UNSTEADY MHD COUETTE FLOW BETWEEN TWO PARALLEL HORIZONTAL POROUS PLATES IN AN INCLINED MAGNETIC FIELD

Magaji A. S.

Department of Mathematical Sciences, Kaduna State University, Kaduna, Nigeria

*Corresponding E-mail: : abu_magaji@kasu.edu.ng

ABSTRACT

In this paper, the study of unsteady Magnetohydrodynamic (MHD) couette flow between two parallel horizontal porous plates in an inclined magnetic field was carried out. The momentum and energy equations are written in a dimensionless form using the dimensionless parameters. Variable separable technique was employed to solve the velocity profile and temperature distribution. However, out of many results, we conclude that, at high Hartmann number Ha, the velocity u of the fluid decreases. When the magnetic field is high, it reduces the energy loss through the plates.

Keywords: *Couette Flow, Porous Plates, Magnetic Field, Hartmann Number, Grashof Number, Prandit Number*

INTRODUCTION

The study of unsteadyMagnetohydrodynamic(MHD) couette flow between two parallel horizontal porous plates in an Inclined Magnetic Field has many applications in different field of engineering and technology. The interaction between the conduction fluid and the magnetic field radically modifies the flow, with effects on such important flow properties as heat transfer, the detail nature of which is strongly dependent on the orientation of the magnetic field. When fluid moves through a magnetic field, an electric field or consequently a current may be induced, and in turn the current interacts with the magnetic field to produce a body force on fluid. The production of this current has led to MHD power generators, MHD devices, nuclear engineering and the possibility of thermonuclear power has created a great practical need for understanding the dynamics of conducting. The influence of a magnetic field in viscous incompressible flow of electrically conducting fluid is of use in extrusion of plastics in the manufacture of rayon, nylon etc.

The study of fluid flow through porous media and heat transfer is fundamental in nature. Hannes Alfven (1942), a Swedish electrical engineer first initiated the study of MHD. Shercliff (1956) considered the steady motion of an electrically conducting fluid in pipes under transverse magnetic fields. Sparrow and Cess (1961) observed that the free convection heat transfer to liquid metals may be significantly affected by the presence of magnetic field. Sato (1961) and Sutton and Sherman (1965) investigated the hydromagnetic flow of a viscous ionized gas between two parallel plates taking Hall effects into account.Drake (1965) considered flow in a channel due to periodic pressure gradient and solved the resulting equation by separation of variables methods. Singh and Ram (1978) studied laminar flow of an electrically conducting fluid through a channel in the presence of a transverse magnetic field under the influence of a periodic pressure gradient and solved the resulting differential equation by the method of Laplace transform. More to this, Ram et al (1984) have analyzed Hall effects on heat and mass transfer flow through porous media. Soundelgekar and Abdulla Ali (1986) studied the flow of viscous incompressible electrically conducting fluid past an impulsive started infinite vertical isothermal plate. Singh (1993) considered steady MHD fluid flow between two parallel plates. John Mooney and Nick Stokes (1997) considered the numerical requirements for MHD flows with free surfaces. Raptis and Perdikis (1999) considered the effects of

thermal radiation and free convectional flow past a moving vertical plate. McWhirter et al. (1998), and Geindreau and Auriault (2002) discussed in detail magnetohydrodynamic flow through porous medium. The investigations considering rotational effects are also very important, and the reason for studying flow in a rotating porous medium or rotating flow of a fluid overlying a porous medium in the presence of a magnetic field is fundamental because of its numerous applications in industrial, astrophysical and geophysical problems. The problem of MHD Couette flow and heat transfer between parallel plates is a classical one that has several applications in MHD accelerators, MHD pumps and power generators, and in many other industrial engineering designs. Thus such problems have been much investigated by researchers such as, Seth et al. (1982), Singh et al. (1994), Chauhan and Vyas (1995), Attia (2006, 2009), Attia and Ewis (2010), Seth et al. (2011), and Attia et al (2011).

In most of the investigations, as above, we notice that, the Hall term is neglected for small or moderate values of the magnetic field in applying Ohm's law in the analysis. When a strong magnetic field is applied, the influence of electromagnetic force is noticeable, and the strong magnetic field induces many complex phenomenons in an electrically conducting flow regime including Hall currents, Joule's heating etc. as stated by Cramer and Pai (1973). In fact, in an ionized gas under strong magnetic field when the density is low, the Hall current is induced which is mutually perpendicular to both electrical and magnetic fields. It has significant effect on the current density and hence on the electromagnetic force. Hall currents can have strong influence on the fluid flow distributions in MHD flow systems, e.g. in MHD power generators, electrically conducting aerodynamics and at mospheric science. Hall effects on MHD flow in a rotating channel have been investigated by Ghosh and Bhattacharjee (2000) in the presence of inclined magnetic field. Al-Hadhrami (2003) discussed flow through horizontal channel and porous material and obtained velocity expressions in terms of the Reynolds number. Ganesh (2007) studied unsteady MHD stokes flow of a viscous fluid between two parallel porous plates.

