To Study The Effect Of Convection And Electric Field Load Parameter On Mhd Couette Flow Past A Channel With Highly Permeable Bed.

[1]Nimisha Yadav, [2]P .C. Yadav, [3]Ritika Yaduvanshi , [4]Shivendu Mishra
[1]Assistant Professor r, [2]Assistant Professor , [3]Assistant Professor
[1,]Department of Mathematics,
U N S I E T V B S Purvanchal University Jaunpur U P- 222001

[2]Department of Electronics and Communication Engg.
U.N.S.I.E.T.V.B.S Purvanchal University Jaunpur U P- 222001

[3]Department of Computer Science Engg.
Mahamaya college of Agriculture and Engg & Technology Akbarpur U P -224122

[4]Department of Computer Science Engg.
R E C Ambedakar Nagar U P -224122

Abstract: In the present investigation, the MHD couette flow of an electrically conducting fluid through a channel with highly permeable bed, has been considered in the presence of buoyancy and magneto-electric forces. The effect of the buoyancy force, permeability of porous medium, load parameter, magnetic field, on the velocity distribution, temperature field, skin-friction, flux and rate of heat transfer are discussed.

***IndexTerms* -** MHD oscillatory flow, Temperature field, Skin friction, Load parameter, Porous medium etc.

I. INTRODUCTION:

Flow through porous media are very much prevalent in nature and therefore the study of flows through porous media has become of principal interest in many scientific and engineering applications e.g. in the field of agricultural engineering to study the underground water resources, seepage of water in riverbeds. The effect of magnetic field on the flow of a electrically conducting viscous fluid has received considerable attention due to its wide range of engineering, geophysical, astrophysical applictions. MHD channel flows have been studied extensively, including their heat transfer aspect. An excellent review of existing theoretical and experimental work on these subjects can be found in the recent books and monographs by Bejan[1], Cebeci[3], Chauhan and Vyas[4], Ingham and Pop[8], Jothimani and Anjalidevi[9], Kaviany[10], Nield and Bejan[14], Pop and Ingham[15] and Singh and Gholami[16].

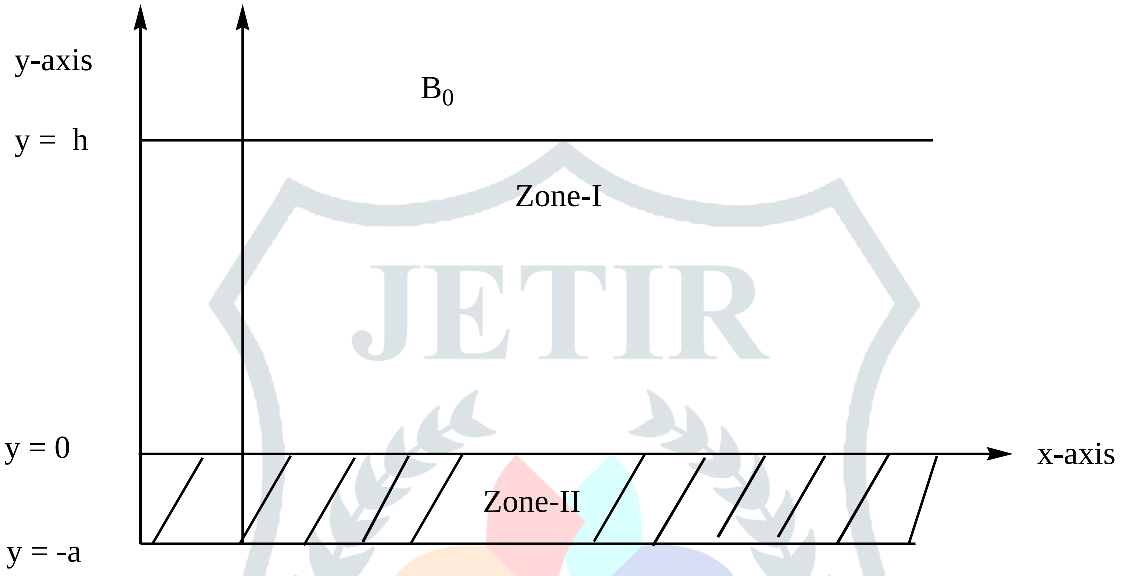
Buoyancy driven convective heat transfer is of interest in relation to the underground spread of pollutants, solar power collectors, geothermal energy systems and others. In past, most of investigations have not been taken into account the effect of buoyance forces since the problems were on horizontal flows.

