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# Influence of viscous dissipation and radiation on MHD Couette flow in a porous Medium

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## *Abstract*

***A study on the influence of viscous dissipation and radiation on magnetohydrodynamic Couette flow in a porous medium was carried out. On the basis of certain simplifying assumptions, the fluid equation of continuity, Navier-Stokes and energy were reduced to mathematical terms, and closed-form analytical solutions of the velocity distribution and energy were obtained on the basis of approximations under the considered parameters. The overall analysis of the study of these parameters in various degrees show an increase in the velocity profile of the fluid, while radiation parameter decreases the temperature profile; viscous dissipation and Reynolds number increase the temperature profile of the fluid.***

**Key word:** Couette flow, viscous dissipation, Magnetohydrodynamics, porous medium.

## 1.0 Introduction:

In the early nineteenth century, Maurice Couette studied the flow of fluid with its motion brought about by the relative movement of two parallel plates or surface or where one of the plates or surfaces is moving laterally in its own plane. The study was later named after him and defines as two parallel plates moving relative to each other which cause a flow of fluid in between them. The plate could be flat, parallel or two concentric cylinders of varying radii, all generally referred to as plane Couette flow. It is a steady laminar flow of viscous incompressible fluid between two infinite parallel plates separated by a distance (d). Bodosa and Borkakati [2] examined the problem of MHD Couette flow with heat transfer between two horizontal plates in the presence of a uniform transverse magnet field. Mebine [6], considering the effect of radiative heat transfer to an unsteady flow of a conducting optically thin fluid between two parallel plates. On the basis of certain simplifying assumptions, the governing hydrodynamic equation were deduced to mathematical terms and closed form analytical solutions of the velocity distribution and energy were obtained and the overall analysis of the study shows that the flow variables are affected mainly by radiation and convection parameters in addition to magnetic factor. The manifestations of these effects are demonstrated analytically and quantitatively although viscous dissipation parameter in the energy equation is assumed negligible and permeability not considered. Oladele et al [9] also examined viscous dissipation effects on the flow of a radiating gas between concentric elliptic cylinders with a view to assessing their global contribution to velocity and temperature distributions in the flow field. The numerical results obtained for the two cases show that the velocity and the temperature of the fluid are increased as a result of increase in thermal internal energy of the fluid caused by viscous dissipation. This present study however, is an attempt to complement the earlier work of [8] by investigating the simultaneous effects of viscous dissipation and magnetic field to his problem of study. This attempt therefore, widens the applicability of problems of this nature.

## Formalism

The basic hydrodynamic equations governing the physics of the problem following the argument of Israel –[5] and [6] are

$$\nabla \cdot V = 0 \qquad (1)$$

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$$\rho\left(\frac{\partial V}{\partial t}+(V.\nabla)V\right)=-\nabla P+\mu\nabla^2 V+\rho g-\frac{\upsilon}{k}V-\frac{\sigma_c\mu H_0 V}{\rho_\infty} \qquad (2)$$

$$\left(\frac{\partial T}{\partial t}+(V\cdot\nabla)T\right)=a^2\nabla^2 T-\frac{1}{\rho c_p}\nabla.q_z+\frac{\mu}{\rho c_p}\left(\frac{\partial V}{\partial Z}\right)^2 \qquad (3)$$

Where $T, V, \rho, P, \mu, g, \upsilon, k, H_0, \rho_\infty, a, q_z$ are respectively temperature, fluid velocity, fluid density, fluid pressure, absolute viscosity, acceleration due to gravity, kinematic viscosity, permeability of the medium, magnetic field, porous medium density, thermal diffusivity and radiative term and

$$\frac{\partial^2 q_z}{\partial Z^2}-3\alpha^2 q_z-16\sigma\alpha T_\infty{}^3\frac{\partial T}{\partial Z}=0 \qquad (4)$$

