Proceedings of the
International Conference on Mechanical Engineering 2009
(ICME2009) 26- 28 December 2009, Dhaka, Bangladesh

ICME09-FM-34

MHD NATURAL CONVECTION FLOW FROM A POROUS VERTICAL PLATE

Amena Ferdousi[1] and M. A. Alim[2]

[1]Department of Electronics and Electrical Engineering, Eastern University, Bangladesh
[2]Department of Mathematics, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh.

ABSTRACT
An analysis of MHD natural convection flow from a porous vertical plate is carried out by using finite difference method together with Keller-Box scheme. This method is applied successfully to predict the surface shear stress , the rate of heat transfer, velocity and temperature profiles . The governing boundary layer equations are first transformed into a non dimensional form and the resulting non linear system of partial differential equations are then solved numerically. The numerical results of the surface shear stress in terms of skin friction coefficient and the rate of heat transfer in terms of local Nusselt number, velocity as well as temperature profiles are shown graphically and tabular form for a selection of parameters set of consisting of magnetohydrodynamic parameter M, Prandtl number Pr. MHD affects the boundary layer flow, so velocity decreases and temperature increase for this the skin friction coefficient and the rate of heat transfer decreases. Increasing value of MHD serves to thin the boundary layer.

Keywords: porous plate, natural convection, magnetohydrodynamic.

1. INTRODUCTION

The study of the flow of electrically conducting fluid in presence of magnetic field is also important from the technical point of view and such types of problems have received much attention by many researchers. The specific problem selected for study is the flow and heat transfer in an electrically conducting fluid adjacent to the surface. The interaction of the magnetic field and the moving electric charge carried by the flowing fluid induces a force, which tends to oppose the fluid motion. And near the leading edge the velocity is very small so that the magnetic force, which is proportional to the magnitude of the longitudinal velocity and acts in the opposite direction, is also very small. Consequently the influence of the magnetic field on the boundary layer is exerted only through induced forces within the boundary layer itself , with no additional effects arising from the free stream pressure gradient . MHD was originally applied to astrophysical and geophysical problems but more recently to the problem of fusion power, where the application is the creation and containment of hot plasmas by electromagnetic forces, since material wall be destroyed. Astrophysical problems include solar structure especially in the outer layers, the solar wind bathing the earth and other planets and interstellar magnetic fields.In the presence of MHD natural convection boundary layer flow from a porous vertical plate of a steady two dimensional viscous incompressible fluid has been investigated. In the present work following assumptions are made:

- Variations in fluid properties are limited only to those density variations which affect the buoyancy terms
- Viscous dissipation effects are negligible and
- The radiative heat flux in the x-direction is considered negligible in comparison with that in the y direction, where the physical coordinates (u, v) are velocity components along the (x, y) axes.

Merkin [1] studied free convection with blowing and suction. Lin and Yu [2] studied free convection on a horizontal plate with blowing and suction. Singh [3] concluded onMHD free-convection flow in the Stokes problem for a porous vertical plate. Chowdhury and Islam [4] considered MHD free convection flow of visco-elastic fluid past an infinite vertical porous plate. Hossain and Takhar [5] studied radiation effect on mixed convection along a vertical plate with uniform surface temperature. Hayat et al [6] pursued the influence of thermal radiation on MHD flow of a second grade fluid. Alam et al. [7] investigated numerical study of the combined free-forced convection and mass transfer flow past a vertical porous plate in a porous medium with heat generation and thermal diffusion. Hossain [8] computed effect of Hall current on unsteady hydromagnetic free convection flow near an infinite vertical porous plate. Hossain et al. [9] studied the effect of radiation on free convection flow from a porous vertical plate. They [9] analyzed a full numerical solution and found an increase in Radiation parameter R_d causes to thin the boundary layer and an increase in surface temperature parameter causes to thicken the boundary layer. The presence of suction ensures that its ultimate fate if vertically increased is a layer of constant thickness. Duwairi and Damseh [10] studied magnetohydrodynamic natural convection heat transfer from radiate vertical porous surfaces. None of the aforementioned studies considered MHD effects on laminar boundary layer flow of the fluids along porous plate.

In the present study, we have investigated MHD natural convection flow from a porous vertical plate numerically. The results will be obtained for different values of relevant physical parameters and will be shown in graphs as well as in tables.

