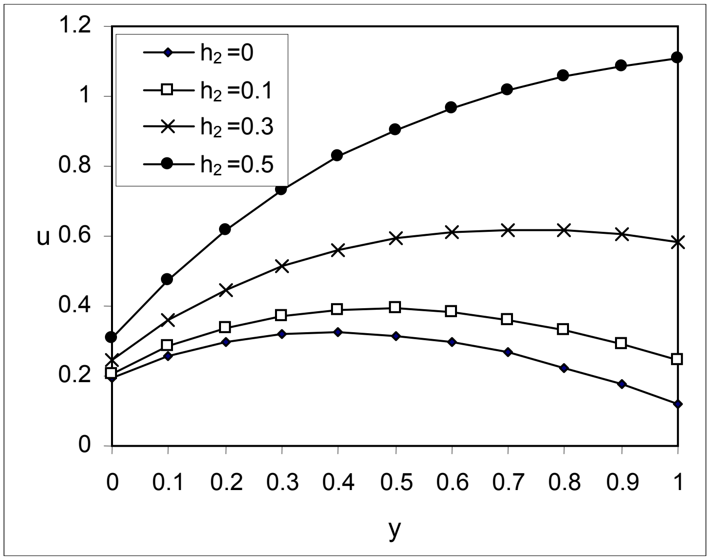

Figure 6: Velocity profiles against y for different values of h_2 with P_r=0.71, ω=0.1, t=0.1, ∈=0.02, G_c= 2, G_r=2, S_c=0.6, K_p=1, F=0.1, A=0.5, B=0.5, h_1=0.1, α_1=0.1 and α_2=0.2

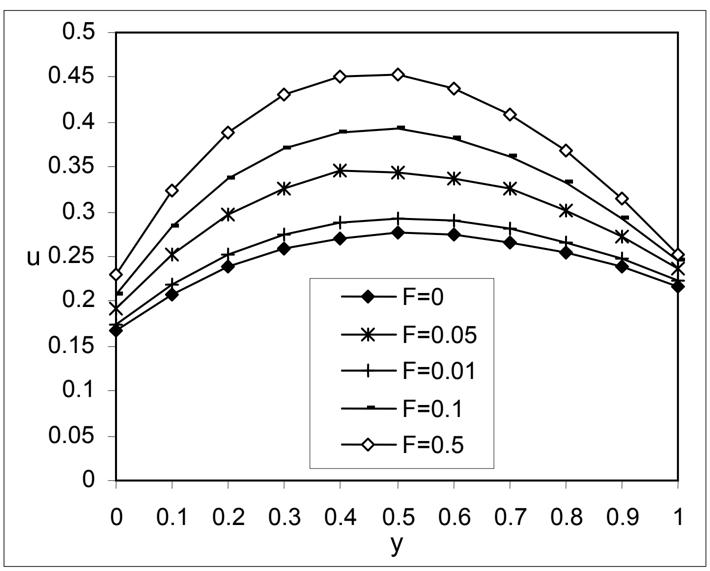

Figure 7: Velocity profiles against y for different values of F with P_r=0.71, ω=0.1, t=0.1, ∈=0.02, G_c= 2, G_r=2, S_c=0.6, K_p=1, A=0.5, B=0.5, h_1=0.1, h_2=0.1, α_1=0.1 and α_2=0.2