With the assumptions that:
the difference in temperature between the plates and that of the fluid is large enough for free convection to flow. In the spirit of [3], (4) reduced to

$$\frac{\partial q_z}{\partial Z}=4\delta^2(T-T_\infty) \qquad (4a)$$

Where
$$\delta^2=\int_0^\infty\left(\alpha_{k^*}\frac{\partial\wedge}{\partial T}\right)dk^* \qquad (4b)$$

$\wedge$ is the planck's function, $\alpha_{k^*}$ is the absorption coefficient, $k^*$ is the frequency of radiation and $T$ is the temperature. If we put (4a) in (3) and under Boussinesq approximation which restrict the effect of variation of density with temperature exclusively to the body force term. With these assumptions, the flow equations that describe the physical situation are given by

$$\frac{\partial V}{\partial Z}=0 \qquad (5)$$

$$\rho\frac{\partial V}{\partial t}=-\frac{\partial P}{\partial Z}+\frac{\mu\partial^2 V}{\partial Z^2}+g\rho_0\xi(T-T_0)-\frac{\upsilon}{k}V-\frac{\sigma_c\mu^2 H_0^2 V}{\rho_\infty} \qquad (6)$$

$$\frac{\partial T}{\partial t}=\frac{a^2\partial^2 T}{\partial Z^2}-\frac{4\delta^2(T-T_0)}{\rho c_p}+\frac{\mu}{\rho c_p}\left(\frac{\partial V}{\partial Z}\right)^2 \qquad (7)$$

Where $\xi$ is coefficient of volume expansion

**Pertubation**

Denoting the disturbance in the velocity field, temperature field, and pressure field by

$$V'=V-V_e,\ P'=P-P_e,\ T'=T-T_e \qquad (8)$$

Where, the subscript e denotes equilibrium values. If we put (8) in (5) , (6) and (7) and retaining only unity terms, we obtain the following lincarized equations

$$\frac{\partial V'}{\partial Z}=0 \qquad (9)$$

$$\rho\frac{\partial V'}{\partial t}=-\frac{\partial P'}{\partial Z}+\frac{\mu\partial^2V'}{\partial Z^2}+g\rho_0\xi(T'-T_0')-\frac{\upsilon}{k}V'-\frac{\sigma_c\mu^2H_0^2V'}{\rho_\infty} \tag{10}$$

$$\frac{\partial T'}{\partial t}=\frac{a^2\partial^2T'}{\partial Z^2}-\frac{4\delta^2(T'-T_0')}{\rho c_p}+\frac{\mu}{\rho c_p}\left(\frac{\partial V'}{\partial Z}\right)^2 \tag{11}$$

Non- dimensional analysis

For dimensional homogeneity of the governing hydrodynamic equations, we substitute the following expressions

$$Z=\frac{V't}{d},\quad P=\frac{P'}{\rho V^2},\quad \alpha^2=\frac{4\delta^2\rho_\infty c_\infty d^2}{\rho c_p\upsilon},\quad K^a=\frac{\upsilon\mu d^2}{k\rho},\quad V=\frac{V'}{U},\quad \beta^2=\frac{a^2\rho^t}{T_\infty},\quad g=\frac{gd}{V^2},$$

$$t'=\frac{Vd}{t},\quad T=\frac{T'-T_0}{T_1-T_2},\quad \mathrm{Re}^{-1}=\frac{\mu}{Vdp},\quad M^2=\frac{\sigma_c\mu H_0^1\upsilon}{\rho_\infty U^2},\quad Gr=g\xi\frac{(T-T_0)d^3}{V^2},\quad \Pr=\frac{\mu c_p}{a^2\rho c_p},$$

Having employed the Rayleigh's technique, into equations (9), (10), and (11), which results in

$$\frac{\partial V}{\partial Z}=0 \tag{12}$$

$$\rho\frac{\partial V}{\partial t'}=-\frac{\partial P}{\partial Z}+\mathrm{Re}^{-1}\frac{\partial^2V}{\partial Z^2}+Gr\theta-K^aV-M^2V \tag{13}$$

$$\frac{\partial\theta}{\partial t'}=\beta^2\frac{\partial^2\theta}{\partial Z^2}-\alpha^2\theta+\Pr Ec\left(\frac{\partial V}{\partial Z}\right)^2 \tag{14}$$