It was assumed that the buoyancy forces are almost negligible in horizontal flows, but some authors have shown that in the case of horizontal flow of liquids with low Prandtl number (Pr), the buoyancy forces cannot be neglected as they significantly affect the flow field. The buoyancy layer flows for such fluids have been discussed by Bejan and Khair [2]. Gholami and Singh [7] analysed the problem of simultaneous heat and mass transfer with the entire range of buoyancy ratio for most practical chemical species in dilute solutions and aqueous solutions. Yan and Chang [17] have investigated numerically the laminar mixed convective flow in the channel and simultaneous influence of the combined buoyancy effects of the thermal and mass diffusion for an air-water system. Garander *et al*.[6] proposed an analytic solution to the governing equation of MHD to be used model the effect of a transverse magnetic field on natural convection. When the fluid is electrically conduction and exposed to a magnetic field the Lorentz force is also active and interacts with the buoyancy force in governing the flow and temperature fields. Employment of an external magnetic field has increasing application in material manufacturing industry as a control mechanism since the Lorentz force suppresses the convection currents by reducing the velocities. Study and through understanding of the momentum and heat transfer in such a process is important for the better control and quality of the manufactured products. The MHD heat transfer in two phase flow with fluid in one phase being electrically conducting was studied by Lohrasbi and Sahai [12]. The problem of MHD heat transfer for short circuit case in a two-phase flow have discussed by Malashetty and Leena [13]. Firat *et al*. [5] observed the Lateral load estimation from visco-plastic mud flow.

In such cases, fluid flows through two zones. In zone I, there is no porous media i.e. in free fluid region, here fluid flow freely governed by Navier-Stokes equation. In another zone the fluid flows through the pores of a permeable solid and in most of the cases of high system, the flow is governed by Brinkman equation. In the light of discussion made by Kim and Russel [11] a modified set of boundary condition is applied at the fluid porous medium interface.

1.1 Formulation of the problem:

The geometry under consideration (shown in Figure given below), consists of two horizontal parallel walls at distance h apart. The upper wall is rigid and moving with a uniform velocity 'U_0' while the lower wall is a stationary porous bed of finite thickness 'a' with an impermeable bottom. The axis of x is taken along the porous interface and y axis is normal to it. The flow regime is divided into two zones: I- the free fluid region (0 ≤ y ≥ h) and II-porous region (-a ≤ y ≥ 0).



Figure

Laminar and fully developed Couette flow of a viscous electrically conducting fluid between two horizontal parallel walls has been considered along the direction of x-axis in the presence of a constant magnetic field of strength B_0 applied in the direction of y-axis. Since the horizontal plates are taken to be of infinite length, therefore all the physical variables are dependent on y only and we assume the velocity [u(y), 0, 0] in the zone I as well as in the zone II. For this model it is assumed that the fluid satisfies the Boussinesq approximation, i.e. the fluctuations in density occur principally as a result of thermal rather than pressure variations. The flow in zone I and II are driven in x-direction by a common pressure gradient $P = -\partial p / \partial x$; the bouyance force and axial temperature gradient $\partial T / \partial x$ and by the shear produced due to the motion of the upper plate.