The governing partial differential equations are reduced to locally non-similar partial differential forms by adopting some appropriate transformations. The transformed boundary layer equations are solved numerically using implicit finite difference scheme together with the Keller box technique [11]. Here, we have focused our attention on the evolution of the surface shear stress in terms of local skin friction and the rate of heat transfer in terms of local Nusselt number, velocity profiles as well as temperature profiles for selected values of parameters consisting of the magnetic parameter *M,* Prandtl number *Pr*.

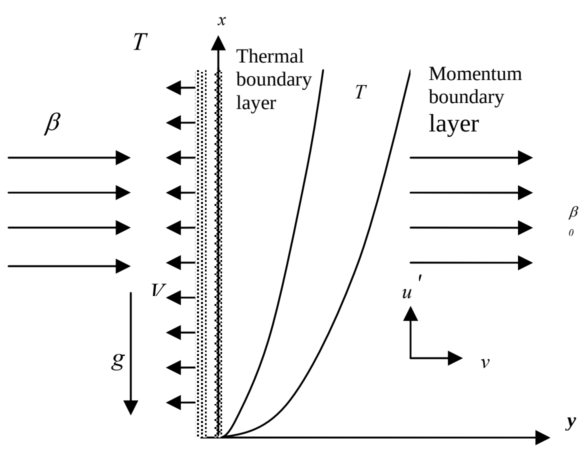


Fig 1. The coordinate system and the physical model

We have investigated MHD natural convection flow from a porous plate . Over the work it is assumed that the surface temperature of the porous vertical plate, T_w, is constant, where $T_w > T_\infty$. The physical configuration considered is as shown in Fig.1:

The conservation equations for the flow characterized with steady, laminar and two dimensional boundary layer; under the usual Boussinesq approximation, the continuity, momentum and energy equations can be written as:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=\mu\frac{\partial^2 u}{\partial x^2}+\rho g\beta(T-T_\infty)-\sigma_0{\beta_0}^2 u \tag{2}$$

$$\rho c_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=k\frac{\partial^2 T}{\partial y^2} \tag{3}$$

With the boundary conditions

$$\begin{aligned} &x=0, y>0, u=0, T=T_\infty. \\ &y=0, x>0, u=0, v=-V,\ T=T_w \\ &y\to\infty, x>0, u=0, T=T_\infty \end{aligned} \tag{4}$$

where ρ is the density, β_0 is the strength of magnetic field, σ_0 is the electrical conduction, k is the thermal conductivity,β is the coefficient of thermal expansion, ν is the reference kinematic viscosity ν = μ/ρ , μ is the viscosity of the fluid, C_p is the specific heat due to constant pressure. Over the work it is assumed that the surface temperature of the porous vertical plate, T_w, is constant, where $T_w>T_\infty$. Here T_∞ is the ambient temperature of the fluid, T is the temperature of the fluid in the boundary layer, g is the acceleration due to gravity, the fluid is assumed to be a grey emitting and absorbing, but non scattering medium.

Now introduce the following non-dimensional variables:

$$\eta=\frac{Vy}{\nu\xi}, \xi=V\left\{\frac{4x}{\nu^2 g\beta\Delta T}\right\}^{\frac{1}{4}}$$

$$\psi=V^{-3}\nu^2 g\beta\Delta T\xi^3\left\{f+\frac{\xi}{4}\right\} \tag{5}$$

$$\theta=\frac{T-T_\infty}{T_w-T_\infty},\ \theta_w=\frac{T_w}{T_\infty} \tag{6}$$

Substituting(5) and (6) into Equations (1), (2) and (3) leads to the following non-dimensional equations

$$f'''+\theta-2f'^2+3ff''+\xi f''=\xi\left(f'\frac{\partial f'}{\partial\xi}f''\frac{\partial f'}{\partial\xi}\right)-\frac{\sigma_0{\beta_0}^2}{\rho}\nu^{-2}\xi^2 f' \tag{7}$$

$$\frac{1}{pr}\frac{\partial}{\partial\eta}\left[\frac{\partial\theta}{\partial\eta}\right]+3f\theta'+\xi\theta'=\xi\left(f'\frac{\partial\theta}{\partial\xi}-\frac{\partial f}{\partial\xi}\theta'\right) \tag{8}$$

Where $Pr=\nu C_p/k$ is the Prandtl number is the heat generation parameter and $M=\beta_0^2\sigma_0/\nu\rho$ is the magneto hydrodynamic parameter.