Further studies of Hall effects on MHD flow in parallel plate channel with perfectly conducting walls with heat transfer characteristics have been presented by Ghosh et al. (2009) who analyzed the asymptotic behavior of the solution. Stamenkovic et al (2010) investigated MHD flow of two immiscible and electrically conducting fluids between isothermal,

insulated moving plates in the presence of applied electric and magnetic field. He matched the solution at the interface and it was found that decrease in magnetic field inclination angle flattens out the velocity and temperature profiles. Rajput and Sahu (2011) studied the effect of a uniform transverse magnetic field on the unsteady transient free convection flow of an incompressible viscous electrically conducting fluid between two infinite vertical parallel porous plates with constant temperature and variable mass diffusion. Monyenge et al studied steady MHD poiseuille flow between two infinite parallel porous plates in an inclined magnetic field and discover that high magnetic field strength decreases the velocity. Sandeep and Sugunamma (2013) analyzed the effect of an inclined magnetic field on unsteady free convection flow of a dusty viscous fluid between two infinite flat plates filled by a porous medium.

Hall currents in MHD Couette flow and heat transfer effects have been investigated in parallel plate channels with or without ion-slip effects by Soundalgekar et al. (1979), Soundalgekar and Uplekar (1986), and Attia (2005). Hall effects on MHD couette flow between arbitrarily conducting parallel plates have been investigated in a rotating system by Mandal and Mandal (1983). The same problem of MHD couette flow rotating flow in a rotating system with Hall current was examined by Ghosh (2002) in the presence of an arbitrary magnetic field. The study of hydromagneticcouette flow in a porous channel has become important in the applications of fluid engineering and geophysics. Krishna et al. (2002) investigated convection flow in a rotating porous medium channel. Bég et al. (2009) investigated unsteady magnetohydrodynamiccouette flow in a porous medium channel with Hall current and heat transfer. When the viscous fluid flows adjacent to porous medium, Ochoa-Tapia (1995) suggested stress jump conditions at the fluid porous interface when porous medium is modeled by Brinkman equation. Using these jump conditions, Kuznetsov (1998) analytically investigated the couette flow in a composite channel partially filled with a porous medium and partially with a clear fluid. Chauhan and Rastogi (2009), heat transfer effects on MHD conducting flow with Hall current in a rotating channel partially filled with a porous material using jump conditions at the fluid porous interface. Chauhan and Agrawal (2010) investigated Hall current effects in a rotating channel partially filled with a porous medium using continuity of velocity components and stresses at the porous interface. Chauhan and Agrawal (2011) further studied effects of Hall current on couette flow

in similar geometry and matching conditions at the fluid porous interface. The current work deals with the rotating magnetohydrodynamic Couette flow of electrically conducting fluid and heat transfer in a channel partially filled by a porous medium, with Hall effects. The jump condition is applied at the fluid porous interface suggested by Ochoa Tapia and Whitaker (1995). Heat transfer effects on rotating MHD couette flow in a channel partially field by a porous medium with hall current has been discussed by Singh and Rastogi (2012).

MATERIALS AND METHODS
Problem Formulation
A magnetic field of field strength represented by the vector B at right angle to the flow of an electrically conducting fluid moving with velocity V was introduced. Here, an electric field vector denoted by E is induced at right angle to both V and B because of their interaction.

We assume that the conducting fluid exhibits adiabatic flow in spite of magnetic field, then we denote the electrical conductivity of the fluid by a scalar σ.

Lorentz force comes in place because the conducting fluid cuts the lines of the magnetic field in electric generator. This vector F is parallel to V but in opposite direction but is perpendicular to the plane of both J and B.

Laminar flow through a channel under uniform transverse magnetic field is important because of the use of MHD generator, MHD pump and electromagnetic flow meter.

Here, we consider an electrically conducting, viscous, unsteady, incompressible fluid moving between two infinite parallel plates both kept at a constant distance 2h.

The equations of motion are the continuity equation

$$\nabla \cdot V = 0 \qquad \text{--------------------(1)}$$

And the Navier-Stokes equation

$$\rho\left[\left(\frac{\partial}{\partial t} + V.\nabla\right)\right]V = f_B - \nabla P + \mu\nabla^2 V$$