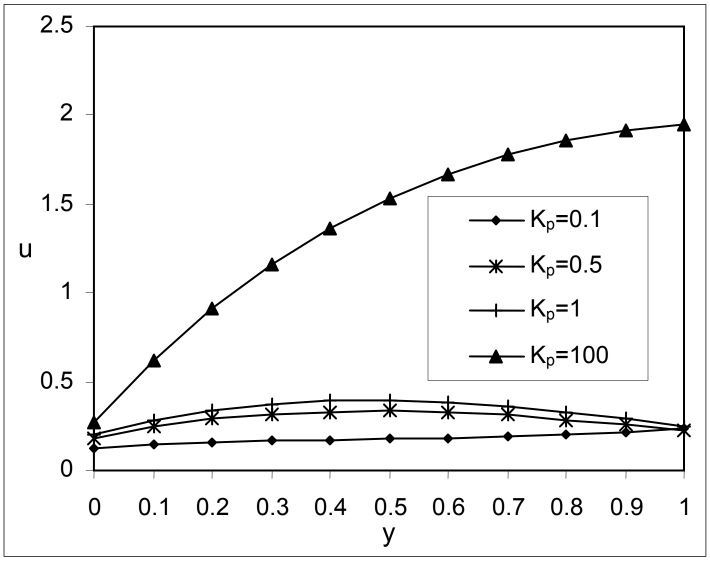

Figure 8: Velocity profiles against y for different values of K_p with P_r=0.71, ω=0.1, t=0.1, ∈=0.02, G_c= 2, G_r=2, S_c=0.6, F=0.1, A=0.5, B=0.5, h_1=0.1, h_2=0.1, α_1=0.1 and α_2=0.2

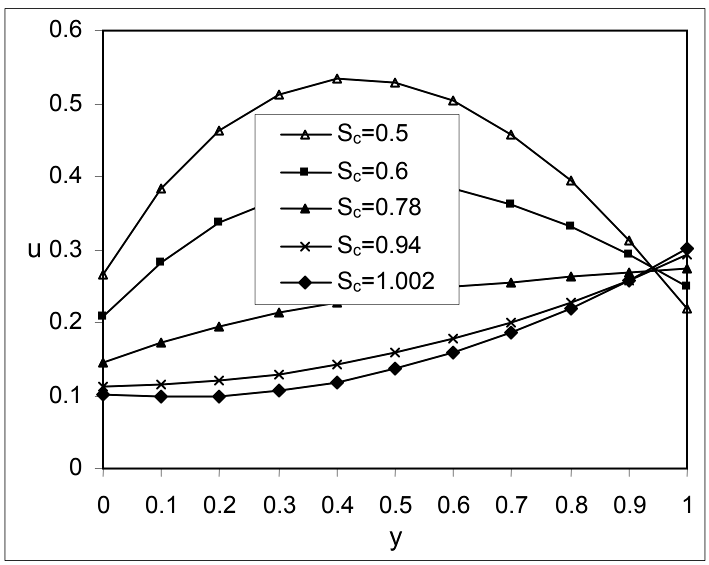

Figure 9: Velocity profiles against y for different values of S_c with P_r=0.71, ω=0.1, t=0.1, ∈=0.02, G_c= 2, G_r=2, K_p=1, F=0.1, A=0.5, B=0.5, h_1=0.1, h_2=0.1, α_1=0.1 and α_2=0.2

4.2. Temperature field

The temperature field suffers a major change in magnitude due to the variation of Prandtl number P_r and radiation parameter *F*. The effects of these parameters on the temperature field are discussed in Figures 10-11. Both the parameters retard the magnitude of temperature of the flow field at all points.

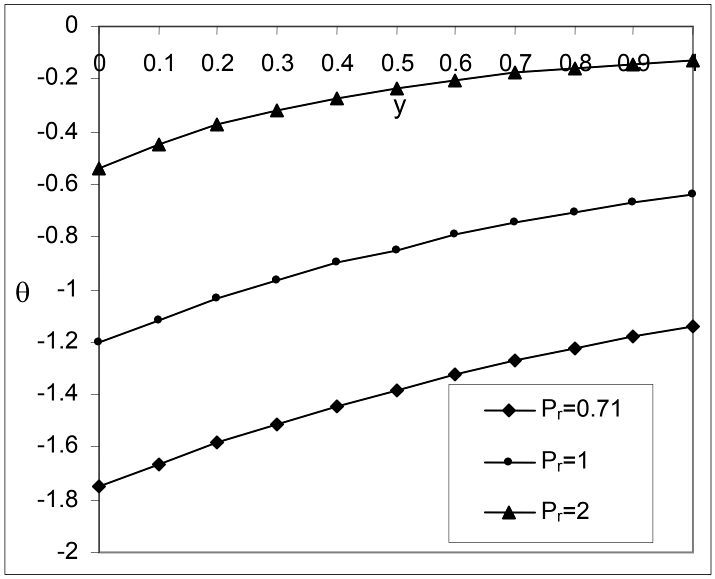

Figure 10: Temperature profiles against y for different values of □ P_r with ω=0.1, t=0.1, ∈=0.02, F=0.1 and A=0.5