The boundary conditions (4) become

$$\begin{aligned} &f=0, f'=0,\ \theta=1 \text{ at } \eta=0 \\ &f'=0,\ \theta=0 \text{ as } \eta\to\infty \end{aligned} \tag{9}$$

The solution of equations (7), (8) enable us to calculate the nondimensional velocity components $\bar{u}$, $\bar{v}$ from the following expressions

(1)

$$\bar{u} = \frac{\nu^2}{Vg\beta(T_w - T_\infty)} u = \xi^2 f'(\xi,\eta)$$
$$\bar{v} = \frac{\nu}{V} = \xi^{-1}(3f + \xi - \eta f' + \xi \frac{\partial f}{\partial \xi}) \quad (10)$$

In practical applications, the physical quantities of principle interest are the shearing stress τ_w and the rate of heat transfer in terms of the skin-friction coefficients C_{fx} and Nusselt number Nu_x respectively, which can be written as

$$Nu_x = \frac{\nu}{V\Delta T}(q_c)_{\eta=0}, C_{fx} = \frac{V}{g\beta\Delta T}(\tau)_{\eta=0} \quad (11)$$

$$\text{where} \quad \tau_w = \mu\left(\frac{\partial u}{\partial y}\right)_{\eta=0} \text{ and } \quad q_c = -k\left(\frac{\partial T}{\partial y}\right)_{\eta=0} \quad (12)$$

q_c is the conduction heat flux.

Using the Equations (6) and the boundary condition (9) into (11) and (12), we get

$$C_{fx} = \xi f''(x,0)$$
$$Nu_x = \xi^{-1}\theta'(x,0) \quad (13)$$

The values of the velocity and temperature distribution are calculated respectively from the following relations:

$$\bar{u} = \xi^2 f'(\xi,\eta), \qquad \theta = \theta(x,y) \quad (14)$$

2. NUMERICAL PROCEDURE

Solutions of the local non similar partial differential equation (7) to (8) subjected to the boundary condition (9) are obtained by using implicit finite difference method with Keller-Box Scheme. which has been described in details by Cebeci [12].

Discussion on the advancement of algorithm on implicit finite difference method is given below taking into account the following Equations (15-16).

$$f''' + 3ff'' - 2(f')^2 + \theta - \xi f'' - Mf'\xi^2 = \xi\left(f'\frac{\partial f'}{\partial \xi} - \frac{\partial f}{\partial \xi}f''\right) \quad (15)$$

$$\frac{1}{\Pr}\frac{\partial}{\partial \eta}\left[\frac{\partial \theta}{\partial \eta}\right] + 3f\theta' + \xi\theta' = \xi\left(f'\frac{\partial \theta}{\partial \xi} - \frac{\partial f}{\partial \xi}\theta'\right) \quad (16)$$

To apply the aforementioned method, we first convert Equations (15)-(16) into the following system of first order equations with dependent variables $u(\xi,\eta)$, $v(\xi,\eta)$, $p(\xi,\eta)$ and $g(\xi,\eta)$ as

$$f' = u, u' = v, \quad g = \theta, \text{ and } \theta' = p \quad (17)$$

$$v' + p_1 fv - p_2 u^2 + g - \xi v - p_5 u\xi^2 = \xi\left(u\frac{\partial u}{\partial \xi} - \frac{\partial f}{\partial \xi}v\right) \quad (18)$$

$$\frac{1}{\Pr}[p'] + p_4 g + \xi p + p_1 fp = \xi\left(u\frac{\partial g}{\partial \xi} - p\frac{\partial f}{\partial \xi}\right) \quad (19)$$

Where $p_1=3$, $p_2=2$, $p_5 = M$ (20)

The corresponding boundary conditions are

$$f(\xi,0) = 0, u(\xi,0) = 0 \text{ and } g(\xi,0) = 0$$
$$u(\xi,\infty) = 0, g(\xi,\infty) = 0 \quad (21)$$

We now consider the net rectangle on the (ξ,η) plane and denote the net point by

$$\eta_0 = 0, \quad \eta_j = \eta_{j-1} + h_j, \qquad j = 1,2,\ldots J$$

$$\xi^0 = 0, \quad \xi^n = \xi^{n-1} + k_n, \quad n = 1,2,\ldots N$$

We approximate the quantities (f, u, v, p) at the points (ξ^n,η_j) of the net by $(f_j^n, u_j^n, v_j^n, p_j^n)$ **(10)**.