Where ρ is the fluid density, f_B is the body force per unit mass of the fluid, μ is the fluid viscosity and P is the pressure acting on the fluid. If one dimensional flow is assumed, so that we choose the axis of the channel formed by the two plates as the x-axis and assume that flow is in this direction. Observed that $\bar{u}, \bar{v}$ and $\bar{w}$ are the velocity components in $\bar{x}$, $\bar{y}$ and $\bar{z}$ directions respectively. Then this implies $\bar{v}=\bar{w}=0$ and $\bar{u} \neq 0$, then the continuity equation is satisfied. From this we infer that u is independent of x and this

will make $[(V.\nabla)V]$ in the Navier-stokes equation to vanish. The body force f_B is neglected and replace with Lorentz force and from the assumption that the flow is one dimensional, it means that the governing equation for this flow is

$$\frac{\partial \bar{u}}{\partial \bar{t}} = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial \bar{x}} + v\frac{\partial^2 \bar{u}}{\partial \bar{y}^2} + \frac{F_x}{\rho} \quad \text{-----------------3}$$

$v = \frac{\mu}{\rho}$ is the kinematics viscosity and F_x is the component of the magnetic force in the direction of x-axis. Assuming unidirectional flow so that $\bar{v}=\bar{w}=0$ and $B_x=B_z=0$ since magnetic field is along y-direction so that $v = i\bar{u}$ and $B=B_{0j}$ where B_0 is the magnetic field strength component. Now,

$$F_x = \sigma\left[\left(i\bar{u} \times jB_0\right] \times jB_0\right) \quad \text{--------------(4)}$$

So that we have

$$\frac{F_x}{\rho} = -\frac{\sigma}{\rho}B_0^2\bar{u} \quad \text{--------------(5)}$$

Then (3) becomes

$$\frac{\partial \bar{u}}{\partial \bar{t}} = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial \bar{x}} + v\frac{\partial^2 \bar{u}}{\partial \bar{y}^2} - \frac{\sigma}{\rho}B_0^2\bar{u} \quad \text{--------------(6)}$$

From (6), when angle of inclination is introduced, we have

$$\frac{\partial \bar{u}}{\partial \bar{t}} = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial \bar{x}} + v\frac{\partial^2 \bar{u}}{\partial \bar{y}^2} - \frac{\sigma}{\rho}B_0^2\bar{u}\sin^2(\alpha) \quad \text{------(7)}$$

Where α is the angle between V and B. Equation (3.7) is general in the sense that both field can be assessed at any angle α for $0 \le \alpha \le \pi$.

Because of the porosity of the lower plate, the characteristic velocity v_0 is taken as a constant so as to maintain the same pattern of flow against suction and injection of the fluid in which it is moving perpendicular to the fluid flow. The origin is taken at the centre of the channel and $\bar{x}, \bar{y}$ coordinate axes are parallel and perpendicular to the channel walls respectively. The governing equation, that is, the momentum equation is as follows

$$\rho\frac{\partial \bar{u}}{\partial t} = -v_0\frac{\partial \bar{u}}{\partial \bar{y}} - \frac{\partial \bar{p}}{\partial \bar{x}} + \mu\frac{\partial^2 \bar{u}}{\partial \bar{y}^2} - \frac{\sigma}{\rho}B_0^2\bar{u}\sin^2(\alpha) + g\beta\left(\bar{T}-\bar{T}_\infty\right) \quad \text{---(8)}$$

Since the flow is isentropic, the energy equation is given as

$$\frac{\partial T}{\partial \bar{t}} = \frac{k}{\rho c_p}\frac{\partial^2 T}{\partial \bar{y}^2} + \frac{1}{\rho c_p}\frac{\partial q}{\partial y} \quad \text{--------(9)}$$

Where k the thermal conductivity of the fluid, ρ is the density, c_p is the specific heat constant pressure and $\bar{T}$ the temperature.

The q in (ii) is called the radiative heat flux. It is given by,

$$\frac{\partial q}{\partial y} = 4\alpha^2(\bar{T} - T) \quad \text{----------------------(10)}$$

The boundary conditions are

$$\bar{u}(y,t) = 0, \bar{T} = \bar{T}_\infty \quad at \ \bar{t} = 0,$$
$$\bar{u}(-L,\bar{t}) = 0, \bar{u}(L,\bar{t}) = \frac{v}{L}, T = T_w \quad at \ \bar{t} > 0 \quad \text{--- (11)}$$

In order to solve the equations (8) and (9) of the problem subject to the boundary conditions (11), we introduce the following dimensionless parameters:

$$\bar{x} = xL, \quad \bar{y} = yL, \quad \bar{p} = pp\frac{v^2}{L^2}, \quad \bar{u} = \frac{uv}{L},$$

$$\bar{t} = \frac{tL^2}{v}, P_r = \frac{\mu c_p}{k}, \theta = \frac{\bar{T} - \bar{T}_\infty}{\bar{T}_w - \bar{T}_\infty}, Ha^2 = \frac{\sigma L^2 B_0^2}{\mu}, Gr = \frac{\rho L^2 gb(\bar{T}_\omega - \bar{T})}{\mu v}, N^2$$

$$= \frac{4a^2 L^2}{k}, Re = \frac{uL}{v}$$

$$\text{---------------(12)}$$

Now equations (8) and (9) become

$$\frac{\partial u}{\partial t} = B\frac{\partial u}{\partial y} + \frac{\partial^2 u}{\partial y^2} - M^2 u + Gr\theta$$

$$\text{---(13)}$$

Where $M = m^*\sin\alpha$ and $m^* = LB_o\sqrt{\frac{\sigma}{\mu}} = Ha, B = \frac{-Re}{\rho}$

$$Pr\frac{\partial\theta}{\partial t} = \frac{\partial^2\theta}{\partial y^2} + N^2\theta$$

