NUMERICAL SOLOTION OF UNSTEADY MHD COUETTE FLOW IN A VERTICAL PLATE IN THE PRESENCE OF THERMAL RADIATION

Gambo Musa[1], Ibrahim D. Yale[2] and Stephen I. Maiwa[3]

[1]*Department of Mathematics, Federal University Birnin Kebbi, Kebbi State, Nigeria*

[2]*Department of Mathematics, Kebbi State University of Science and Technology, Aliero, Nigeria*

[3]*Department of Mathematics, Federal University Birnin Kebbi, Kebbi State, Nigeria*

Email address: musa.gambo@fubk.edu.ng

Abstract: *The unsteady MHD Couette flows in a vertical plate with effect of thermal radiation have been studied. The governing equations at first were transformed by usual transformation non-dimensional form. The numerical solutions for time dependent velocity, temperature and special concentration are obtained by the implicit finite difference method. The computed values of fluid velocity, temperature and concentrations are analyzed for different flow parameters such as thermal Grashof number Gr, modify Grashof number Gm, Prandtl number Pr, thermal radiation parameter R and Schmidt number Sc. The effect of these parameters depicting physical situation of the flow profile is expressed with the aid of graphs. Results obtained showed that the velocity, temperature and concentration increased with increase in thermal radiation, magnetic field parameters and time, and decreases with the effect of Prandtl number, Schmidt number at increasing values.*

Keywords: MHD, Couette Flow, Porous Channel, Thermal Radiation, Variable Temperature

1. INTRODUCTION

Amount of efforts have been instilled in the study of unsteady laminar free convection phenomenon in a vertical channels owing to its importance to chemical, biomedical, and environmental engineering and sciences. The interest in this field relates to its great practical importance to variety of applications. For example, the nuclear reactors solid matrix heat exchangers, thermal insulation, surface catalysis of chemical reactions, oil recovery, dispersion of chemical contaminants in various processes, storage of nuclear waste, materials, grain storage and drying and many others, Jha *et al.* (2013).

The behavior of the unsteady free convective Couette flow under the influence of the transverse magnetic field and the thermal radiation for a simple system consisting of two infinite vertical plates held at different temperature. We use the Roseland approximation to describe the radiative heat flux in the energy equation, Bala *et al.* (2018). The work is motivated to study Unsteady MHD free-convective Couette flow between vertical porous plates with thermal radiation, Jha *et al.* (2015). Special attention to the combined effects of Frank-Kamenetskii, activation energy parameters and the Prandtl number on an unsteady/steady natural convection flow of a viscous reactive fluid in a vertical annulus, Jha *et al.* (2013). They studied the unsteady oscillatory Couette flow between vertical parallel plates, where the moving plate is subjected to constant radiative heat flux and the plate at rest is isothermal, Bunonyo *et al.* (2018). To investigate the unsteady MHD free convective flow past a vertical porous plate in porous medium with

Hall current, thermal diffusion and heat source, here their main objectives are to study the effect of Soret number and Hall parameter on the flow and transport characteristics, Ahmed *et al.* (2010). Considering study unsteady flow of a reactive variable viscosity fluid between two parallel porous plates acted upon by nonconstant pressure. Both the lower and upper walls of the channel are subjected to asymmetric convective heat exchange with the channel are subjected to asymmetric convective heat exchange with the ambient and allow for uniform suction/injection in the transverse direction. Tirivanhu, C., and Makinde, O., D (2013). However, in all these studies, the authors have not yet discovered the investigation of the unsteady flow of a viscous, incompressible, electrically and thermally conducting fluid between two infinite parallel porous walls placed at two different locations. In addition to that, they have not examined the electrically conducting fluid which is driven by the mutual action of the imposed pressure gradient, thermal buoyancy and heat source or sink and most importantly Makinde, O. D. *et al.* (2019). To analyze the effect of suction/injection on time dependent unsteady as well as steady-state free convection Couette flow of viscous reactive fluid in a vertical channel formed by two infinite vertical parallel porous plates, Jha *et al.* (2012). The objective of the present work is to study the free convective flow through a porous medium past a vertical plate with ramped wall temperature in presence of magnetic field. Consider the effects of magnetic field which is found to be very important in controlling and regulating the fluid velocity and viscous drag at wall, Sinha *et al.* (2017).