$$\xi^{n-1/2} = \tfrac{1}{2}(\xi^n + \xi^{n-1}) \quad (22)$$
$$\eta_{j-1/2} = \tfrac{1}{2}(\eta_j - \eta_{j-1})$$
$$g_j^{n-1/2} = \tfrac{1}{2}(g_j^n + g_j^{n-1})$$
$$g_{j-1/2}^n = \tfrac{1}{2}(g_j^n + g_{j-1}^n)$$

Now we write the difference equations that are to approximate Equations (17) - (18) by considering one mesh rectangle for the midpoint $(\xi^n, n_{j-1/2})$ to obtain

$$\frac{1}{2}\left(\frac{v_j^n - v_{j-1}^n}{h_j} + \frac{v_j^{n-1} - v_{j-1}^{n-1}}{h_j}\right) + (p_1 fv)_{j-\frac{1}{2}}^{n-\frac{1}{2}} - (p_2 u^2)_{j-\frac{1}{2}}^{n-\frac{1}{2}}$$
$$+ (g)_{j-\frac{1}{2}}^{n-\frac{1}{2}} - (\xi v)_{j-\frac{1}{2}}^{n-\frac{1}{2}} - (p_5 u\xi^2)_{j-\frac{1}{2}}^{n-\frac{1}{2}} \quad (23)$$
$$= (\xi)_{j-\frac{1}{2}}^{n-\frac{1}{2}}\left((u)_{j-\frac{1}{2}}^{n-\frac{1}{2}}\frac{u_j^n - u_{j-1}^n}{k_n} + (v)_{j-\frac{1}{2}}^{n-\frac{1}{2}}\frac{f_j^{n-1} - f_{j-1}^{n-1}}{k_n}\right)$$

$$\frac{1}{\Pr}[h_j^{-1}(p_j^n - p_{j-1}^n) + \xi_{j-1/2}^n p_{j-1/2}^n + (p_1)_{j-1/2}^n (fp)_{j-1/2}^n = -M_{j-1/2}^{n-1}$$
$$+\alpha_n[-(ug)_{j-1/2}^{n-1} + (fp)_{j-1/2}^{n-1}] + \alpha_n[(ug)_{j-1/2}^n - (fp)_{j-1/2}^n \quad (24)$$
$$-u_{j-1/2}^n g_{j-1/2}^{n-1} + u_{j-1/2}^{n-1} g_{j-1/2}^n\} + p_{j-1/2}^n f_{j-1/2}^{n-1} - p_{j-1/2}^{n-1} f_{j-1/2}^n]$$

Similarly Equations (18) – (19) are approximate by centering about the midpoint $(\xi^{n-1/2}, n_{j-1/2})$, Where

$$L_{j-\frac{1}{2}}^{n-1} = (p_1)_{j-\frac{1}{2}}^{n-1}(fv)_{j-\frac{1}{2}}^{n-1} - (p_2)_{j-\frac{1}{2}}^{n-1}(u^2)_{j-\frac{1}{2}}^{n-1}$$
$$+ g_{j-\frac{1}{2}}^{n-1} - (\xi p)_{j-\frac{1}{2}1}^{n-1} + h_j^{-1}(v_j^{n-1} - v_{j-1}^{n-1})$$
$$- (p_5)_{j-1/2}^{n-1} u_{j-1/2}^{n-1} (\xi^2)_{j-1/2}^{n-1}$$

$$\text{and } R_{j-\frac{1}{2}}^{n-1} = -L_{j-\frac{1}{2}}^{n-1} + \alpha_n\left\{-(u^2)_{j-\frac{1}{2}}^{n-1} + (fv)_{j-\frac{1}{2}}^{n-1}\right\}$$

where

$$M_{j-1/2}^{n-1} = \frac{1}{\Pr}[h_j^{-1}(p_j^{n-1} - p_{j-1}^{n-1}) + [\xi_{j-1/2}^{n-1} p_{j-1/2}^{n-1} +$$
$$(p_4)_{j-1/2}^{n-1} g_{j-1/2}^{n-1} + (p_1)_{j-1/2}^{n-1}(fp)_{j-1/2}^{n-1}]$$
$$T_{j-1/2}^{n-1} = -M_{j-1/2}^{n-1} + \alpha_n\,[(fp)_{j-1/2}^{n-1} - (ug)_{j-1/2}^{n-1}]$$