---------------------------(14)

The boundary conditions in dimensionless form are

$$u(y,t) = 0, \theta(-1,t) = 0 \quad at\ t = 0$$

$$u(-1,t) = 0, \quad u(1,t) = 1, \quad \theta(1,t) = 1\ at\ t > 0 \quad -----(15)$$

Method of Solution/Solution of The Problem

The momentum equation, energy equation and concentration equation can be reduced to the set of ordinary differential equations, which are solved analytically. This can be done by representing the velocity, temperature of the fluid in the perturbation series as follows

$$(y,t) = U_0(y) + \varepsilon U_1(y)e^{i\omega t} + O(\varepsilon^2) \quad -----------(16)$$

$$\theta(y,t) = \theta_0(y) + \varepsilon\theta_1(y)e^{i\omega t} + O(\varepsilon^2) \quad ---------(17)$$

Substituting equations (16) and (17) into equations (13), (14) and (15). Equating the coefficients of harmonic and non-harmonic term and neglecting the coefficients of higher order of ε^2, we get:

$$U_0''(y) + BU_0'(y) - M^2 U_0(y) = -Gr\theta_0(y) \quad ---(18)$$

$$U_1''(y) + AU_1'(y) - bU_1(y) = -Gr\theta_1(y) \quad ----(19)$$

Where $b = M^2 + i\omega$,

$$\theta_0''(y) + N^2\theta_0(y) = 0 \qquad -----------(20)$$

$$\theta_1''(y) - a_1\theta_1(y) = 0 \qquad -------------(21)$$

Where $a_1 = i\omega Pr - N^2$

The corresponding boundary conditions become

$$U_o(-1,t) = 0, \theta_o(-1,t) = 0$$

$$U_o(1,t) = 1, \theta_o(1,t) = 1$$

$$U_1(-1,t) = 0, \theta_1(-1,t) = 0$$

$$U_1(1,t) = 1, \theta_1(1,t) = 1 \qquad --------------------(22)$$

We now solve equations (16) – (22) under the relevant boundary conditions for the mean flow and unsteady flow separately.

The mean flows are governed by the equations (18) and (20) where U_0, θ_0 and are called the mean velocity, mean temperature and mean concentration respectively. The unsteady flows are governed by equations (19) and (20) where U_1, θ_1 are the unsteady components.

These equations are solved analytically under the relevant boundary conditions (22) as follows;

Solving equations (18) and (20) subject to the corresponding relevant boundary conditions in (22), we obtain the mean velocity and mean temperature as follows

$$U_0(y) = C_5 e^{m_1 y} + C_6 e^{m_2 y} + K_1 cosNy + K_2 sinNy \quad ----(23)$$

$$(y) = c_1 cosNy + c_2 sinNy \qquad -------------(24)$$

Similarly, solving equations (19) and (21) under the

relevant boundary conditions in (22), the unsteady velocity, unsteady temperature B

$$U_1(y) = C_7 e^{m_3 y} + C_8 e^{m_4 y} + K_3 e^{\sqrt{a}y} + K_4 e^{-\sqrt{a}y} \quad --(25)$$

$$\theta_1(y) = C_3 e^{\sqrt{a}y} + C_8 e^{-\sqrt{a}y} \qquad ---------------(26)$$

Therefore, the solutions for the velocity and temperature profiles are

$$U(y,t) = C_5 e^{m_1 y} + C_6 e^{m_2 y} + K_1 cosNy + K_2 sinNy$$
$$+ \varepsilon[C_7 e^{m_3 y} + C_8 e^{m_4 y} + K_3 e^{\sqrt{a}y} + K_4 e^{-\sqrt{a}y}]e^{iwt}$$

------------------------(27)

$$\theta(y,t) = c_1 cosNy + c_2 sinNy + \varepsilon[C_3 e^{\sqrt{a}y} + C_8 e^{-\sqrt{a}y}]e^{iwt}$$

--------------------------------------(28)

RESULTS AND DISCUSSION

To discussunsteady MHD couette flow between two parallel horizontal porous plates in aninclined magnetic field, the velocity profile u and the temperature distribution θare showngraphically against y using Matlab for different values of the following parameters such as Hartmann number Ha, Grashof number Gr, Radiation parameter N and Prandtl number Pr.