With a parallel flow approximation, we can take the temperature field as the sum of a linearly varying longitudinal part and an unknown transe distribution for the present model as-

$$T - T_0 = N_x + \theta(y) \quad .... (1)$$

(a) Fluid motion: For zone I (Free fluid region):

$$\mu \frac{d^2u}{dy^2} - \sigma(E + uB_0)B_0 = \frac{\partial p}{\partial x} \quad .... (2)$$

$$\frac{\partial p}{\partial y} = -\rho g \quad .... (3)$$

$$\rho = \rho_0[1 - \beta(T - T_0)] \quad .... (4)$$

For zone II (Porous region)

$$\bar{\mu} \frac{d^2u}{dy^2} - \sigma u B_0^2 - \frac{\mu}{k_0} u = \frac{\partial p}{\partial x} \quad .... (5)$$

The boundary conditions are

at

$$y = h \quad : \quad (u)_I = U_0$$

$$y = 0 \quad : \quad (u)_I = (U)_{II} \quad , \left(\mu \frac{du}{dy}\right)_I = \left(\bar{\mu}\frac{du}{dy}\right)_{II} \qquad \text{...(6)}$$

$$y = -a \quad : \quad (u)_{II} = 0$$

Solving eqn. (3) with the help of equations (1) and (4), we obtain the pressure distribution as

$$p = -\rho_0 g\left[y - \beta Nxy - \beta\int\theta(y)dy\right] + F(x) \qquad \text{............} \quad (7)$$

Introducing the following non-dimensional quantities

$$u^* = \frac{uh}{\upsilon p_0}, \quad y^* = \frac{y}{h}, \quad x^* = \frac{x}{h}, \quad \upsilon = \frac{\mu}{\rho_0}, \quad a^* = \frac{a}{h}$$

$$P_0 = -\frac{h^3}{\rho_0\upsilon^2}\frac{d}{dx}F(x), \quad \overset{*}{K_0} = \frac{K_0}{h}, \quad R_e = \frac{Eh}{u\upsilon P_0 B_0}$$

$$G = \frac{g\beta Nh^4}{\upsilon^2 P_0}, \quad M^2 = \frac{\sigma B_0^2 h^2}{\mu}, \quad \phi_1 = \frac{\mu}{\bar{\mu}} \quad and \quad M_1^2 = \left(M^2 + \frac{1}{K_0}\right)\phi_1 \qquad (8)$$

Using non-dimensional quantities after eliminating pressure with the help of equation (7), the equations (2) and (5) become,

$$\frac{d^2y}{dy^2} - M^2(R_e + 1)u = (Gy - 1) \qquad \text{(For zone I)} \quad \text{......} \quad (9)$$

$$\frac{d^2y}{dy^2} - M_1^2 = \phi_1(Gy - 1) \qquad \text{(For zone II)......} \quad (10)$$

and the boundary conditions (6) become

$$y = 1 \quad : \quad (u)_I = U_0$$

at $$y = 0 \quad : \quad (u)_I = (U)_{II} \quad , \phi_1\left(\frac{du}{dy}\right)_I = \left(\frac{du}{dy}\right)_{II} \qquad \text{........(11)}$$

$$y = -a \quad : \quad (u)_{II} = 0$$

Here asterisks are dropped for convenience.
Solving equations (9) and (10) under the boundary conditions (11), we get the velocity distribution.

$$u_I = C_1 e^{Ay} + C_2 e^{-Ay} + \frac{(1 - Gy)}{M^2(R_e + 1)} \qquad \text{............} \quad (12)$$

$$u_{II} = C_3 e^{-M_1 y} + C_4 e^{-M_1 y} + \phi_1\frac{(1 - Gy)}{M_1^2} \qquad \text{............} \quad (13)$$

The skin friction at the porous interface is given by

$$\left(\frac{du}{dy}\right)_{y=0} = A(C_1 - C_2) - \frac{G}{M^2(R_e + 1)} \qquad \text{............} \quad (14)$$

The skin friction at the bottom is given by

$$\left(\frac{du}{dy}\right)_{y=0} = M_1\left(C_3 e^{-M_1 a} - C_4 e^{M_1 a}\right) - \phi_1 G/M_1^2 \qquad \text{............} \quad (15)$$