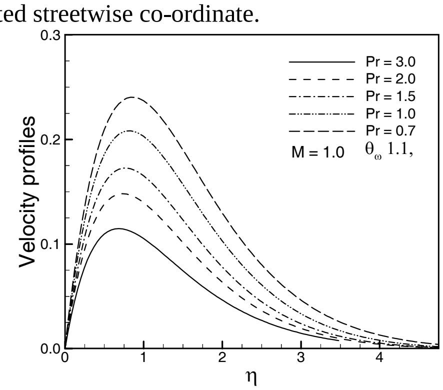
The corresponding boundary conditions become

$$f_0^n = 0, \quad u_0^n = 0, \quad g_0^n = 1, \; u_J^n = 0, \quad g_J^n = 0$$

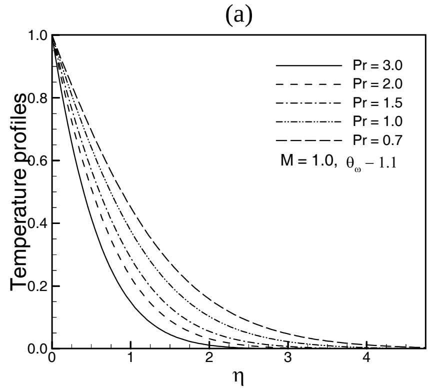
Now the system of linear Equations momentum and energy equations together with the boundary conditions can be written in matrix or vector form, where the coefficient matrix has a block tri-diagonal structure. The whole procedure, namely reduction to first order followed by central difference approximations, Newton’s quasi-linearization method and the block Thomas algorithm, is well known as the Keller- box method.

3. RESULT AND DISCUSSION

In this exertion MHD natural convection flow on a porous vertical plate is investigated. Numerical values of local rate of heat transfer are calculated in terms of Nusselt number Nu_x for the surface of the porous vertical plate from lower stagnation point to upper stagnation point, for different values of the aforementioned parameters and these are shown in tabular form in Table:1 . The effect for different values MHD parameter M on local skin friction coefficient C_{fx} and the local Nusselt number Nu_x, as well as velocity and temperature profiles are displayed in Fig.2 to 5.The aim of these figures are to display how the profiles vary in ξ ,the selected streetwise co-ordinate.



(a)

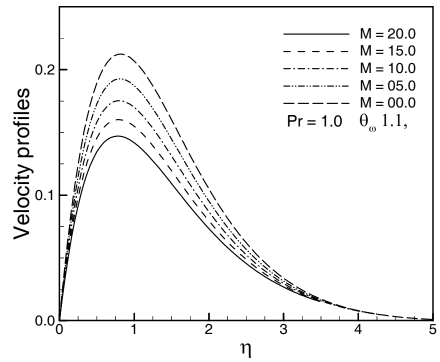


(b)

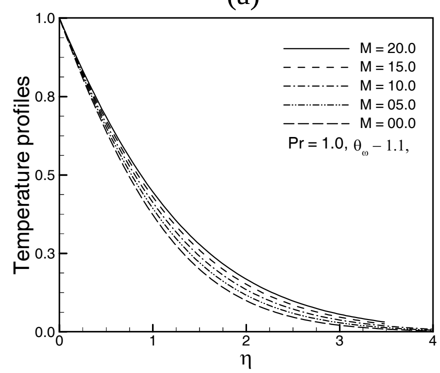
Fig 2. (a) Velocity and (b) temperature profiles for different values of prandtl number Pr with others fixed parameters

In figures 2(a)-2(b) it has been shown that when the Prandtl number Pr = 0.7, 1.0, 1.5, 2.0 and 3.0 increases with θ_w = 1.1 and M=*1*.0, both the velocity and temperature profiles decrease.

Figures 3(a) display results for the velocity profiles for different values of magnetic parameter M with Prandtl number Pr = 1.0 and surface temperature parameter θ_w = 1.1. It has been seen from figure 3(a) that as the magnetic parameter M increases, but th velocity profiles decrease with the increase of magnetic parameter. It is also observed from figure 3(a) that the changes of velocity profiles in the η direction reveals the typical velocity profile for natural convection boundary layer flow, i.e., the velocity is zero at the boundary wall then the velocity increases to the peak value as η increases and finally the velocity approaches to zero (the asymptotic value) . The maximum values of velocity are recorded to be 0.14712 , 0.16024, 0.17466, 0.19259 and 0.21244 for M = 20.0, 15.0, 10.0, 5.0, and 0.0, at η=0.73363, η=0.78384 and η=0.83530. Here, it is observed that the velocity decreases by 27.77% as the magnetic parameter M changes from 0 to 20.0. . Figure 3(b) displays results for the increasing temperature profiles, for different values of magnetic parameter M while Prandtl number Pr = 1.0 and surface temperature parameter θ_w = 1.1.