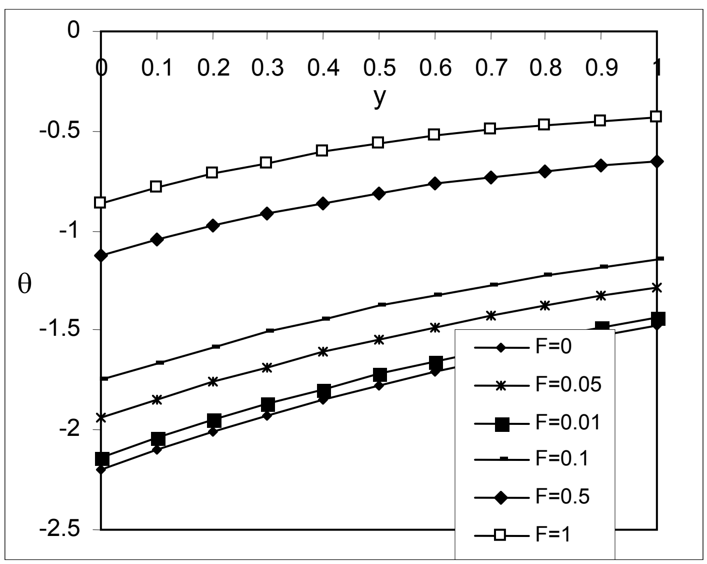

Figure 11: Temperature profiles against y for different values of F□with P_r=0.71, ω=0.1, t=0.1, ∈=0.02 and A=0.5

4.3. Concentration distribution

The presence of foreign mass in the flow field greatly affects the concentration boundary layer thickness of the flow field at all points. The factor responsible for this variation is Schmidt number S_c. In Fig.12, keeping other parameters of the flow field constant, the Schmidt number S_c is varied in steps and its effect on the concentration boundary layer of the flow field is studied. It is observed that a growing Schmidt number reduces the concentration boundary layer of the flow field at all points.

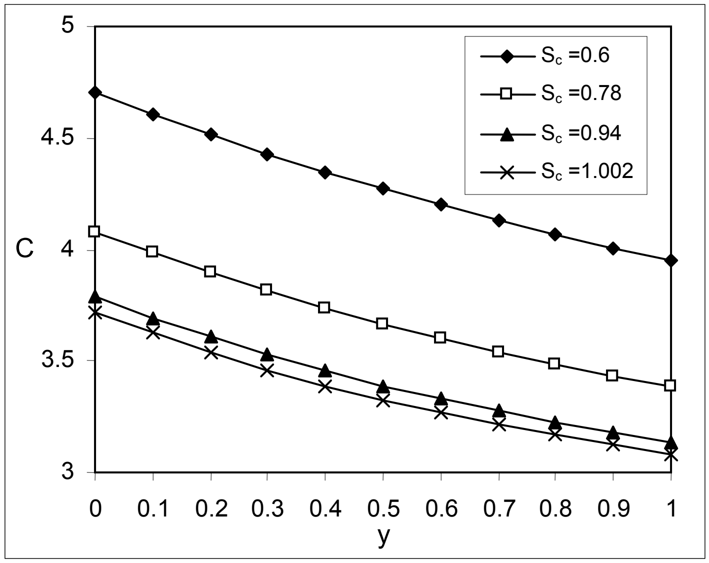

Figure 12: Concentration profiles against y for different values of S_c with ω=0.1, t=0.1, ∈=0.02 and A=0.5

5. Conclusions

We present below some of the important features of the flow field due to the variation of the flow parameters.

1. Both the suction parameters α_1 and α_2 are observed to have an accelerating effect on the velocity of the flow field at all points.