The volume flux in the channel (free fluid region) is given by

$$Q = \int_0^1 u\,dy = \frac{1}{2A^2}\left[2AC_1\left(e^A - 1\right) + 2AC_2\left(1 - e^{-A}\right) + (2 - G)\right] \qquad \text{............} \quad (16)$$

where, $C_1 = \left(C - C_2 e^{-A}\right)e^{-A}$; $C_2 = \dfrac{B_1 - C_4 A_2}{A_1}$

$$C_3 = \left(D - C_4 e^{M_1 a}\right)e^{M_1 a} \quad ; \quad C_4 = \frac{B_1 A_3 - A_1 B_2}{A_2 A_3 - A_1 A_4}$$

$$A_1 = \left(1 - e^{-2A}\right); \qquad A_2 = \left(e^{2M_1 a} - 1\right); \qquad A_3 = -A\left(1 + e^{-2A}\right)$$

$$A_4 = M_1 \phi_1^{-1}\left(1 - e^{2M_1 a}\right); \qquad B_1 = \left(E - Ce^{-A} + De^{M_1 a} - \frac{1}{M^2 R_e}\right)$$

$$B_2 = B + M_1 \phi_1^{-1} De^{M_1 a} - ACe^{-A} \quad ; \quad E = \left(\frac{\phi_1}{M_1^2} - \frac{1}{M^2}\right)$$

$$B = \left(\frac{G}{M^2 (R_e + 1)} - \frac{G}{M_1^2}\right); \qquad C = U_0 - \frac{(1 - G)}{M^2 (R_e + 1)};$$

$$D = -\frac{\phi_1 (1 + Ga)}{M_1^2} \qquad\qquad A = M\sqrt{(R_e + 1)}$$

Temperature distribution

$$\rho_0 C_p u \frac{\partial T}{\partial x} = k\frac{\partial^2 T}{\partial y^2} + \mu\left(\frac{du}{dy}\right)^2 + \sigma\left(E + uB_0^2\right) \quad \text{(For zone I)} \quad ....(17)$$

$$\rho_0 C_p u \frac{\partial T}{\partial x} = \bar{k}\frac{\partial^2 T}{\partial y^2} + \bar{\mu}\left(\frac{du}{dy}\right)^2 + \frac{\mu}{\bar{k}K_0}u^2 \quad \text{(For zone II)} \quad ...... \quad (18)$$

The boundary conditions are

at $y = h$: $(T)_I = N_x + T_I$, for all x ;

$(T)_I = T_I$ for x = 0

$y = 0$: $(T)_I = (T)_{II}$, $\left(k\dfrac{\partial T}{\partial y}\right)_I = \left(\bar{k}\dfrac{\partial T}{\partial y}\right)_{II}$

$y = -a$: $(T)_{II} = N_x + T_0$, for all x,

$(T)_{II} = T_0$ for x = 0 .... (19)

Using equation (1), the energy equations (17) and (18) becomes

$$\frac{d^2\theta}{dy^2} = \frac{\rho_0 C_p uN}{k} - \frac{\mu}{k}\left(\frac{du}{dy}\right)^2 - \frac{\sigma}{k}(E + uB_0)^2 \quad \text{(For zone I)} \quad .... \quad .(20)$$

$$\frac{d^2\theta}{dy^2} = \frac{\rho_0 C_p uN}{k} - \frac{\bar{\mu}}{k}\left(\frac{du}{dy}\right)^2 - \frac{\bar{\mu}}{\bar{k}}\left(\frac{du}{dy}\right)^2 - \frac{\mu}{\bar{k}K_0}u^2 \quad \text{(For zone II)} \; .... \quad (21)$$