Where M is dimensionless magnetic field parameter, Pr is prandtl number, Ec is Eckert number and Gr is Grashof number. (13) and (14) are now subject to the boundary conditions

$$\theta(0)=1,\quad \theta(\infty)=0,\quad V(0)=0,\quad V(d)=U.$$

Assuming that, the fluid velocity at the wall of the plates is equal to the wall velocity (no-slip condition).

## Method of solution

The problem posed in (13) and (14) are highly nonlinear equations and generally will involve a step by step numerical integration of the explicit finite difference scheme. However, analytical solution is possible, if we assume small Reynolds number (Re) Bestman [1], Gbadeyan & Idowu [4] and by adopting regular perturbation of the form in Israel- Cookey et al [5].

$$\theta(Z,t')=\theta_0(Z)+\mathrm{Re}\,\theta_1(Z)e^{i\omega t},\quad V(Z,t')=V_0(Z)+\mathrm{Re}V_1(Z)e^{i\omega t} \tag{15}$$

Substituting (15) into (13) and (14), neglecting 0(Re $^{2)}$ and simplifying, we obtain the following sequence of approximations after collecting terms of the same order:

$$\mathrm{Re}^{-1}V^{it}(Z)+Gr\theta_0(Z)-K^aV_0(Z)-M^2V_0(Z)-K_p=0 \tag{16}$$

$$\beta^2\theta_0^{it}(Z)-\alpha^2\theta_0(Z)+\Pr EcV_0^1(Z)=0 \tag{17}$$

Subject to: $\theta_0(0)=1,\quad \theta_0(\infty)=0,\quad V_0(0)=0,\quad V_0(d)=U$ (18)

For 0(1) equations, and

$$i\omega V_1(Z)=\mathrm{Re}^{-1}V_1^{it}(Z)+Gr\theta_1(Z)-K^aV_1(Z)-M^2V_1(Z) \tag{19}$$

$$i\omega\theta_1(Z)=\beta^2\theta_1^{it}(Z)-\alpha^2\theta_1(Z)+2\Pr EcV_1^1(Z)V_1'(Z) \tag{20}$$

Subject to: $\theta_1(0)=1, \quad \theta_1(\infty)=0, \quad V_1(0)=0, \quad V_1(d)=U$ (21)

For 0(Re) equations.

Where, $k_p = \frac{1}{\rho}\frac{\partial P}{\partial Z}$ is a constant pressure gradient.

To solve (16) - (17) and (19) – (20), we further assume that the Eckert number (Ec) is small, and there, advance an asymptotic expansion for the flow temperature and velocity as follows

$$V_0(Z)=V_{01}(Z)+EcV_{02}(Z),\ \theta_0(Z)=\theta_{01}(Z)+EcV_{02}(Z),\ V_1(Z)=V_{11}(Z)+EcV_{12}(Z),$$
$$\theta_1(Z)=\theta_{11}(Z)+EcV_{12}(Z) \quad (22)$$

Substituting (22) into (16) – (17) and (19) - (20) and neglecting squares and products of perturbation quantities, we obtain the following sequence of approximations:

$$\mathrm{Re}^{-1}V_{01}^{it}(Z)+Gr\theta_{01}(Z)-(K^a+M^2)V_{01}(Z)-K_p=0 \quad (23)$$
$$\beta^2\theta_{01}^{it}(Z)-\alpha^2\theta_{01}(Z)=0 \quad (24)$$
$$\mathrm{Re}^{-1}V_{02}^{it}(Z)+Gr\theta_{02}(Z)-(K^a+M^2)V_{02}(Z)-K_p=0 \quad (25)$$
$$\beta^2\theta_{02}^{it}(Z)-\alpha^2\theta_{02}(Z)=0 \quad (26)$$