2. The Grashof number for heat transfer G_r is found to retard the velocity of the flow field at all points and the effect of a growing Grashof number for mass transfer G_c is to accelerate the magnitude of velocity of the flow field at all points.

3. The slip flow parameters h_1 and h_2 enhance the velocity of the flow field at all points in a different manner. The parameter h_1 tends to converge the velocity profiles at a point and there after the effect reverses while the parameter h_2 tends to diverge the velocity profiles from a point.

4. A growing radiation parameter F is found to accelerate the velocity of the flow field at all points.

5. The effect of increasing permeability parameter K_p is to accelerate the velocity of the flow field at all points.

6. The Prandtl number P_r and the radiation parameter F retard the magnitude of temperature of the flow field at all points.

7. A growing Schmidt number reduces the concentration boundary layer thickness of the flow field at all points.

References

[1] T. Govindarajulu, Couette flow in hydromagnetics with time-dependent suction, Ind. J. Pure Appl. Math., 9(12), 1978, 1359-1364.

[2] M. A. Sattar and M. M. Alam, Thermal diffusion effect as well as transpiration effect on MHD free convection and mass transfer flow past an accelerated vertical porous plate, Ind. J. Pure Appl. Math., 25(6), 1994, 679-688.

[3] M. A. Sattar and H. Kalim, Unsteady free convection interaction with thermal radiation in a boundary layer flow past a vertical porous plate, J. Math. Phys. Sci., 30, 1996, 25-37.

[4] H. A. Attia and N. A. Kotb, MHD flow between two parallel plates with heat transfer, Acta Mech., 117, 1996, 215-220.

[5] A. Raptis and C. Perdikis, Radiation and free convection flow past a moving plate, Appl. Mech. Engng., 4(4), 1999, 817-821.

[6] P. Nagaraju, A. J. Chamkha H. S. Takhar and B. C. Chandrasekhara, Simultaneous radiative and convective heat transfer in a variable porosity medium, J. Heat Mass Trans., 37(2-3), 2001, 243-250.

[7] S. Sreekanth, A. S. Nagrajan, S. Venkata Ramana,Transient MHD free convention flow of an incompressible viscous dissipative fluid, Ind. J. Pure Appl. Math., 32(7), 2001, 1051-1058.

[8] A. J. Chamkha, MHD flow of a uniformly stretched vertical permeable surface in the presence of heat generation /absorption and chemical reaction, Int. Commun. Heat Mass Trans., 30, 2003, 413-422.

[9] C. I. Cookey, A. Ogulu and V. M. Omubo-Pepple, 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, Int. J. Heat Mass Trans., 46, 2003, 2305-2311.

[10] M. Y. Gokhale and F. M. Alsamman, Effects of mass transfer on the transient free convection flow of a dissipative fluid along a semi-infinite vertical plate with constant heat flux, Int. J. Heat Mass Transfer, 46, 2003, 999-1011.

[11] P. Singh and C. B. Gupta, MHD free convective flow of viscous fluid through a porous medium bounded by an oscillating porous plate in slip flow regime with mass transfer, Ind. J. Theo. Phys., 53(2), 2005, 111-120.

[12] S. S. Das, S. K. Sahoo and G. C. Dash, Numerical solution of mass transfer effects on unsteady flow past an accelerated vertical porous plate with suction, Bull. Malays. Math. Sci. Soc., 29(1), 2006, 33-42.

[13] F. S. Ibrahim, A. M. Elaiw and A. A. Bakr, Effect of the chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate with heat source and suction, Commun. Non- linear Sci. Numer. Simul., 13, 2008, 1056-1066.

[14] S. S. Das, Effect of suction and injection on MHD three dimensional couette flow and heat transfer through a porous medium, J. Naval Architecture Marine Engng., 6(1), 2009, 41-51.

[15] S. S. Das, U. K. Tripathy and J. K. Das, Hydromagnetic convective flow past a vertical porous plate through a porous medium with suction and heat source, Int. J. Ener. Environ., 1(3), 2010, 467-478.