(a)

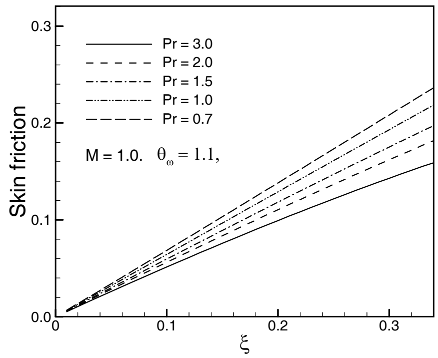


(b)

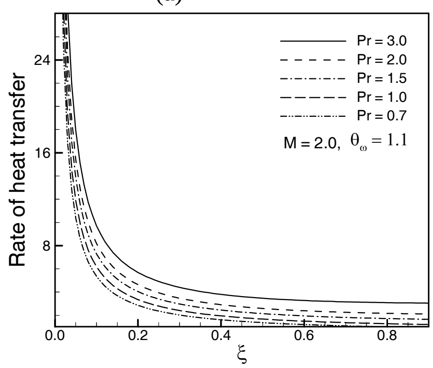
Fig 3. (a) Velocity and (b) temperature profiles for different values of magnetic parameter M with others fixed parameters

The variation of the local skin friction coefficient C_{fx} and local rate of heat transfer Nu_x for different values of Prandtl number Pr while θ_w = 1.1, Q = 1.0 and M=*1*.0 are shown in Figures 4(a)-4(b). We can observe from these figures that as the Prandtl number Pr increases, the skin friction coefficient decreases and rate of heat transfer increases.

Figures 5(a)-5(b) show that skin friction coefficient C_{fx} and heat transfer coefficient Nu_x decreases for increasing values of magnetic parameter M while Prandtl number Pr = 1.0, and surface temperature parameter θ_w = 1.1. The values of skin friction coefficient C_{fx} and Nusselt number Nu_x are recorded to be 0.27168, 0.30664, 0.36150, 0.46883 and 0.84175 and 1.00479, 1.00477, 1.00465, 1.00527 and 1.05097 for M=20.0, 15.0.10.0, 5.0 and.0.0 respectively which occur at the same point ξ = 1.5. Here, it observed that at ξ = 1.5, the skin friction decreases by 67.72% and Nusselt number Nu_x decreases by 4.39% as the magnetic parameter M changes from 0.0 to 20.0.

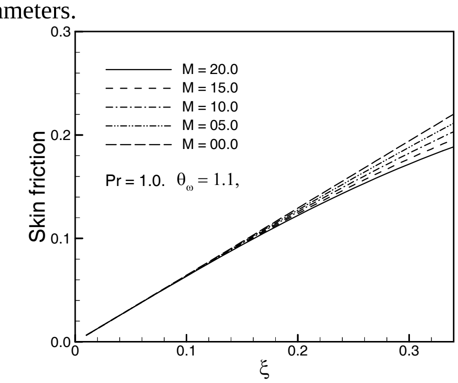


(a)

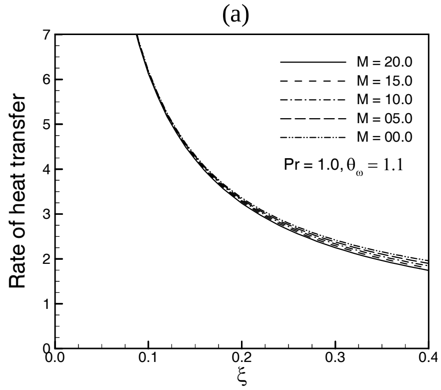


(b)

Fig 4.(a) Skin friction and (b) rate of heat transfer for different values of prandtl number Pr with others fixed parameters.



(a)



(b)

Fig 5.(a) Skin friction and (b) rate of heat transfer for different values of magnetic parameter M with others fixed parameters.