The boundary condition (19) becomes:

$$y = h \quad : \quad (\theta)_I = T_1$$

at $$y = 0 \quad : \quad (\theta)_I = (\theta)_{II} \quad , \left(k\frac{d\theta}{dy}\right)_I = \left(\bar{k}\frac{d\theta}{dy}\right)_{II} \quad \ldots\ldots\ldots \quad \ldots(22)$$

$$y = -a \quad : \quad (\theta)_{II} = T_0$$

Introducing $\left(\theta^* = \frac{\theta}{T_1 - T_0}\right)$, and using non-dimensional quantities from equation (8), the equations (20)–(22) become

$$\frac{d^2\theta}{dy^2} = \Pr N_0 u - \Pr E_c\left(\frac{du}{dy}\right)^2 - M^2 \Pr E_c (R_e + 1)^2 u^2 \quad \text{(For zone I)} \quad \ldots\ldots\ldots \quad ..(23)$$

$$\frac{d^2\theta}{dy^2} = \phi_2 \Pr N_0 u - \frac{\phi_2}{\phi_1}\Pr E_c\left(\frac{du}{dy}\right)^2 - \frac{\phi_2}{K_0}\Pr E_c u^2 \quad \text{(For zone II)} \ldots\ldots\ldots \quad (24)$$

where, $\phi_2 = \frac{k}{\bar{k}}, \quad N_0 = \frac{NL}{T_1 - T_0}, \quad \Pr = \frac{P_0 \rho_0 C_p \upsilon}{k}, \quad E_c = \frac{P_0 \upsilon^2}{C_p h^2 (T_1 - T_0)}$

and the boundary conditions are

at

$$y = 1 \quad : \quad (\theta)_I = 1$$

$$y = 0 \quad : \quad (\theta)_I = (\theta)_{II} \quad , \phi_2\left(\frac{d\theta}{dy}\right)_I = \left(\frac{d\theta}{dy}\right)_{II} \quad \ldots\ldots\ldots \quad \ldots..(25)$$

$$y = -a \quad : \quad (\theta)_{II} = 0$$

We obtain the temperature distribution after solving equations (23) & (24) under the corresponding boundary conditions (25)

$$\theta_I(y) = N_0 \Pr\left[\frac{\left(C_1 e^{Ay} + C_2 e^{-Ay}\right)}{A^2} - \frac{\left(3y^2 - Gy^3\right)}{6A^2}\right]$$

$$- \Pr E_c\left[\frac{\left(C_1^2 e^{2Ay} + C_2^2 e^{-2Ay}\right)}{4}\right] - A^2 C_1 C_2 y^2$$

$$-2G\frac{\left(C_1 e^{-Ay}\right)}{A^3} + \frac{G^2 y^2}{2A^4} + M^2\frac{\left(C_1^2 e^{2Ay} - C_2^2 e^{-2Ay}\right)}{4A^2} + C_1 C_2 M^2 y^2 + \frac{2M^2}{A^2}$$

$$\left\{\frac{\left(C_1 e^{Ay} + C_2 e^{-Ay}\right)}{A^2} - \frac{Gy}{A^2}\left(C_1 e^{Ay} + C_2 e^{-Ay}\right) + \frac{2G}{A^3}\left(C_1 e^{Ay} - C_2 e^{-Ay}\right)\right\}$$

$$+ M^2\frac{\left(6y^2 + G^2 y^2 - 4Gy^3\right)}{12A^4} + D_1 y + D_2 \quad \text{(For zone I)} \quad \ldots \quad \ldots(26)$$

$$\theta_{II}(y) = N_0 \phi_2 \Pr\left[\frac{\left(C_3 e^{M_1 y} + C_4 e^{-M_1 y}\right)}{M_1^2} + \phi_1\frac{\left(3y^2 - Gy^2\right)}{6M_1^2}\right]$$

$$-\phi_2 \Pr E_c \left[\frac{C_3^2 e^{2M_1 y} + C_4^2 e^{-2M_1 y}}{M_1^2} - C_3 C_4 M_1^2 y^2 + \frac{\phi_1^2 G^2 y^2}{2M_1^4} \right.$$