It is proposed to study chemical reaction effects on unsteady hydrodynamic past a moving vertical plate with time dependent suction in the presence of heat source in a slip flow regime with free convection flow slip due to jump in temperature and concentration, Balamurugan *et al.* (2015). The unsteady hydro-magnetic free convection flow with heat transfer of a linearly viscous, incompressible, electrically conducting fluid near a moving vertical plate with the constant heat is investigated Nehad *et al.* (2019). Investigated flow formation in Couette motion in magnetohydrodynamics with time varying suction and taking into account the effects of heat and mass transfer, Salama (2011). The main objective is to investigate the effect of the applied magnetic field on the velocity field, temperature field, skin friction and Nusselt number at the plates, induced magnetic field, current density and the induced electric field. It is also proposed to study the effects of dissipative heat and Prandtl number on the heat transport characteristics Nazibuddin Ahmed (2012). They have investigated the radiation effects on free convection MHD Couette flow of a viscous incompressible heat generating fluid in the presence of variable temperature, Sanatan Das et al. (2012). They have considered the work on three-dimensional unsteady MHD convective flow of nanofluid over a non-linear stretching sheet in a porous medium in the presence of non-linear thermal radiation, slip effect and convective boundary condition, K. Jagan et al. (2018). Their research focuses on the effect of chemical reaction on unsteady MHD free convective two immiscible fluids flow. Joseph, K. M. et al. (2017). Couette flow of a Casson fluid in an inclined composite duct partly filled with fluid and partly filled with porous material is investigated. The velocity of the fluid through porous layers and velocity of fluid in free flow region are calculated. Uppuluri, V. M. K et al. (2019). Considering one dimensional Couette flow of an electrically conducting fluid between two infinite parallel porous plates under the influence of inclined magnetic field with heat transfer, Joseph, K. M., et al. (2014). The objective of the paper, is to investigate an unsteady flow of an incompressible and electrically conducting fluid between two horizontal parallel plates, one of which is at rest, other moving in its own plane with a velocity u0 in the presence of a uniform transverse magnetic field is analyzed, Bodosa, G., and Borkakati, A. K. (2003).

His work concerns with the effect of free convection on the unsteady Couette motion. The resulting system of coupled linear partial differential equations has been solved by Laplace transform. Singh, A. K. (1988). He has studied the combined effect of radiation, joule heating and viscous dissipation on MHD Marangoni convection flow in the presence of suction or injection. The objectives of his work are to investigate the effects of radiation parameter, magnetic parameter, Eckert number as well as suction or injection parameter on the surface velocity, surface temperature gradient as well as the velocity and temperature profile. Abdul, H. R. et al. (2013). This research will only consider the Unsteady MHD Couette flow in a vertical porous channel with effect of thermal radiation and variable temperature.

2. GOVERNING EQUATIONS

We consider a time dependent unsteady MHD Couette flow in a vertical porous channel, incompressible, electrically conducting and radiating fluid separated between two infinite vertical parallel plates of a distance H. At time $t' \leq 0$, both the fluid and plates are assumed to be at rest at temperature T_0. At some time $t' > 0$, the temperature of the plate at $y' = 0$ rise to T_w and the plate starts moving on its own plane with impulsive motion with velocity U while the plate at a distance H from it is fixed. A strong homogeneous magnetic field of strength B_0 is imposed normal to the plates in the presence of an incident radiative heat flux of intensity q_r , which is absorbed by the plate and transferred to the fluid. The Cartesian (x′, y ′) co-ordinate systems are taken with x′-axis along the moving plate in the upward direction and the y′ -axis normal to it as shown in Figure-1

The plates are infinite in length the velocity and temperature are functions of y′ and t′ alone. Using Boussinesq's approximation, the governing equations for the present physical situation in dimensional form as:

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

The velocity equation is given by;

$$\frac{\partial u'}{\partial t'} = v\frac{\partial^2 u'}{\partial y'^2} + g\beta(T' - T_0) + g\beta_\infty(C' - C_0) - \frac{\sigma_1 B_0^2 u'}{\rho} \tag{2}$$

The temperature equation is expressed as;

