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UNSTEADY MHD POISEUILLE DISSIPATIVE FLUID FLOW THROUGH A POROUS MEDIUM WITH TRANSPIRATION COOLING

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ABSTRACT

In this paper, an analysis of an oscillatory flow of a viscous, incompressible and electrically conducting fluid with heat radiation in a horizontal porous channel with dissipation function is carried out. The lower stationary plate and the upper plate in unsteady periodic motion are subjected to a same constant injection and suction velocity respectively. The temperature of the upper plate in periodic motion varies periodically with time. The flow in the channel is also acted upon by periodic variation of the pressure gradient. A magnetic field of uniform strength is applied in the direction normal to the plates. A closed form solution of the problem is obtained. The effects of various flow parameters on the velocity and temperature fields have been shown graphically and discussed in detail.

KEYWORDS: *Heat Radiation, Incompressible Fluid, MHD, Porous Medium and Unsteady*

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1. INTRODUCTION

The problem of finding exact solutions of the Navier-Stokes equations presents insurmountable mathematical difficulties. This is primarily due to the fact that Navier-Stokes equations are non-linear. This non-linearity is because of the presence of the convective term $\vec{V}.\nabla V$ in these non-linear equations. There are only a few exact solutions of the Navier-Stokes equations known in the closed form and that too for very simple configurations of the flow patterns where the term $\vec{V}.\nabla V$ vanishes in a natural way. The very basic exact solutions of the Navier-Stokes equations are found in the plane Couette flow, Poiseuille flow, Stokes flow etc. (Schlichting and Gersten [1]). Exact solutions for non-steady Couette flow were derived by Steinhauer [2] for the case when one of the walls is at rest in a steady flow and then suddenly accelerated to a given constant velocity. Eckert [3] obtained an exact solution of the plane Couette flow with transpiration cooling, which is a very effective process to protect certain structural elements in space shuttle during the re-entry, in the turbojet and rocket engines, exhaust nozzles etc. Singh [4] analyzed a three dimensional Couette flow with transpiration cooling. Taking magnetic field into account Singh and Sharma [5] have also studied MHD three dimensional Couette flow with transpiration cooling. A magneto hydrodynamic flow between two parallel plates with heat transfer has been analyzed by Attia and Kotb [6]. Chang and Lundgren [7] analyzed a duct flow in the magnetohydrodynamics. Nanda and Mohanty

[8] studied the hydromagnetic flow in rotating channel. Singh and Mathew [9] investigated the effects of injection/suction on an oscillatory hydromagnetic flow in a rotating horizontal channel. Exact solution of an oscillatory free convective MHD flow in a rotating channel in the presence of radiactive heat has also been studied by Singh and Garg [10]. An analysis of an oscillatory flow of a viscous, incompressible and electrically conducting fluid with heat radiation in a horizontal porous channel is studied by Singh [11]. Poonia & Chaudhary [14] and Poonia & Umashanker [15] studied radiation and chemical reaction effects of MHD free convective flow past an accelerated vertical plate embedded in a porous medium.

The present study is aimed to analyze the oscillatory MHD flow in a horizontal porous channel with thermal radiation and viscous dissipation. The upper plate which is oscillating in its own plane is at a periodically varying temperature.

2. MATHEMATICAL FORMULATION

Consider the flow of an electrically conducting, viscous incompressible fluid in a horizontal channel. The two insulated plates of the channel are distance ‘d’ apart. The fluid is injected through the lower stationary porous plate and then simultaneously sucked through the upper porous plate in oscillating motion in its own plane. The constant injection and the suction velocities at both the respective porous plates is V. A Cartesian coordinate system (x', y') is introduced so that x'-axis lies along the centerline of the channel and y'-axis, along which a magnetic field of uniform strength B_0 is applied, is perpendicular to the parallel plates. The magnetic Reynolds number is assumed to be very small, so that the induced magnetic field is negligible. The temperature difference of the plates is assumed to be high enough to induce radiation heat. All the physical quantities are independent of x' for this fully developed laminar flow. The flow is then governed by the following equations:

$$\frac{\partial v'}{\partial y'} = 0 \tag{2.1}$$

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = -\frac{1}{\rho}\frac{\partial P'}{\partial u'} + \upsilon\frac{\partial^2 u'}{\partial y'^2} - \frac{\sigma B_0^2 u'}{\rho} - \frac{\upsilon u'}{K'} + g\beta T' \tag{2.2}$$