Numerical values of rate of heat transfer Nu_x and skin friction coefficient C_f are calculated from Equations (13) from the surface of the vertical porous plate. Numerical values of C_{fx} and Nu_x are shown in Table 1.

Table 1: Skin friction coefficient and rate of heat transfer against x for different values of magnetic parameter M with other controlling parameters Pr = 1.1 and θw =1.1.

ξ	M=00.0		M=05.0	
	C_{fx}	Nu_x	C_{fx}	Nu_x
0.01	0.00642	57.68614	0.00642	57.68336
0.05	0.03219	11.90384	0.03216	11.89554
0.10	0.06441	6.18952	0.06417	6.17415
0.50	0.32307	1.68751	0.29579	1.61497
1.00	0.61989	1.18088	0.44698	1.08005
1.10	0.67172	1.14138	0.45801	1.04684
1.20	0.72014	1.11037	0.46458	1.02581
1.30	0.76484	1.08588	0.46784	1.01378
1.40	0.80545	1.06641	0.46892	1.00779
1.50	0.84175	1.05097	0.46883	1.00527
ξ	M=00.0		M=05.0	
	C_{fx}	Nu_x	C_{fx}	Nu_x
0.01	0.00642	57.67780	0.00642	57.67502
0.05	0.03209	11.87897	0.03206	11.87071
0.10	0.06370	6.14360	0.06347	6.12841
0.50	0.25337	1.49227	0.23693	1.44212
1.00	0.30773	1.02211	0.27312	1.01591
1.10	0.30813	1.01152	0.27298	1.00955
1.20	0.30786	1.00744	0.27261	1.00708
1.30	0.30742	1.00590	0.27224	1.00596
1.40	0.30700	1.00518	0.27194	1.00525
1.50	0.30664	1.00477	0.27168	1.00479

In the above table the values of the values of skin friction coefficient C_{fx} and Nusselt number Nu_x are recorded to be 0.27168, 0.30664, 0.36150, 0.46883 and 0.84175 and 1.00479, 1.00477, 1.00465, 1.00527 and 1.05097 for M=20.0, 15.0.10.0, 5.0 and.0.0 respectively which occur at the same point $\xi =$ 1.5. Here, it observed that at $\xi = 1.5$, the skin friction increases by 67.72% and Nusselt number Nu_x decreases by 4.39% as the magnetic parameter M changes from 0.0 to 20.0.

5 Comparison of the results

Table 2: Comparison of the present result with [9]

ξ	θw= 1.1			
	Hossain		Hossain	
	C_{fx}	Nu_x	C_{fx}	Nu_x
0.1	0.0655	6.4627	0.06535	6.48306
0.2	0.1316	3.4928	0.13138	3.50282
0.4	0.2647	2.0229	0.26408	2.03018
0.6	0.3963	1.5439	0.39519	1.55522
0.8	0.5235	1.3247	0.52166	1.32959
1.0	0.6429	1.1995	0.64024	1.20347
1.5	0.8874	1.0574	0.88192	1.06109
ξ	θw = 2.5			
	Hossain		Hossain	
	C_{fx}	C_{fx}	C_{fx}	C_{fx}
0.1	0.0709	8.0844	0.07078	8.10360
0.2	0.1433	4.2858	0.14313	4.29682
0.4	0.2917	2.4003	0.29120	2.40669
0.6	0.4423	1.7863	0.44145	1.78912
0.8	0.5922	1.4860	0.59080	1.48991
1.0	0.7379	1.1098	0.73590	1.31822
1.5	1.0613	1.1098	1.05693	1.11262

In order to verify the accuracy of the present work, the values of Nusselt number and skin friction for $R_d = 0.05$, $Pr = 1.0$, $M = 0$ and various surface temperature $\theta_w = 1.1$, $\theta_w = 2.5$ at different position of ξ are compared with Hossain [9] as presented in Table 2. The results are found to be in excellent agreement.

6. CONCLUSION

For different values of relevant physical parameters including the magnetic parameter M on natural convection flow from a porous vertical plate has been investigated. The governing boundary layer equations of motion are transformed into a non-dimensional form and the resulting non-linear systems of partial differential equations are reduced to local non-similarity boundary layer equations, which are solved numerically by using implicit finite difference method together with the Keller-box scheme. From the present investigation the following conclusions may be drawn:

- For increasing values of Prandtl number Pr leads to decrease the velocity profile, the temperature profile and the local skin friction coefficient C_{fx} but the local rate of heat transfer Nu_x increases.
- An increase in the values of M leads to decrease the velocity profiles, the local skin friction coefficient C_{fx} and the local rate of heat transfer Nu_x but the temperature profiles increases. Electrically conducting fluid increases the temperature so the rate of heat transfer decreases. An increase of M increase the Lorentz force , which opposes the flow also increases and leads to enhanced deceleration of the flow. So velocity as well as skin friction decrease.