Figures 1, 2, 3, and 4 depict decrease in velocity u as Hartmann number Ha increases with effect of increase in the angle of inclination α on velocity. To this effect, the magnetic field suppresses the turbulence of flow.

Figure 5, 6, 7, and 8 show the effect of Grashof number Gr on velocity profile u. it is observed that the velocity u increases with increase in Grash of number Gr.

Figure 9 shows the effects of Radiation parameter N on temperature distribution θ. It is shown that the temperature θ increases with increase in radiation parameter N.

Figure 10 depicts the effect of Prandtl number Pr on temperature distribution θ. It shows that the temperature θ decreases with increase in Prandtl number Pr.
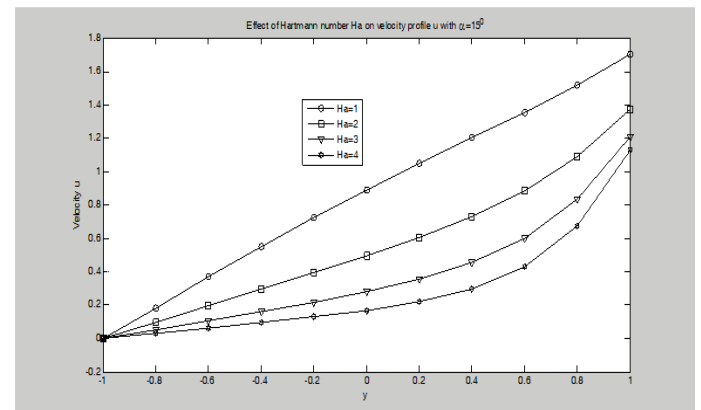

Figure1: Effect of Hartmann number Ha on velocity profile u with α=15⁰,B=1,t=0.5,ε=0.02,Gr=1,N=1 andω=1.

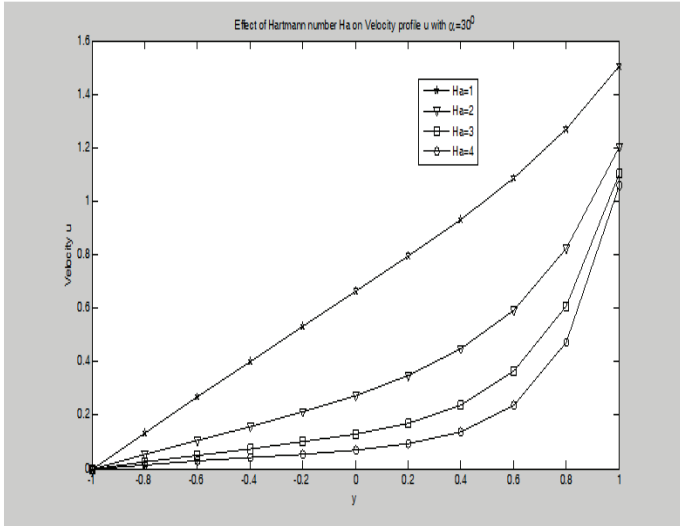Figure2: Effect of Hartmann number Ha on velocity profile u with $\alpha=30^0$,B=1,t=0.5,ε=0.02,Gr=1,N=1 andω=1
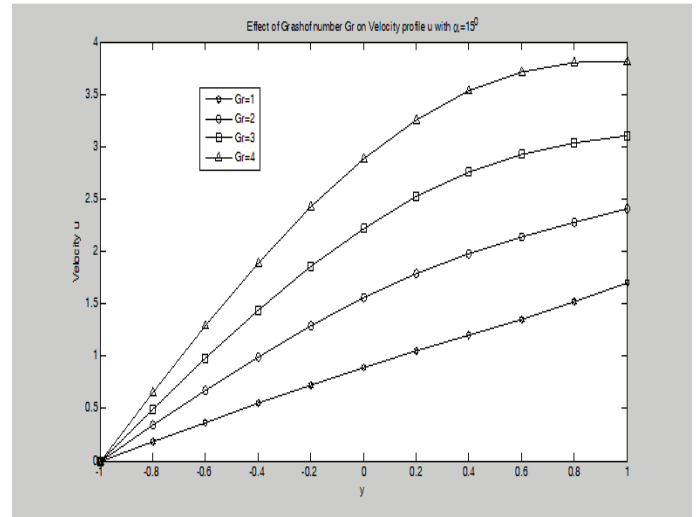

Figure5: Effect of Grashof number Gr on velocity profile u with $\alpha=15^0$,t=0.5,ε=0.02,Ha=1,N=1 andω=1.