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = -\frac{1}{\rho C_p}\frac{\partial q'}{\partial y'} + \frac{\kappa}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} + \frac{1}{\rho C_p}\left(\frac{\partial u'}{\partial y'}\right)^2 \tag{2.3}$$

$$\frac{\partial q'}{\partial y'} = 4\alpha^2 T' \tag{2.4}$$

where, α is the mean radiation absorption coefficient.

The relative boundary condition can be written as

$$\left.\begin{aligned} &u' = U(1+\varepsilon\cos\omega' t'), v' = V, T' = T_0(1+\varepsilon\cos\omega' t') \quad at \quad y' = \frac{d}{2} \\ &u' = 0, v' = V, T' = 0 \quad at \quad y' = -\frac{d}{2} \end{aligned}\right\} \tag{2.5}$$

where, ω' is the frequency of oscillation. For the oscillatory internal flow in the channel the periodic pressure gradient variables are assumed to be of the form

$$-\frac{1}{\rho}\frac{\partial P'}{\partial u'} = P\cos\omega' t' \tag{2.6}$$

Because of the assumption of constant injection and suction velocity V at the lower and upper plates respectively, continuously equation (2.1) integrates to

$$v' = V \tag{2.7}$$

Substituting equation (2.7) and introducing the following non-dimensional quantities $x = \frac{x'}{d}, y = \frac{y'}{d}, u = \frac{u'}{U}, \theta = \frac{T'}{T_0}, t = \omega' t', \omega = \frac{\omega'}{\upsilon}, P = \frac{P'}{\rho UV}, K = \frac{K'}{d^2}$

into equations (2.2) and (2.3), we get

$$\omega\frac{\partial u}{\partial t} + R_e\frac{\partial u}{\partial y} = -R_e\frac{\partial P}{\partial x} + \frac{\partial^2 u}{\partial y^2} - \left(M^2 + \frac{1}{K}\right)u + G_r\theta \tag{2.8}$$

$$\omega\frac{\partial \theta}{\partial t} + R_e\frac{\partial \theta}{\partial y} = E\left(\frac{\partial u}{\partial y}\right)^2 + \frac{1}{P_r}\frac{\partial^2 u}{\partial y^2} - \frac{N^2}{P_r}\theta \tag{2.9}$$

where, $R_e = \frac{Vd}{\upsilon}, M^2 = \frac{\sigma B_0^2 d^2}{\mu}, P_r = \frac{\mu C_p}{\kappa}, N^2 = \frac{4\alpha^2 d^2}{\kappa}, E = \frac{U^2}{C_p T_0}, G_r = \frac{g\beta d^2 T_0}{U\upsilon}$

The boundary condition in dimensionless form become

$$\left.\begin{aligned} &u = 1 + \varepsilon\cos t, \theta = 1 + \varepsilon\cos t \quad at \quad y = -\frac{1}{2} \\ &u =, \theta = 0 \quad at \quad y = \frac{1}{2} \end{aligned}\right\} \tag{2.10}$$

3. SOLUTION OF THE PROBLEM

For the mathematical solution of this unsteady periodic flow in the porous channel when the fluid is also acted upon by a periodic drop in pressure, we assume the solution in complex variable notations as

$$u(y,t) = u_0(y) + \varepsilon\, \mathrm{u}_1 e^{it}, \quad \theta(y,t) = \theta_0(y) + \varepsilon\theta_1 e^{it}, \quad -\frac{\partial P}{\partial x} = \varepsilon P e^{it} \tag{3.1}$$

where, P is a constant. The real part of the solution will have a physical significance.