Subject to: $V_{01}(0)=0, \quad V_{01}(d)=U, \quad V_{02}(0)=0, \quad V_{02}(d)=U$

and $\theta_{01}(0)=1, \quad \theta_{01}(\infty)=0, \quad \theta_{02}(0)=1, \quad \theta_{02}(\infty)=0$ (27)

For 0(1) equations and

$$i\omega V_{11}'(Z)=\mathrm{Re}^{-1}V_{11}^{it}(Z)+Gr\theta_{11}(Z)-(K^a+M^2)V_{11}(Z) \quad (28)$$
$$i\omega\theta_{11}(Z)=\beta^2\theta_{11}^{it}(Z)-\alpha^2\theta_{11}(Z) \quad (29)$$
$$i\omega V_{12}'(Z)=\mathrm{Re}^{-1}V_{12}^{it}(Z)+Gr\theta_{12}(Z)-(K^a+M^2)V_{12}(Z) \quad (30)$$
$$i\omega\theta_{12}(Z)=\beta^2\theta_{12}^{it}(Z)-\alpha^2\theta_{12}(Z) \quad (31)$$

Subject to: $V_{11}(0)=0, \quad V_{11}(d)=U, \quad V_{12}(0)=0, \quad V_{12}(d)=U$

and $\theta_{11}(0)=1, \quad \theta_{11}(\infty)=0, \quad \theta_{12}(0)=1, \quad \theta_{12}(\infty)=0$ (32)

For 0(Ec) equations.

Solving (26), we assume a solution of the form

$$\theta_{02}(Z)=e^{\lambda Z} \quad (33)$$

Substituting (33) into (26) together with the appropriate boundary conditions of equation (27), we get

$$\theta_{02}(Z)=e^{m_1 Z} \quad (34)$$

If we substitute (34) into (25) and simplify, we obtain

$$V_{02}''(Z)-AV_{02}(Z)=-\mathrm{Re}\,Gre^{m_1 Z} \quad (35)$$

Solutions to (35) after the application of the appropriate boundary condition of (27), gives

$$V_{02}(Z)=A_1e^{m_6 Z}+Ue^{-m_6 Z}-A_2e^{m_1 Z} \quad (36)$$

Following the same procedure as in (26), the solution of (31) is given by

$$\theta_{12}(Z)=e^{m_2 Z} \quad (37)$$

Substituting (37) into (30) and simplifying, results

$$V_{12}''(Z) - A_3 V_{12}'(Z) - AV_{12}(Z) = -A_2 e^{m_2 Z} \quad (38)$$

The complete solution of (38) is therefore,

$$V_{12}(Z) = (C_1 + U)e^{m_3 Z} + Ue^{m_4 Z} + C_1 e^{m_2 Z} \quad (39)$$

Following the same steps taken in (26), the solution of (30) can be written as

$$\theta_{11}(Z) = e^{m_2 Z} \quad (40)$$

Substituting (40) into (28) and rearrangement results in

$$V_{11}''(Z) - A_3 V_{12}'(Z) - AV_{11}(Z) = -A_2 e^{m_2 Z} \quad (41)$$

Following the approach in determining the solution of (38), the solution of (41) after imposing the boundary conditions of (32) is

$$V_{11}(Z) = (C_1 + U)e^{m_3 Z} + Ue^{m_4 Z} + C_1 e^{m_2 Z} \quad (42)$$

Following the same method in determining the complete solution of (29), (34) can be written as

$$\theta_{01}(Z) = e^{m_1 Z} \quad (43)$$

We substitute (43) into (23) and after simplification, we get

$$V_{01}''(Z) - AV_{01}'(Z) - AV_{11}(Z) = A_4 - A_2 e^{m_1 Z} \quad (42)$$

Following the method adopted in determining the complementary function of (35) and a similar method in solving for the particular integral of the same equation, the solution of (44), is given by

$$V_{01}(Z) = (U - C_3)e^{m_5 Z} + (C_2 + U)e^{-m_5 Z} - C_2 - C_3 e^{m_1 Z} \quad (45)$$