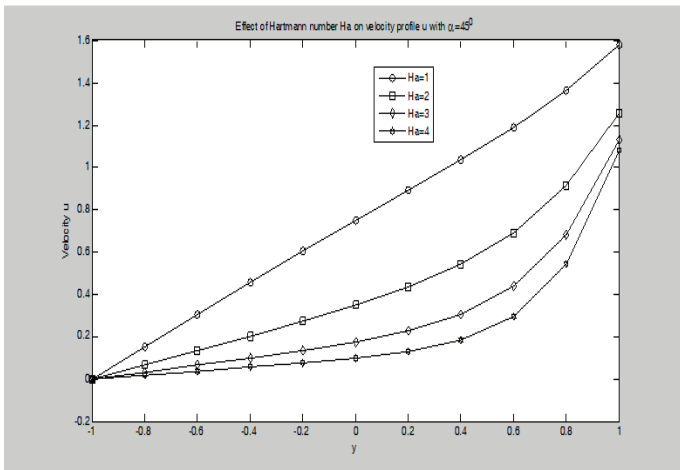Figure3: Effect of Hartmann number Ha on velocity profile u with $\alpha=45^0$,B=1,t=0.5,ε=0.02,Gr=1,N=1 andω=1.
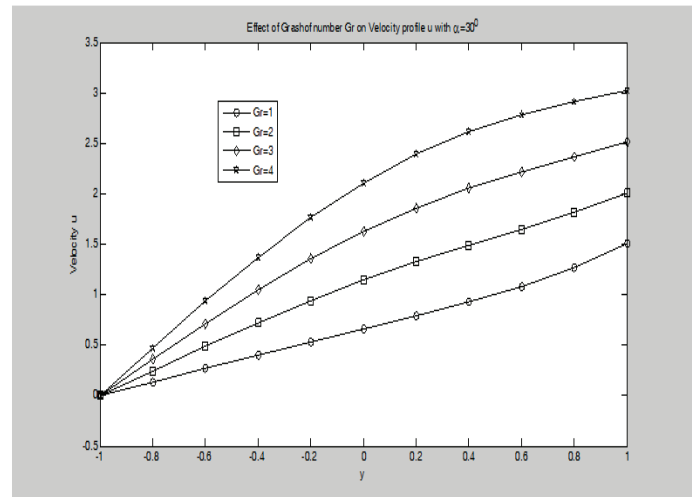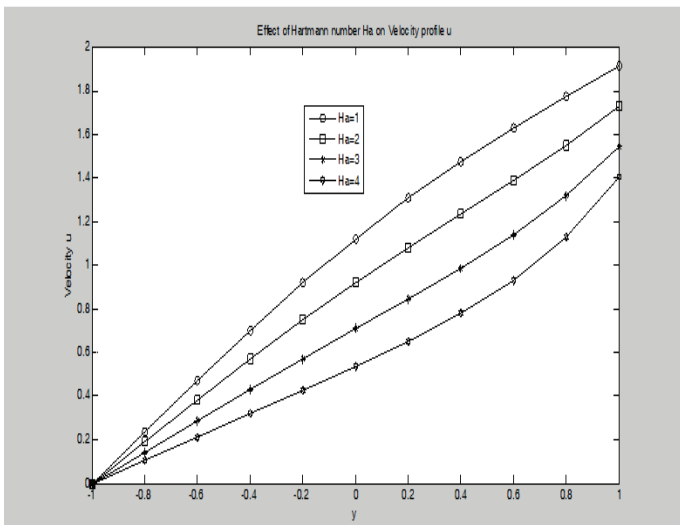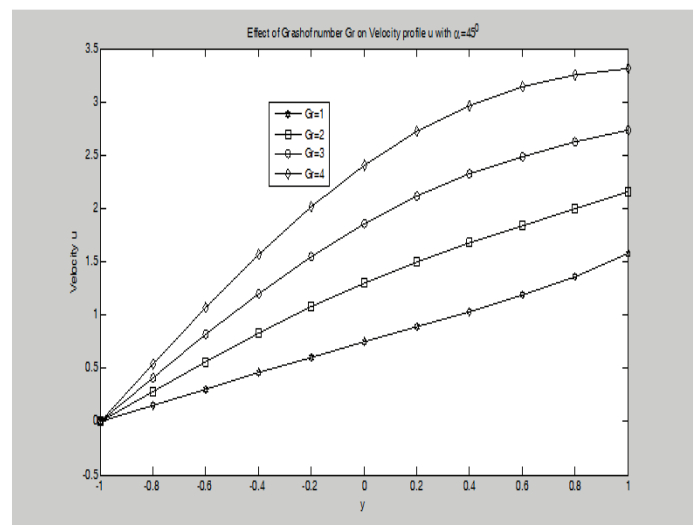

Figure6: Effect of Grashof number Gr on velocity profile u with $\alpha=30^0$,B=1,t=0.5,ε=0.02,Ha=1,N=1 andω=1.

Figure4: Effect of Hartmann number Ha on velocity profile u with $\alpha=60^0$,B=1,t=0.5,ε=0.02,Gr=1,N=1 andω=1.