The boundary condition can also be written in complex notation

$$\left.\begin{aligned} &u = 1+\varepsilon e^{it}, \theta = 1+\varepsilon e^{it} \quad at \quad y=-\frac{1}{2} \\ &u =, \theta = 0 \quad at \quad y=\frac{1}{2} \end{aligned}\right\} \tag{3.2}$$

Substituting expressions (3.1) into equations (2.8) and (2.9), we get

$$u_0'' - R_e u_0' - \left(M^2+\frac{1}{K}\right)u_0 = -G_r\theta_0 \tag{3.3}$$

$$u_1'' - R_e u_1' - \left(M^2+\frac{1}{K}+i\omega\right)u_1 = -PR_e - G_r\theta_1 \tag{3.4}$$

$$\theta_0'' - P_r R_e \theta_0' - N^2\theta_0 = -EP_r u_0' \tag{3.5}$$

$$\theta_0'' - P_r R_e \theta_0' - \left(N^2 + i\omega P_r\right)\theta_0 = -2EP_r u_0' u_1' \tag{3.6}$$

where, the primes in these ordinary differential equations denote differentiation w. r. t. y.

The boundary condition (3.2) reduces to

$$\left.\begin{aligned} &u_0 = 1, u_1 = 1, \theta_0 = 1, \theta_1 = 1 \quad at \quad y=\frac{1}{2} \\ &u_0 = 0, u_1 = 0, \theta_0 = 0, \theta_1 = 0 \quad at \quad y=-\frac{1}{2} \end{aligned}\right\} \tag{3.7}$$

The Equations (3.3) to (3.6) are still coupled and non-linear, whose exact solution are not possible, so we can expand $u_0, u_1, \theta_0, \theta_1$ in terms of E (Eckert no.) in following form, as the Eckert number is very small for incompressible flows.

$$\left.\begin{aligned} &u_0(y) = u_{01}(y) + Eu_{02}(y) \\ &u_1(y) = u_{11}(y) + Eu_{12}(y) \\ &\theta_0(y) = \theta_{01}(y) + E\theta_{02}(y) \\ &\theta_1(y) = \theta_{11}(y) + E\theta_{12}(y) \end{aligned}\right\} \tag{3.8}$$

Introducing Equation (3.8) into (3.3) to (3.7), we obtain the following systems of equations.

$$u_{01}''(y) + u_{01}'(y) - \left(M^2+\frac{1}{K}\right)u_{01}(y) = -G_r\theta_{01}(y) \tag{3.9}$$

$$u_{02}''(y) + u_{02}'(y) - \left(M^2+\frac{1}{K}\right)u_{02}(y) = -G_r\theta_{02}(y) \tag{3.10}$$

$$u_{11}''(y) + -R_e u_{11}'(y) - \left(M^2+\frac{1}{K}+i\omega\right)u_{11}(y) = -PR_e - G_r\theta_{11} \tag{3.11}$$

$$u''_{12}(y)+-\mathrm{Re}\,u'_{12}(y)-\left(M^{2}+\frac{1}{K}+i\omega\right)u_{12}(y)=-G_r\theta_{12} \quad (3.12)$$

$$\theta''_{01}(y)-R_eP_r\theta'_{01}(y)-N^2\theta_{01}(y)=0 \quad (3.13)$$

$$\theta''_{02}(y)-R_eP_r\theta'_{02}(y)-N^2\theta_{02}(y)=-P_ru'^{2}_{01}(y) \quad (3.14)$$

$$\theta''_{11}(y)-R_eP_r\theta'_{11}(y)-(N^2+i\omega)\theta_{11}(y)=0 \quad (3.15)$$