7. REFERENCES

1. J. H. Merkin, 1972, "Free convection with blowing and suction", International journal of heat and mass transfer, 15: 989-999.
2. H. T. Lin, W. S. Yu, 1988, "Free convection on horizontal plate with blowing and suction", Transactions on ASME journal of Heat Transfer 110: 793-796.
3. AK. Singh, 1982, "MHD free-convection flow in the Stokes problem for a porous vertical plate", Astrophysics and Space Science, 87: 455-461.
4. A Chowdhury, MK, A Islam, MN, 2000, "MHD free convection flow of visco-elastic fluid past an infinite vertical porous plate", Journal of Heat and mass transfer, 36: 439-447 .
5. M. A. Hosain, H.S. Takhar, 2001, "Radiation effect on mixed convection along a vertical plate with uniform surface", Journal of Temperature, Heat and Mass Transfer, 31: 243-248.
6. A Hayat, T, A Abbas, Z, A Sajid, M, Asghar, S, 2007, "The influence of thermal radiation on MHD flow of a second grade fluid", International Journal of Heat and Mass Transfer, 50: 931-941.
7. A Alam, MS, A Rahman, MM, A Samad, MA, 2006, "Numerical study of the combined free-forced convection and mass transfer flow past a vertical porous plate in a porous medium with heat generation and thermal diffusion", Journal of Nonlinear Analysis, 11: 331-343 .
8. A Hossain, MA, 1986, "Effect of Hall current on unsteady hydromagnetic free convection flow near an infinite vertical porous plate", Journal of the Physical Society of Japan, 55: 2183-2190.
9. M. A. Hossain, M. A. Alim, D. A. S. Rees, 1999, "The effect of radiation on free convection flow from a porous vertical plate", International Journal of Heat and Mass Transfer, 42:81-91.
10. A Duwairi, HM, A Damseh, RA, 2004, "Magnetohydrodynamic natural convection heat transfer from radiate vertical porous surfaces", Journal of Heat and Mass Transfer, 40: 787-792.
11. H.B. Keller, 1978, "Numerical methods in boundary layer theory", Annual Review of Fluid Mechanics, 10: 417-433.
12. T. Cebeci, P. Bradshaw, 1984, "Physical and Computational Aspects of Convective Heat Transfer", Springer, New York,.

7. NOMENCLATURE

Nomenclatures

C_f Local skin friction coefficient
C_p Specific heat at constant pressure(J.kg^{-1}k^{-1})
f Dimensionless stream function
g Acceleration due to gravity(m.s^{-2})
k Thermal conductivity(W.m^{-1}K^{-1})
Nu_x Local Nusselt number
Pr Prandtl number
q_w Heat flux at the surface(W.m^{-2})
q_c Conduction heat flux
T Temperature of the fluid in the boundary layer(K)
T_∞ Temperature of the ambient fluid(K)
T_w Temperature at the surface(K)
(u, v) Dimensionless velocity components along the (x, y) axes
V Wall suction velocity
(x, y) Axis in the direction along and normal to the surface respectively

Greek symbols

β Coefficient of thermal expansion(K^{-1})
η Similarity variable
θ Dimensionless temperature function
θ_{W} Surface temperature parameter
μ Viscosity of the fluid(kg.m^{-1}s^{-1})
ν Kinematic viscosity(m^{2}s^{-1})
ξ Similarity variable
ρ Density of the fluid(kg.m^{-3})
σ Stephman-Boltzman constant(W,m^{-2}K^{-4})
μ_f absolute Viscosity at the film temperature
τ Coefficient of skin friction
τ_{w} Shearing stress
ψ Non-dimensional stream function

Subscripts

w wall conditions
∞ Ambient temperature

8. MAILING ADDRESS

Amena Ferdousi
Senior Lecturer, Department of Electronics and Electrical Engineering,
Eastern University, R#4, Dhanmondi, Dhaka-1207, Bangladesh
E-mail: amena@easternuni.edu.bd