Substituting (36) and (45) into (22a), gives

$$V_0(Z) = (U - C_3)e^{m_3 Z} + (C_2 + U)e^{-m_3 Z} - C_2 - C_3 e^{m_1 Z} + Ec(A_1 e^{m_6 Z} + Ue^{-m_6 Z} - A_2 e^{m_1 Z}) \quad (46)$$

Also substituting (34) and (43) into (22b) results,

$$\theta_0(Z) = e^{m_1 Z} + Ece^{m_1 Z} \quad (47)$$

Again, substituting (42) and (43) into (22c) results,

$$V_1(Z) = (C_1 + U)e^{m_3 Z} + Ue^{m_4 Z} + C_1 e^{m_2 Z} + Ec(C_1 + U)e^{m_3 Z} + Ue^{m_4 Z} + C_1 e^{m_2 Z} \quad (48)$$

Finally, putting (37) and (40) into (22d), we get

$$\theta_1(Z) = e^{m_2 Z} + Ece^{m_2 Z} \quad (49)$$

Similarly, if we put (46) and (48) into (15a) and also (47) and (49) into (15b), we obtain the velocity and temperature profile of the flow respectively as:

$$V(Z,t) = (U - C_3)e^{m_5 Z} + (C_2 + U)e^{-m_5 Z} - C_2 - C_3 e^{m_1 Z} + Ec(A_1 e^{m_6 Z} + Ue^{-m_6 Z} - A_2 e^{m_1 Z}) + \mathrm{Re}[(C_1 + U)e^{m_3 Z} + Ue^{m_4 Z} + C_1 e^{m_2 Z} + Ec(C_1 + U)e^{m_3 Z} + Ue^{m_4 Z} + C_1 e^{m_2 Z}]e^{i\omega t} \quad (50)$$

$$\theta(Z,t) = (1 + Ec)e^{m_2 Z} + (\mathrm{Re}\, e^{m_2 Z}\, \mathrm{Re}\, Ece^{m_2 Z})e^{i\omega t} \quad (51)$$

For Couette flow, $k_p = 0$ which turns $C_2 = 0$ and (50) reduces to

$$V(Z,t) = (U - C_3)e^{m_5 Z} + (U)e^{-m_5 Z} - C_3 e^{m_1 Z} + Ec(A_1 e^{m_6 Z} + Ue^{-m_6 Z} - A_2 e^{m_1 Z}) + \mathrm{Re}[(C_1 + U)e^{m_3 Z} + Ue^{m_4 Z} + C_1 e^{m_2 Z} + Ec(C_1 + U)e^{m_3 Z} + Ue^{m_4 Z} + C_1 e^{m_2 Z}]e^{i\omega t}$$

## Results

We have formulated and solved the problem of the influence of viscous dissipation and radiation on magnetodynamic Couette flow in a porous medium based on fairly realistic assumptions and approximations. The solutions (51 and 52) of the field variables, show that the parameters entering the problem are Reynolds number (Re), free convection parameter or Grashof number (Gr), Prandtl number (Pr), viscous dissipation parameter or Eckert number (Ec), dimensionless radiation parameter (α), dimensionless magnetic parameter (M), and dimensionless permeability term ($k^a$). Others are constant dimensionless frequency of oscillation (ω), constant thermal diffusivity (β), and dimensionless constant time (t). In other get physical insight and numerical validation of the problem, a typical value of the Prandtl number corresponding to an astrophysical body (Air) at $25^0$c is chosen as 0.71. Air is chosen because it is weakly electrically conducting under assumed circumstances and the problem under study in particular. The values of the other parameters made use of are $\alpha = 2.0$; $t = 2.0$; $\beta = 0.8$; $k_p = 2.5$; $U = 5$; $Re = 10, 20, 30, 40, 50$; $Ec = 0.01, 0.05, 0.10, 0.15, 0.20$; $M^2 = 2, 4, 6, 8, 10$; $K^a = 0.4, 0.8, 1.2, 1.6, 2.0$; $\alpha^2 = 2, 4, 6, 8, 10$; $Gr = 2, 4, 6, 8, 10$.