$$\theta''_{12}(y)-R_eP_r\theta'_{12}(y)-(N^2+i\omega)\theta_{12}(y)=-2P_ru'_{01}(y)u'_{11}(y) \quad (3.16)$$

and the corresponding boundary conditions are

$$\left.\begin{array}{l} y=\frac{1}{2}, u_{01}=1, u_{02}=0, u_{11}=1, u_{12}=0, \theta_{01}=1, \theta_{02}=0, \theta_{11}=1, \theta_{12}=0 \\ y=-\frac{1}{2}, u_{01}=0, u_{02}=0, u_{11}=0, u_{12}=0, \theta_{01}=0, \theta_{02}=0, \theta_{11}=0, \theta_{12}=0 \end{array}\right\} \quad (3.17)$$

Solving equations (3.9) to (3.16) under the boundary conditions (3.17), we get

$$\theta_{01}(y)=a_1e^{m_1y}+a_2e^{m_2y} \quad (3.18)$$

$$u_{01}(y)=a_6e^{m_3y}+a_7e^{m_4y}+a_8e^{m_1y}+a_9e^{m_2y} \quad (3.19)$$

$$\begin{aligned}\theta_{02}(y)=&a_{22}e^{m_1y}+a_{23}e^{m_2y}-[a_{10}e^{2m_3y}+a_{11}e^{2m_4y}+a_{12}e^{2m_1y}+a_{13}e^{2m_2y}+a_{14}e^{(m_3+m_4)y}\\&+a_{15}e^{(m_1+m_3)y}+a_{16}e^{(m_2+m_3)y}+a_{17}e^{(m_1+m_4)y}+a_{18}e^{(m_2+m_4)y}+a_{19}e^{(m_1+m_2)y}]\end{aligned} \quad (3.20)$$

$$\begin{aligned}u_{02}(y)=&a_{26}e^{m_3y}+a_{27}e^{m_4y}-(a_{28}e^{m_1y}+a_{29}e^{m_2y}+a_{30}e^{2m_3y}+a_{31}e^{2m_4y}+a_{32}e^{2m_1y}\\&+a_{33}e^{2m_2y}+a_{34}e^{(m_3+m_4)y}+a_{35}e^{(m_1+m_3)y}+a_{36}e^{(m_2+m_3)y}+a_{37}e^{(m_1+m_4)y}+a_{38}e^{(m_2+m_4)y}\\&+a_{39}e^{(m_1+m_2)y})\end{aligned} \quad (3.21)$$

$$\theta_{11}(y)=b_3e^{n_1y}+b_4e^{n_2y} \quad (3.22)$$

$$u_{11}(y)=b_7e^{n_3y}+b_8e^{n_4y}+b_9+b_{10}e^{n_1y}+b_{11}e^{n_2y} \quad (3.23)$$

$$\begin{aligned}\theta_{12}(y)=&b_{30}e^{n_1y}+b_{31}e^{n_2y}-(b_{12}e^{(m_3+n_3)y}+b_{13}e^{(m_3+n_4)y}+b_{14}e^{(m_3+n_1)y}+b_{15}e^{(m_3+n_2)y}\\&+b_{16}e^{(m_4+n_3)y}+b_{17}e^{(m_4+n_4)y}+b_{18}e^{(m_4+n_1)y}+b_{19}e^{(m_4+n_2)y}+b_{20}e^{(m_1+n_3)y}+b_{21}e^{(m_1+n_4)y}\\&+b_{22}e^{(m_1+n_1)y}+b_{23}e^{(m_1+n_2)y}+b_{24}e^{(m_2+n_3)y}+b_{25}e^{(m_2+n_4)y}+b_{26}e^{(m_2+n_1)y}+b_{27}e^{(m_2+n_2)y})\end{aligned} \quad (3.24)$$