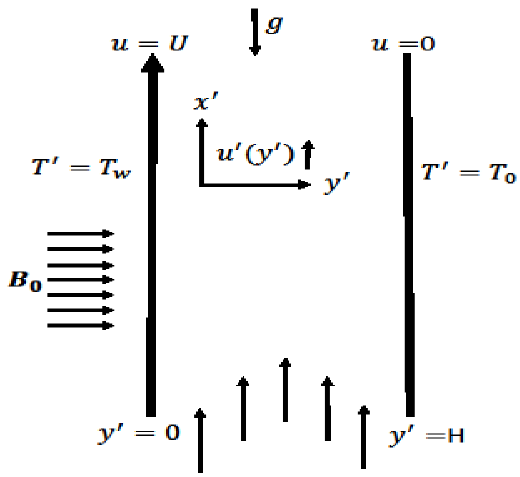
$$\frac{\partial T'}{\partial t'} = \alpha\left[\frac{\partial^2 T'}{\partial y'^2} - \frac{1}{k}\frac{\partial q_r}{\partial y'}\right] \tag{3}$$

The concentration equation is expressed as;

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial y'^2} \tag{4}$$

The quantity q_r appearing on the right-hand side of equation (3) represents the radiative heat flux in the x′ - direction. The radiative heat flux in the x′ - direction is considered insignificant in comparison with that in the y′ - direction. The radiative heat flux term in the problem is simplified by using the Rosseland diffusion approximation for an optically thick fluid according to Rashad (2009).

$$q_r = \frac{4\sigma\partial T'^4}{3k^*\partial y} \tag{5}$$



This approximation is valid for intensive absorption, that is, for an optically thick boundary layer. Hence, the Rosseland approximation has been used with positive result in a variety of problems ranging from the transport of radiation through gases at low density to the study of the effects of radiation on blast waves by nuclear explosion Ali et al. (2014).

The corresponding initial and boundary conditions are:

$t' \leq 0$: $\{u' = 0, T' = T_0', 0 \leq y' \leq H\}$

$$t' \geq: \begin{cases} u' = U, T' = T_\omega, & at\ y' = 0 \\ u' = 0, T' = T_0, & at\ y' = H \end{cases} \quad (6)$$

where y is the Cartesian co-ordinate; H distance between two parallel plates t' dimensional time t dimensionless time, g is the acceleration due to gravity T' dimensional temperature of the fluid, B_0 applied magnetic field T_0 initial temperature of fluid and plate ($t' = 0$), T_ω temperature of the plat $y' = 0$ at $t' > 0$ u, v are the velocity components, g is the local acceleration due to gravity, β is the thermal expansion coefficient, β_ω is the concentration expansion coefficient, v is the kinematic viscosity, ρ is the density, σ_1 is the fluid electrical conductivity, k is permeability, K is the thermal conductivity, k^* is the concentration of the chemical reaction coefficient, u' is the dimensional velocities, u is the dimensionless velocities, U is the velocity of the plate at $y' = 0$, x' is the vertical coordinate, direction of the fluid, y' is the dimensional coordinate perpendicular to the plate, α is the thermal diffusivity, D is the coefficient of mass diffusivity, q is the constant radiative heat flux per unit area. with the following dimensionless quantities.

$$t=\frac{vt^{'}}{H^{2}},y=\frac{y^{'}}{H},u=\frac{u}{U},\Pr=\frac{v}{\alpha},R=\frac{4\sigma\left(T_{\omega}-T_{0}\right)}{k^{*}K},C_{T}=\frac{T_{0}}{\left(T_{\omega}-T_{0}\right)},M=\frac{\sigma_{1}B_{0}^{2}H}{v\rho},$$

$$Gr=\frac{g\beta H^{2}\left(T_{\omega}-T_{0}\right)}{vU},\ Gc=\frac{g\beta_{\omega}H^{2}\left(C_{\omega}-C_{0}\right)}{vU},\theta=\frac{T^{'}-T_{0}}{T\omega-T_{0}} \qquad (7)$$

Resolving the dimensionless quantities of equations (7) and its derivative we have.