Figure7: Effect of Grashof number Gr on velocity profile u with $\alpha=45^0$,B=1,t=0.5,ε=0.02,Ha=1,N=1 andω=1.
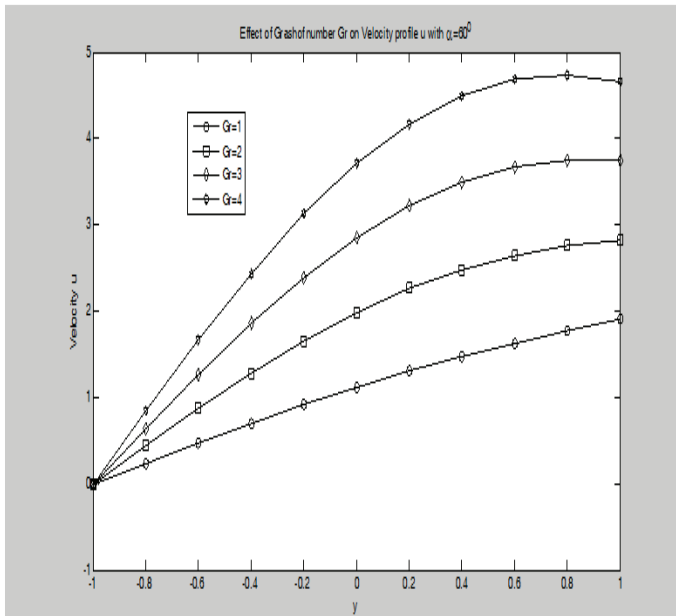
Figure8: Effect of Grashof number Gr on velocity profile u with $\alpha=60^0$,B=1,t=0.5,ε=0.02,Ha=1,N=1 andω=1.
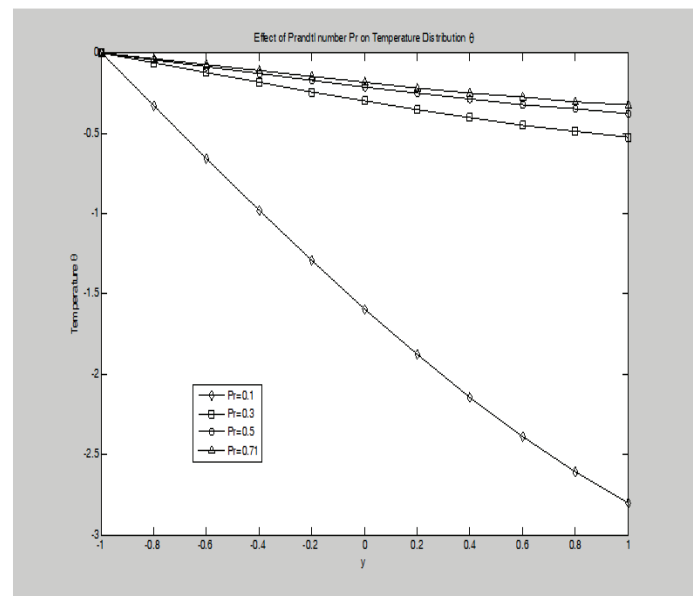

Figure10: Effect of Prandtl number Pr on temperature distribution θ with B=1,t=0.5,ε=0.02,Ha=1,N=1,Gr=1 andω=1.
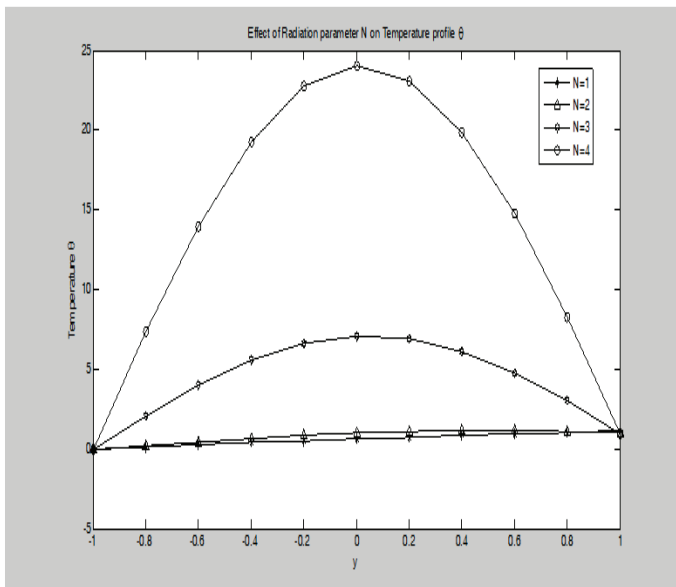
CONCLUSION

In this paper we studied the effect of inclined Hartmann in an unsteady MHD couette flow between two infinite parallel porous plates in an inclined magnetic field.The momentum and energy equations are written in a dimensionless form using the dimensionless parameters. Variable separable technique was employed to solve the velocity profile and temperature distribution. It was concluded that, at high Hartmann number Ha, the velocity uof the fluid decreases. When the magnetic field is high, it reduces the energy loss through the plates. The velocity u increases with increase in Grashof number Gr. Also, when the Prandlt number Pr increases, the temperature distribution θ decreases. Thus, it shows that magnetic field has significant effect to the flow of an unsteady MHD couette flow between two parallel horizontal porous plates in an inclined magnetic field.