$$\begin{aligned}u_{12}(y)=&b_{52}e^{n_3y}+b_{53}e^{n_4y}-(b_{32}e^{n_1y}+b_{12}e^{n_2y}+b_{34}e^{(m_3+n_3)y}+b_{35}e^{(m_3+n_4)y}\\&+b_{36}e^{(m_3+n_1)y}+b_{37}e^{(m_3+n_2)y}+b_{38}e^{(m_4+n_3)y}+b_{39}e^{(m_4+n_4)y}+b_{40}e^{(m_4+n_1)y}+b_{41}e^{(m_4+n_2)y}\\&+b_{42}e^{(m_1+n_3)y}+b_{43}e^{(m_1+n_4)y}+b_{44}e^{(m_1+n_1)y}+b_{45}e^{(m_1+n_2)y}+b_{46}e^{(m_2+n_4)y}+b_{47}e^{(m_2+n_4)y}\\&+b_{48}e^{(m_2+n_1)y}+b_{49}e^{(m_2+n_2)y})\end{aligned} \quad (3.25)$$

Skin-Friction

The expression for the shear stress is given by

$$\tau = -\left(\frac{\partial F}{\partial y}\right)_{y=0} = -\left(u_0' + \varepsilon u_1' e^{it}\right)_{at\ y=0} \tag{3.26}$$

Nusselt Number

The expression for the rate of heat transfer is given by

$$Nu = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = -\left(\theta_0' + \varepsilon \theta_1' e^{it}\right)_{at\ y=0} \tag{3.27}$$

4. RESULTS AND DISCUSSION

In order to have a physical insight into the problem we have evaluated, numerically the expressions for the velocity $u(y,t)$, the Temperature $\theta(y,t)$, the skin friction τ and the rate of heat transfer Nu. These numerical values are shown graphically to assess the effects of the variables of Reynolds number Re, Hartmann number M, The Pressure gradient P, The Porosity Parameter K, The Eckert number E and the frequency of oscillation ω. The effect of various parameters on skin friction and Nusselt number is also shown in table-1 and 2.

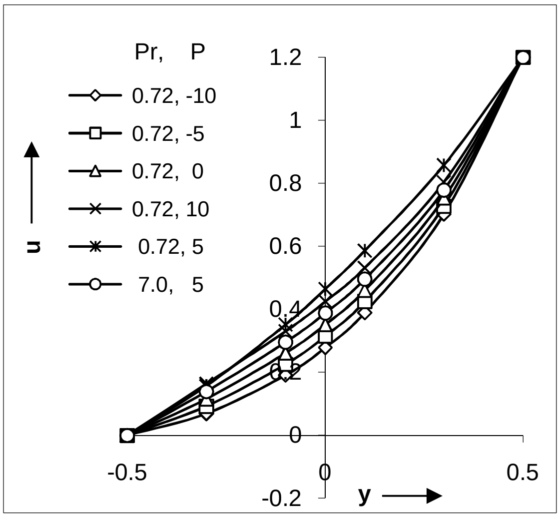

Figure 1: Effects of Pr and P on Velocity Profile (Re=0.5, N=1, M=2, K=1, Gr=1, ω=5,E=1, ε=0.2)

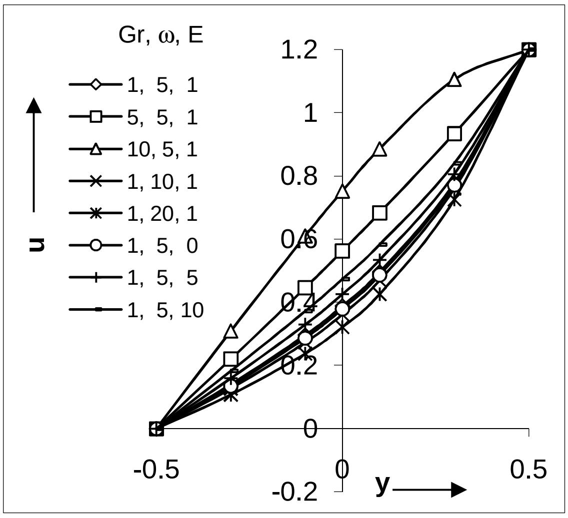

Figure 2: Effects of Gr, ω and E on Velocity Profile (P=5, Pr=0.72, Re=0.5, N=1, M=2, K=1, ε=0.2)