$$t=\frac{vt^{'}}{H^{2}}\rightarrow vt^{'}=H^{2}t\rightarrow t^{'}=\frac{H^{2}t}{v}\rightarrow\partial t^{'}=\frac{H^{2}\partial t}{v},y=\frac{y^{'}}{H}\rightarrow y^{'}=yH\rightarrow\partial y^{'}=\partial yH$$
$$\rightarrow\partial y^{'2}=\partial\left(yH\right)^{2},\ u=\frac{u^{'}}{U}\rightarrow u^{'}=uU\rightarrow\partial u^{'}=U\partial u\rightarrow\partial^{2}u^{'}=U\partial^{2}u,\theta=\frac{T^{'}-T_{0}}{T_{\omega}-T_{0}} \qquad (8)$$
$$\rightarrow T^{'}-T_{0}=\theta\left(T_{\omega}-T_{0}\right)\rightarrow T^{'}=T_{0}+\theta\left(T_{\omega}-T_{0}\right)\rightarrow\partial T^{'}=\partial\theta\left(T_{\omega}-T_{0}\right)\rightarrow\partial^{2}T^{'}$$
$$=\partial^{2}\theta\left(T_{\omega}-T_{0}\right)$$

Now substituting the resolved dimensionless quantities of equation (7) into 1, 2 and 3 respectively.

$$\frac{\partial u}{\partial t}=\frac{\partial^{2}u}{\partial y^{2}}+Gr\theta+Gmc-M^{2}u \qquad (9)$$

$$\Pr\frac{\partial\theta}{\partial t}=\left[1+\frac{4R}{3}\left(C_{T}+\theta\right)^{3}\right]\frac{\partial^{2}\theta}{\partial y^{2}}+4R\left[C_{T}+\theta\right]^{2}\left(\frac{\partial\theta}{\partial y}\right)^{2} \qquad (10)$$

$$\frac{\partial c}{\partial t}=\frac{1}{Sc}\frac{\partial^{2}c}{\partial y^{2}} \qquad (11)$$

The dimensionless initial and boundary conditions are;

$$t\leq 0:\left\{u=0,\ \theta=0,c=0,\ at\ y\leq H\right.$$
$$t\geq 0:\begin{cases}u=1,\ \theta=1,\ c=1,\ at\ y=0\\ u=0,\ \theta=0,\ c=0,\ at\ y=1\end{cases} \qquad (12)$$

Substituting the non-dimensional quantities in the boundary condition

3. NUMERICAL SOLUTION

The Implicit finite difference scheme of the differential terms in the governing equations (9), (10) and (11) are determines as;

$$\frac{\partial u}{\partial t}=\frac{u_i^{j+1}-u_i^j}{\partial t},\ \frac{\partial u}{\partial y}=\frac{u_{i+1}^j-u_i^j}{\partial y},\ \frac{\partial^2 u}{\partial y^2}=\frac{u_{i-1}^{j+1}-2u_i^{j+1}+u_{i+1}^{j+1}}{(\partial y)^2},\ \frac{\partial T}{\partial t}=\frac{T_i^{j+1}-T_i^j}{\partial t},$$

$$\frac{\partial T}{\partial y}=\frac{T_{i+1}^j-T_i^j}{\partial y},\ \frac{\partial^2 T}{\partial y^2}=\frac{T_{i-1}^{j+1}-2T_i^{j+1}+T_{i+1}^{j+1}}{(\partial y)^2},\ \frac{\partial c}{\partial t}=\frac{c_i^{j+1}-c_i^j}{\partial t},\ \frac{\partial c}{\partial y}=\frac{c_{i+1}^j-c_i^j}{\partial y}, \quad (13)$$

$$\frac{\partial^2 c}{\partial y^2}=\frac{c_{i-1}^{j+1}-2c_i^{j+1}+c_{i+1}^{j+1}}{(\partial y)^2},\ \frac{\partial \theta}{\partial t}=\frac{\theta_i^{j+1}-\theta_i^j}{\partial t},\ \frac{\partial \theta}{\partial y}=\frac{\theta_{i+1}^j-\theta_i^j}{\partial y},\ \frac{\partial^2 \theta}{\partial y^2}=\frac{\theta_{i-1}^{j+1}-2\theta_i^{j+1}+\theta_{i+1}^{j+1}}{(\partial y)^2}$$

Considering the implicit finite difference scheme of equation (13) to substitute into equations (9), (10) and (11) respectively.