$$-2G\phi_1 \frac{\left(C_3 e^{M_1 y} - C_4 e^{-M_1 y}\right)}{M_1^3} + \frac{1}{k_0} \frac{\left(C_3^2 e^{2M_1 y} + C_4^2 e^{-2M_1 y}\right)}{4M_1^2} + C_3 C_4 y^2$$

$$+\phi_1^2 \frac{\left(6y^2 + G^2 y^4 - 4Gy^3\right)}{12M_1^4} + \frac{2\phi_1}{M_1^5} \left\{ C_3 e^{M_1 y} \left(M_1(1-Gy) + 2G\right) \right.$$

$$\left. \left. + C_4 e^{-M_1 y} \left(M_1(1-Gy) - 2G\right) \right\} \right] + D_3 y + D_4 \quad \text{(For zone II)} \quad ....(27)$$

The rate of heat transfer at the porous interface is given by

$$\left(\frac{d\theta}{dy}\right)_{y=0} = N_0 \Pr \frac{(C_1 - C_2)}{A}$$

$$-\Pr E_c \left[\frac{A}{4}\left(C_1^2 - C_2^2\right) - \frac{2G}{A^2}(C_1 + C_2) + \frac{M^2}{2A}\left(C_1^2 + C_2^2\right) \right]$$

$$\left. + \frac{2M^2}{A^2} \left\{ \frac{(C_1 - C_2)}{A} - \frac{G}{A^2}(C_1 + C_2) + \frac{2G}{A^2}(C_1 + C_2) \right\} \right] + D_1$$

where, $D_1 = C' + D_3 \phi_2^{-1}$ $\qquad D_2 = A' - C' - D_3 \phi_2^{-1}$

$$D_3 = \frac{A' - C' + D' + B'}{\left(a + \phi_2^{-1}\right)} \qquad D_4 = A' - C' + D' - \phi_2^{-1} D_3$$

$$A' = 1 - \Pr N_0 \left\{ \frac{\left(C_1 e^{A} + C_2 e^{-A}\right)}{A^2} - \frac{(3 - G)}{6A^2} \right\}$$

$$+\Pr E_c \left[\frac{\left(C_1^2 e^{2A} + C_2^2 e^{-2A}\right)}{4} - A^2 C_1 C_2 - 2G \frac{\left(C_1 e^{A} - C_2 e^{-A}\right)}{A^3} \right.$$

$$+ \frac{G^2}{2A^4} + M^2 \frac{\left(C_1^2 e^{2A} - C_2^2 e^{-2A}\right)}{4A^2} + C_1 C_2 M^2$$

$$+ \frac{2M^2}{A^2} \left\{ \frac{\left(C_1 e^{A} + C_2 e^{-A}\right)}{A^2} - \frac{Gy}{A^2}\left(C_1 e^{A} + C_2 e^{-A}\right) + \frac{2G}{A^3}\left(C_1 e^{A} - C_2 e^{-A}\right) \right\}$$

$$\left. + M^2 \frac{\left(6 + G^2 - 4G\right)}{12A^4} \right]$$

$$B' = N_0 \phi_2 \Pr \left\{ \frac{\left(C_3 e^{-M_1 a} + C_4 e^{M_1 a}\right)}{M_1^2} + \phi_1 \frac{\left(3a^2 + Ga^3\right)}{6M_1^2} \right\}$$

$$-\phi_2 \Pr E_c\left[\frac{\phi_1^{-1}\left(C_3^2 e^{-2M_1 a}+C_4^2 e^{2M_1 a}\right)}{4}-C_3 C_4 M_1^2 a^2\right.$$

$$+\frac{\phi_1 G^2 a^2}{2M_1^4}-2G\phi_1\frac{\left(C_3 e^{-2M_1 a}-C_4 e^{M_1 a}\right)}{M_1^3}+\frac{1}{k_0}\frac{\left(C_3^2 e^{-2M_1 a}-C_4^2 e^{2M_1 a}\right)}{4M_1^2}$$