Figure9: Effect of Radiation parameter N on temperature distribution θ with B=1,t=0.5,ε=0.02,Ha=1,N=1,Gr=1 andω=1.

REFERENCE

Al-Hadhrami, A. K., Elliot, L. and Ingham, D. B., "A New Model for Viscous Dissipation inPorous Media across a Range of Permeability Values," *Transport in Porous Media, Vol. 53, pp. 117_122* (2003).

Attia, H. A., "MHD Couette Flow with Temperature Dependent Viscosity and Ion Slip," *Tamkang J Sci. Engng., Vol. 8, pp. 11_16 (2005).*

Attia, H. A., "Influence of Temperature-Dependent Viscosity in the MHD Couette Flow of Dusty Fluid with Heat Transfer," Diff Eqn and Nonlinear Mechanics, pp. 1_14 (2006).

Attia, H. A., "Ion Slip Effect on Unsteady Couette Flow with Heat Transfer under Exponential Decaying Pressure Gradient," *Tamkang J SciEngng., Vol. 12, pp. 209_214 (2009).*

Attia, H. A. and Ewis, K. M., "Unsteady MHD Couette Flow with Heat Transfer of a Viscoelastic Fluid under Exponential Decaying Pressure Gradient," *Tamkang J Sci. Engng., Vol. 13, pp. 359_364 (2010).*

Attia, H. A., Al-kaisy, A. M. A. and Ewis, K. M., "MHD Couette Flow and Heat Transfer of a Dusty Fluid with Exponential Decaying Pressure Gradient," *Tamkang J Sci. Engng., Vol. 14, pp. 91_96 (2011).*

Bég, O. A., Zueco, J. and Takhar, H. S., "Unsteady Magnetohydrodynamic Hartmann-Couette Flow and Heat Transfer in a Darcian Channel with Hall Current, Ionslip, Viscous and Joule Heating Effects: Network Numerical Solutions," Commun in Nonlinear Sci and Numer Simulation, Vol. 14, pp. 1082_1097 (2009).

Chauhan, D. S. and Rastogi, P., "Hall Current and Heat Transfer Effects on MHD Flow in a Channel Partially Filled with a Porous Medium in a Rotating System," *Turkish J EngEnv Sci., Vol. 33, pp. 167_184 (2009)*.

Chauhan, D. S. and Agrawal, R., "Effects of Hall Current on MHD Flow in a Rotating Channel Partially Filled with a Porous Medium," ChemEngng Comm., Vol. 197, pp. 830_845 (2010).

Chauhan, D. S. and Agrawal, R., "Effects of Hall Current on MHD Couette Flow in a Channel Partially Filled with a Porous Medium in a Rotating System," Meccanica, DOI 10.1007/s11012-011-9446-9 (2011).

Geindreau, C. and Auriault, J. L., "Magnetohydrodynamic Flows in Porous Media," *J Fluid Mech., Vol. 466, pp. 343_363 (2002)*.

hosh, S. K. and Bhattacharjee, P. K., "Hall Effects on Steady Hydromagnetic Flow in a Rotating Channel in the Presence of an Inclined Magnetic Field," *Chech J Phys., Vol. 50, pp. 759_767 (2000)*.

Ghosh, S. K., "Effects of Hall Current on MHD Couette Flow in a Rotating System with Arbitrary Magnetic Field," *Czech J Phys., Vol. 52, pp. 51_63(2002)*.

Ghosh, S. K., Bég, O. A. and Narahari, M., "Hall Effects on MHD Flow in a Rotating System with Heat Transfer Characteristics," *Meccanica, Vol. 44, pp. 741_765 (2009)*.

Krishna, D. V., Prasada Rao, D. R. V. and Ramachandra Murthy, A. S., "Hydromagnetic Convection Flow through a Porous Medium in a Rotating Channel," *J EngPhysThermophys, Vol. 75, pp. 281_291 (2002)*.

Nield, D. J. and Bejan, A., Convection in Porous Media, USA: Springer (2006).

Seth, G. S., Ansari, M. S. and Nandkeolyar, R., "Unsteady Hydromagnetic Couette Flow within a Porous Channel," *Tamkang J SciEngng., Vol. 14, pp. 7_14 (2011)*.

W.A. Manyonge, D.W. Kiema, C.C.W. Iyaya, (2012): Steady MHD Poiseuille Flow between two infinite parallel porous plates in an inclined magnetic field, *Inter. Journal of Pure and Applied Maths., 76(5): 661-668*