The velocity, temperature and concentration equations given in equations (2), (3) and (4) are solved numerically using implicit finite difference method in solving equations non dimensional quantities were introduced to reduce the equations into dimensionless form and obtain the solution using implicit finite difference technique. The finite difference scheme for the velocity equation, temperature and concentration equations are written below

$$\frac{u_i^{j+1}-u_i^j}{\partial t}=\alpha\frac{\left(u_{i-1}^{j+1}-2u_i^{j+1}+u_{i+1}^{j+1}\right)}{\partial y^2}+(1-\alpha)\frac{\left(u_{i-1}^j-2u_i^j+u_{i+1}^j\right)}{\partial y^2}+Gr\theta_i^j+Gmc_i^j-M^2u_i^j \quad (14)$$

$$\frac{\Pr\left(\theta_i^{j+1}-\theta_i^j\right)}{\partial t}=\alpha\frac{\left(\theta_{i-1}^{j+1}-2\theta_i^{j+1}+\theta_{i+1}^{j+i}\right)\left[1+\frac{4R}{3}\left(C_T-\theta_i^j\right)^3\right]}{(\partial y)^2}+(1-\alpha)\frac{\left(\theta_{i-1}^j-2\theta_i^j+\theta_{i+1}^j\right)\left[1+\frac{4R}{3}\left(C_T-\theta_i^j\right)^3\right]}{(\partial y)^2}+$$
$$4R\left[C_T-\theta_i^j\right]^2\left(\frac{\theta_{i+1}^j-\theta_{i-1}^j}{2(\partial y)}\right)^2 \quad (15)$$

$$\frac{c_i^{j+1}-c_i^j}{\partial t}=\frac{1}{Sc}\frac{c_{i-1}^{j+1}-2c_i^{j+1}+c_{i+1}^{j+1}}{(\partial y)^2} \quad (16)$$

Following the implicit scheme, we obtained the following equations which will be computed in MATLAB version R2017a and plot the corresponding graphs respectively.

$$-r1u_{i-1}^{j+1}+(1+2r1)u_i^{j+1}-r1u_{i+1}^{j+1}=r2u_{i-1}^j+\left(1-2r2-\partial tM^2-\partial tL\right)u_i^j+r2u_{i+1}^{j+1}+$$
$$\partial tGr\theta_i^j+\partial tGmc_i^j \quad (17)$$

$$-r1q1\theta_{i-1}^{j+1}+(\Pr+2r1q1)\theta_i^{j+1}-r1q1\theta_{i+1}^{j+i}=r2q1\theta_{i-1}^j+(\Pr-2r2q1)\theta_i^j+r2q1\theta_{i+1}^j+$$
$$Rr1\left[C_T-\theta_i^j\right]^2\left(\theta_{i+1}^j-\theta_{i-1}^j\right)^2 \quad (18)$$

$$-r1c_{i-1}^{j+1}+(Sc+2r1)c_i^{j+1}+r1c_{i+1}^{j+1}=r2c_{i-1}^j+(Sc-2r2)c_i^j+r2c_{i+1}^j \quad (19)$$

Taking that $r1 = \frac{\alpha \partial t}{(\partial y)^2}$, $r2 = \frac{(1-\alpha)\partial t}{(\partial y)^2}$ *and* $r3 = \frac{\partial t}{(\partial y)^2}$

4. RESULTS AND DISCUSSION

The study was carried out for the following physical parameters namely Grashof number Gr, Mass Grashof number Gm, Prandtl number Pr, Schmidt number Sc, Time t, Thermal radiation parameter *R*, and Magnetic number *M*. The results for the velocity profile are obtained and presented in figure 2.0 to 5.0. In figure 2.0 it is observed that the fluid velocity decreases as the *M* increased for fixed value of other parameters. In figure 3.0 it is observed that the fluid velocity significantly increases as *Gr* increased for fixed values of other parameters. This means that the external cooling of the channel plates which result in thickening the boundary layer and assist the velocity. This shows that the flow is accelerating. It is observed in figure 4.0, that the velocity of the flow increases as *Gm* increased for fixed value of other parameters. In figure 5.0 that the velocity of the flow increases as t increase for the fixed value of other parameters