Figure 1, shows the effects of Prandtl number Pr and the Pressure gradient P on velocity profile against y. It can be seen that velocity profile is increasing exponentially as increasing y. It also observed that as the favorable pressure gradient P increasing the velocity also increases and remains positive over the entire width of the channel. This means that the increasing favorable pressure gradient accelerates the flow field. It is also examined that the velocity for Pr=0.72 is higher than that of Pr=7.0. Physically it is possible because fluids with higher Prandtl number have high viscosity and hence move slowly.

The variation of the velocity profile with the Grashof number Gr. The frequency of oscillations ω and the Eckert number E are shown in figure 2. The magnitude of velocity leads to an increase with an increase in Gr. It is due to the fact an increase in the value of the thermal Grashof number has the tendency to increase the thermal buoyancy effect. It is also observed that increasing the frequency of oscillation leads to decrease in the velocity field, whereas, an increase in the Eckert number results an increase in the velocity field.

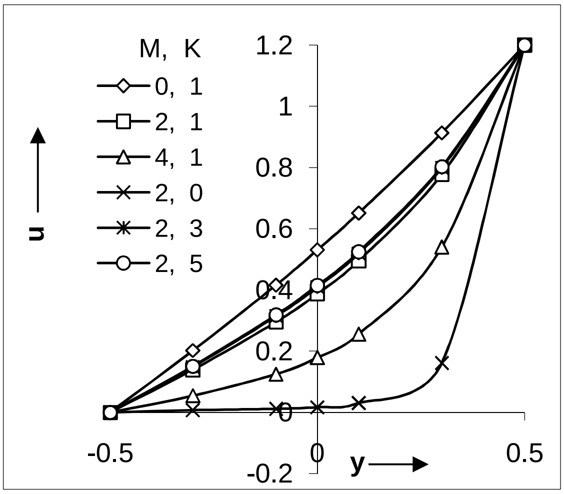

Figure 3: Effects of M and K on Velocity Profile (P=5,Pr=0.72,Re=0.5,N=1,Gr=1, ω=5,E=1, ε=0.2)

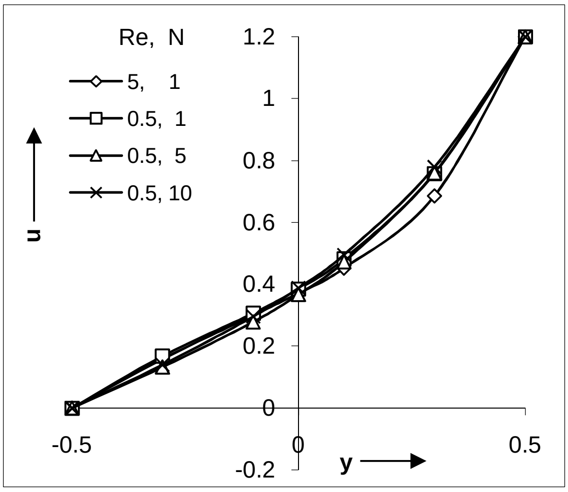

Figure 4: Effects of Re and N on Velocity Profile (P=5,Pr=0.72, M=2, K=1, Gr=1, ω=5, E=1, ε=0.2)

Figure 3, shows the variation of velocity profiles under the influence of magnetic parameter M, the porosity parameter K, it is evident from figure 3 that the velocity decreases with increase of magnetic parameter. This is because of the reason that the effect of a transverse magnetic field on an electrically conducting fluid gives rise to a resistive type force (called Lorentz Force) similar to drag force and upon increasing the values of M increases the drag force which has a tendency to slow down the motion of the fluid. It is also examined that the velocity increases with increasing the porosity parameter. The presence of a porous medium increases the resistance to flow resulting in a decrease in the flow velocity. This behavior is depicted by the decrease in the velocity as K decreases.