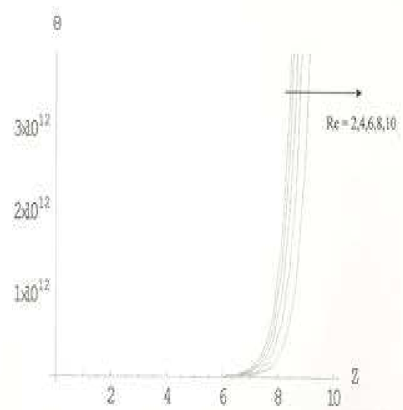


Figure. 5.1: The dependence of temperature profile on the boundary layer with Reynolds number varying.

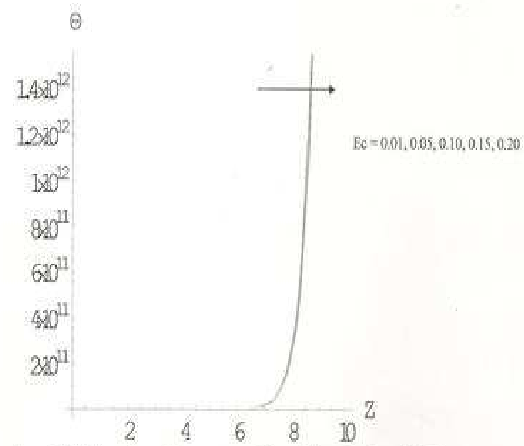


Figure.5.2: The dependence of temperature profile on the boundary layer with Eckert number varying.

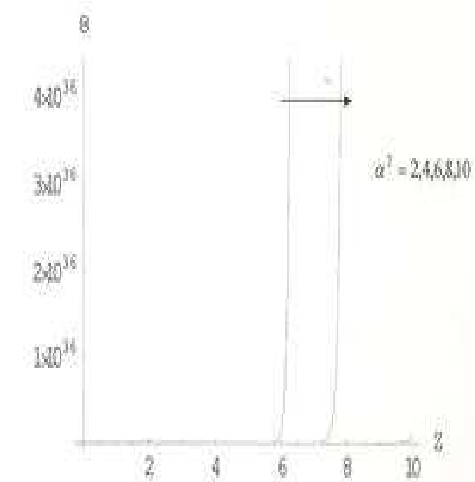


Figure. 5.3: The dependence of temperature profile on the boundary layer with radiation parameter varying.

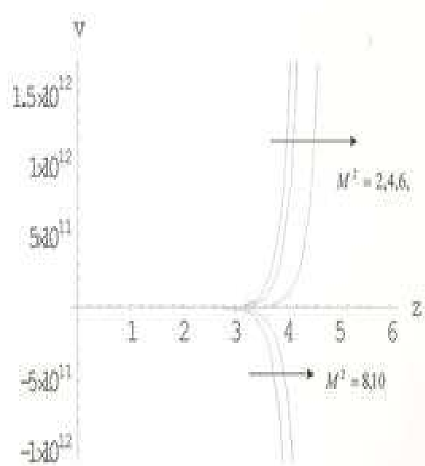


Figure.5.4. Graph of velocity profile against coordinate with magnetic (M) parameter varying.