$$+C_3 C_4 a^2+\phi_1^2\frac{\left(6a^2+G^2 a^4+4Ga^3\right)}{12M_1^4}+\frac{2\phi_1}{M_1^5}\left\{C_3 e^{-M_1 a}\left(M_1(1+Ga)+2G\right)\right.$$

$$\left.\left.+C_4 e^{M_1 a}\left(M_1(1+Ga)-2G\right)\right\}\right]$$

$$C' = N_0 \Pr\left\{\frac{(C_3-C_4)}{M_1}-\frac{(C_1-C_2)}{A}\right\}$$

$$+\Pr E_c\left[A\frac{\left(C_1^2-C_2^2\right)}{2}-\frac{2G(C_1+C_2)}{A^2}+\frac{M^2\left(C_1^2+C_2^2\right)}{2A}\right.$$

$$+\frac{2M^2}{A^3}(C_1-C_2)+\frac{4M^2 G}{A^4}(C_1+C_2)$$

$$-2\phi_1^{-1}M_1\frac{\left(C_3^2-C_4^2\right)}{4}+\frac{2G\phi_1(C_3+C_4)}{M_1^2}$$

$$\left.-\frac{1}{k_0}\frac{\left(C_3^2-C_4^2\right)}{2M_1}-\frac{2\phi_1}{M_1^5}\left\{(C_3-C_4)M_1^2+GM_1(C_3+C_4)\right\}\right]$$

$$D' = \Pr N_0\left\{\frac{(C_1+C_2)}{A^2}-\phi_2\frac{(C_3+C_4)}{M_1^2}\right\}$$

$$-\Pr E_c\left[\frac{\left(C_1^2+C_2^2\right)}{4}-\frac{2G(C_1-C_2)}{A^3}+\frac{M^2\left(C_1^2-C_2^2\right)}{4A^2}\right.$$

$$+\frac{2M^2}{A^2}\left\{\frac{(C_1+C_2)}{A^2}+\frac{2G}{A^3}(C_1-C_2)\right\}$$

$$-\phi_2\phi_1^{-1}\frac{\left(C_3^2+C_4^2\right)}{4}+\frac{2G\phi_1\phi_2(C_3-C_4)}{M_1^3}$$

$$\left.-\frac{\phi_2}{k_0}\frac{\left(C_3^2+C_4^2\right)}{4M_1}-\frac{2\phi_1\phi_2}{M_1^5}\left\{C_3(M_1+2G)+C_4(M_1-2G)\right\}\right]$$

Results and Discussion

Table shows the numerical values of the skin friction at the fluid porous medium interface and the volume flux of the fluid in the channel for various values of parameters. It is observed that skin friction decreases with increase in G, M, K_0 and R_e and volume flux increases slightly with increase in K_0 and decreases with increase in G, M and R_e.

Table-1: Skin-friction and flux for U_0=5.0, □$_1$=0.8 and a=0.5

M	K_0	G	Re	Skin friction $\left(\frac{du}{dy}\right)_{y=0}$	Q (Volume flux)
1	0.5	5	1	3.9869	1.8929
1	0.5	10	1	3.4407	1.6850
1	0.5	-10	1	5.6255	2.5167
1	0.5	-5	1	5.0793	2.3088
1	0.5	0	1	4.5331	2.1008
2	0.5	10	1	1.2621	1.3734
4	0.5	+10	1	0.1735	0.7935
2	0.5	-10	1	2.4640	1.8888
4	0.5	-10	1	0.5679	1.0627
2	1	10	1	1.2577	1.3739
4	1	-10	1	0.5657	1.0027
1	0.5	5	0	4.3680	2.0573
4	0.5	10	0	0.3929	1.0784
4	0.5	10	0.5	0.2298	0.9038
4	0.5	10	0.25	0.2898	0.9798
4	0.5	10	0.75	0.1944	0.8432

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