The variation of velocity profile with the Reynold number Re and the radiation parameter N are shown in figure 4. It is concluded that an increase in Reynold number results a decrease in the velocity profile.

Figure 5 shows the variation of temperature under the influence of the Prandtl number Pr, the Reyonld number Re and the radiation parameter N against y. It is examined that temperature profile increases with increasing the Prandtl number for y < -0.2, after that the magnitude of temperature for air (Pr=0.72) is greater than of water (Pr=7.0). This is due to fact that the thermal conductivity of fluid decreases with increasing Pr, resulting a decrease in thermal boundary layer thickness. It also concluded that the temperature profile decreases with increasing Re.

In both figures 4 and 5, velocity and temperature profile increase with the increase of radiation parameter N. The effect of radiation is to increase the rate of energy transport to the gas, there by making the thermal boundary layer become thicker and fluid become warmer, this enhances the effect of thermal buoyancy of the driving body force due to the mass density variation which are coupled to temperature and there for, increasing the fluid velocity.

The variation of temperature profile in the frequency of oscillations ω and the Eckert number E are exhibited in figure 6. It is found that the temperature field goes on increasing with the increase of ω four $y<0$ and after that the temperature field decreases with increasing ω. It is also examined that an increase in the Eckert number leads to an increase in temperature profile.

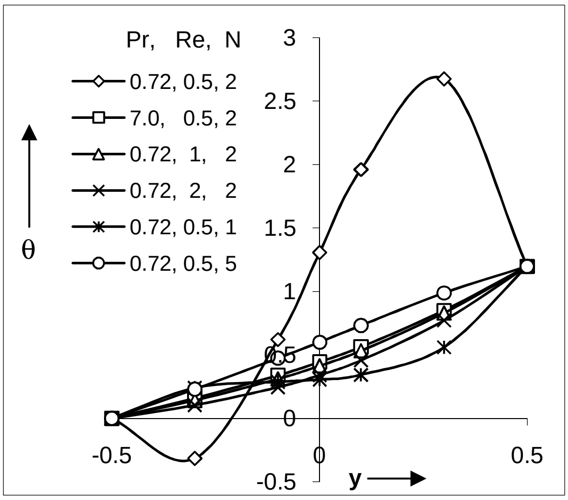

Figure 5: Effects of Pr, Re and N on Temperature Profile, (P=5, M=2, K=1, Gr=1, ω=5, E=1, ε =0.2)

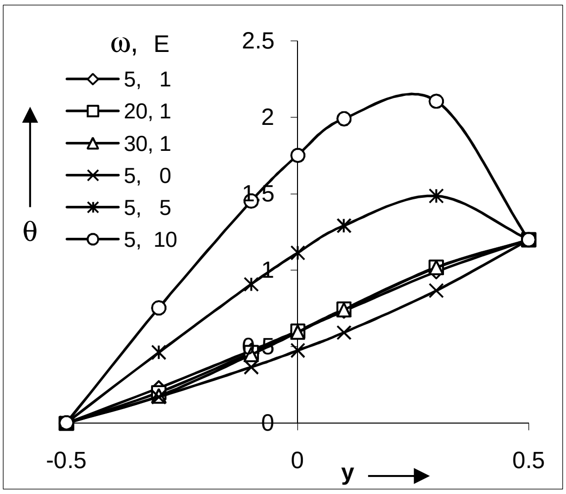

Figure 6: Effects of ω and E on Temperature Profile, (P=5,Pr=0.72, Re=0.5,N=1,M=2,K=1,Gr=1, ε =0.2)

Table 1 and Table 2 shows that the effect of various flow parameters on skin-friction and Nusselt number respectively. It is concluded from table-1 that skin-friction increases with increasing Re, N and M, where as, it decreases with increasing P, Pr, K, Gr and E. It can be seen from table-2 that Nusselt number increases with increasing Re and N, where as, it decreases with increasing Pr and E.