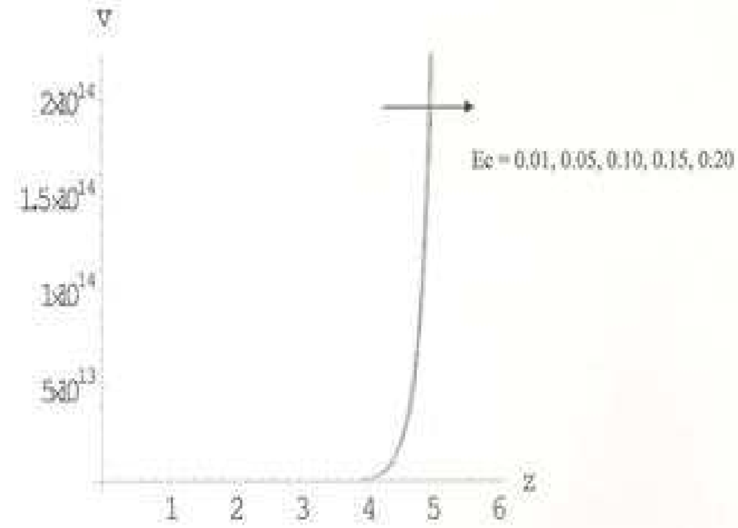


Figure.5.5. Graph of velocity profile against coordinate with Eckert number (Ec) varying.

## Discussions

In the analysis, we start with the temperature profile due to its primary importance in astrophysics environments. The effect of increase in Reynolds number (Re) is shown in Fig 5.1. It is evident that an increase in Reynolds number (Re), shows an increase in the temperature distribution. Fig 5.2 shows the effect of viscous dissipation parameter or Eckert number (Ec) on temperature and the result shows that further increase in Eckert number leads to a slight increase in temperature and later temperature stagnation. This observation is in agreement with the findings of Israel-Cookey *et al* [5], that a greater heating by viscous dissipation caused a rise in temperature. Fig 5.3 displays the variations on temperature profile with various values of the radiation parameter ($\alpha$ ). It is evident that an increase in radiation parameter leads to a decrease in the temperature. This result is consistent with the findings of Mebine [6] that increase in radiation function, brings about a decrease in temperature. Figures 5.4 and 5.5 are graphs of (52). Fig 5.4 shows the effect of magnetic field on the velocity profile. It reveals that increase in magnetic field parameter brings about a drastic decrease in velocity profile.

This result was shared by Mebine [6]. Analysis of figure 5.5 shows that an increase in viscous dissipation parameter results in an increase in velocity profile owing to an increase in thermal internal energy of the fluid. In the absence of viscous dissipation parameter or Eckert number and magnetic field parameter, the results have already been reported by Ngjangia and Wonu [7].

## Conclusion

In this study, we have provided an approximate solution to the governing hydrodynamic equations. Generally, difficulty in closed-form solutions owing to non linearity and sometimes difficult geometries is well known but realistic assumptions and approximations employed in analyzing the problem revealed that, increase in magnetic field parameter and permeability term results in an increase in the velocity profile while increase in viscous dissipation, and radiation, results in a decrease in the velocity profile. Finally, a decrease in temperature profile is observed when radiation parameter increases but increase in temperature profile is observed when Eckert number and Reynolds number are respectively increased. In all, the observed result are in qualitative and quantitative agreement with results of earlier works of Ngiangia [8] and Mebine [6] and also sheds light on the applicability of problems of this nature.

## Appendix

The following constants have been used.

$$m_1 = (\frac{\alpha}{\beta})^2, \quad m_2 = \frac{\alpha^2 + i\omega}{\beta^2}, \quad m_3 = \frac{A_3 + \sqrt{A_3^2 + 4A}}{2}, \quad m_4 = \frac{A_3 - \sqrt{A_3^2 + 4A}}{2},$$

$$m_5 = \sqrt{A}, \quad m_6 = \sqrt{b_1}, \quad A = \text{Re}\, b_1, \quad A_1 = \text{Re}\, Gr - U, \quad A_2 = \frac{\text{Re}\, Gr}{M^2 - A}, \quad A_3 = \text{Re}\, i\omega,$$

$$A_4 = \text{Re}\, k_p, \quad b_1 = K^a + M^2, \quad C_1 = \frac{A - A_2}{M^2 - A_3}, \quad C_2 = \frac{A_4}{A}, \quad C_3 = \frac{A_2}{M^2 - A},$$

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