NOMENCLATURE

U - the constant velocity of vertical porous channel ($m.s^{-1}$)

T_0 - the temperature at the channel (K), T - the temperature in the boundary (K)

u', v' - denotes the component of velocity in the boundary layer in x' and y' respectively ($m.s^{-1}$)

t' - the time (s), d – constant, g – the acceleration due to the gravity ($m.s^{-1}$)

C_P - the heat capacity of the fluid ($J.Kg^{-1}.K^{-1}$), B_0 - the magnetic induction, q' – the Radiactive heat flux,

P_r - the Prandtl number, K' – the Porosity parameter, K – Non-dimensional Porosity parameter

M - the magnetic parameter, Re – the Reynold number, E – the Eckert number, P – the pressure gradient

N – the radiation parameter, G_r - the thermal Grashof number, Nu – the Nusselt number

GREEK LETTERS

α - the mean radiation absorption coefficient

β - the volumetric coefficient of thermal expansion (K^{-1}), ρ - the density of the fluid, $Kg.m^{-3}$

θ - Dimensionless temperature, μ - the coefficient of viscosity (Pa.s)

τ - Dimensionless skin-friction, υ - the kinematics viscosity ($m^2.s^{-1}$)

σ - the electrical conductivity, κ - the coefficient of thermal conductivity ($Wm^{-1}K^{-1}$)

ω - the frequency of the suction velocity

Table 1

□	P	Pr	Re	N	M	K	Gr	E
-0.98132	-10	0.72	0.5	1	2	1	1	1
-0.98985	0	0.72	0.5	1	2	1	1	1
-0.99838	10	0.72	0.5	1	2	1	1	1
-0.99412	5	0.72	0.5	1	2	1	1	1
-1.17644	5	7	0.5	1	2	1	1	1
-0.96154	5	0.72	1	1	2	1	1	1
-0.89339	5	0.72	2	1	2	1	1	1
-0.98783	5	0.72	0.5	2	2	1	1	1
-0.96239	5	0.72	0.5	5	2	1	1	1
-1.17572	5	0.72	0.5	1	0	1	1	1
-0.63611	5	0.72	0.5	1	4	1	1	1
-1.02814	5	0.72	0.5	1	2	5	1	1
-1.03252	5	0.72	0.5	1	2	10	1	1
-1.18569	5	0.72	0.5	1	2	1	5	1
-1.3862	5	0.72	0.5	1	2	1	10	1
-1.01755	5	0.72	0.5	1	2	1	1	5
-1.04683	5	0.72	0.5	1	2	1	1	10

Table 2

Nu	Pr	Re	N	E
-1.29427	0.72	0.5	1	1
-8.07233	7	0.5	1	1
-1.28016	0.72	1	1	1
-1.20662	0.72	2	1	1
-1.12064	0.72	0.5	2	1
-0.25769	0.72	0.5	5	1
-1.93679	0.72	0.5	1	5
-2.73993	0.72	0.5	1	10

5. CONCLUSIONS

In this paper, we analyzed an oscillatory flow of a viscous, incompressible and electrically conducting fluid with heat radiation in a horizontal porous channel with dissipation function. The lower stationary plate and the upper plate in unsteady periodic motion are subjected to a same constant injection and suction velocity respectively.

The velocity for Pr=0.72 is higher than that of Pr=7.0 due to fluids with higher Prandtl number have high viscosity and hence move slowly. It is observed that increasing the frequency of oscillation leads to decrease in the velocity field, whereas, an increase in the Eckert number results in an increase in the velocity field and also examined that the velocity increases with increasing the porosity parameter because the presence of a porous medium increases the resistance to flow resulting in a decrease in the flow velocity.

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