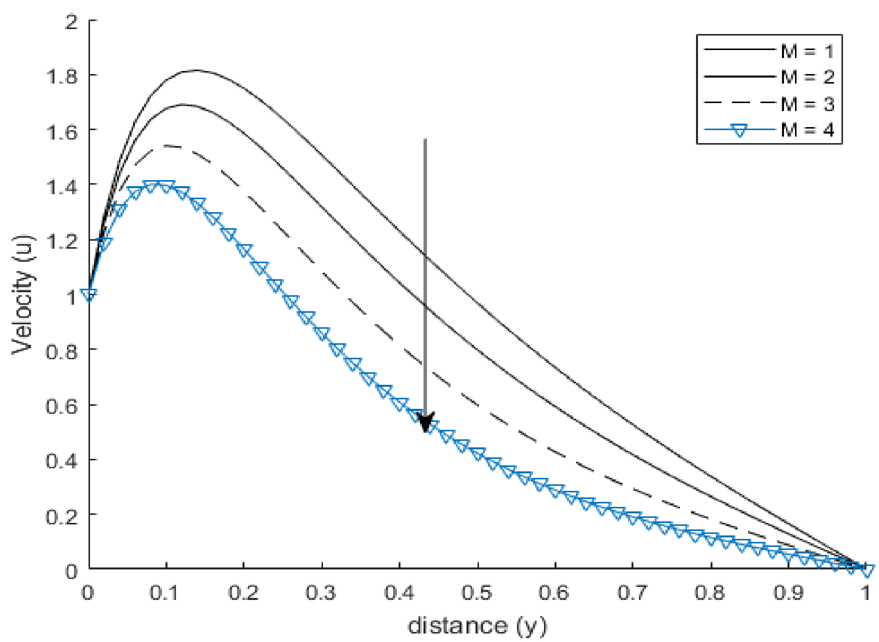


Figure-2: Velocity profile for difference value of M, effect of magnetic parameter on velocity when Pr = 0.70, dt = 0.002, dy = 1/m, y = 0: dy: 1, dy2 = 2.0*dy, Gr = 5, Gm = 5, Sc = 0.57, and R = 2.

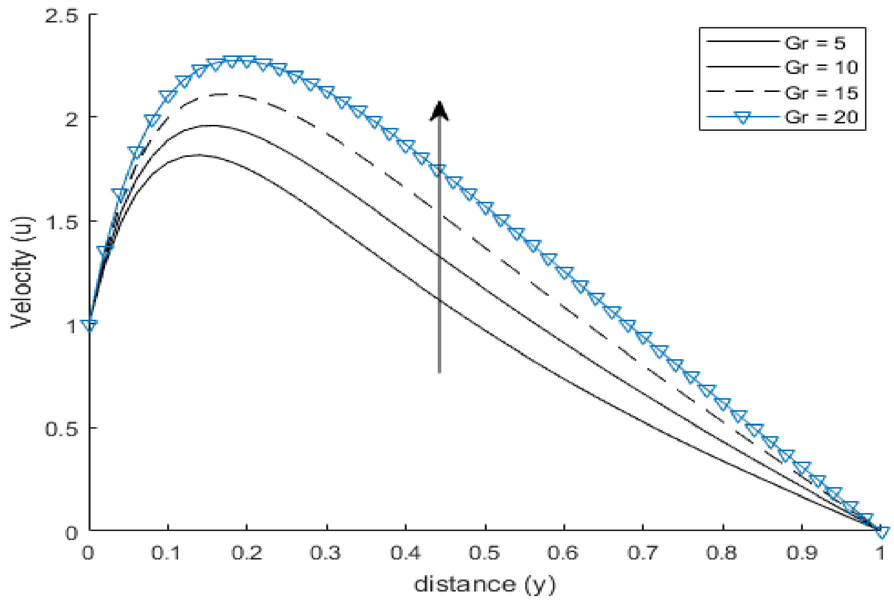


Figure-3: Velocity profile for difference value of Gr, effect of Grashoft number on velocity when M = 1, Pr = 0.70, dt = 0.002, dy = 1/m, y = 0: dy: 1, dy2 = 2.0*dy, Gm = 5, Sc = 0.57, and R = 2.

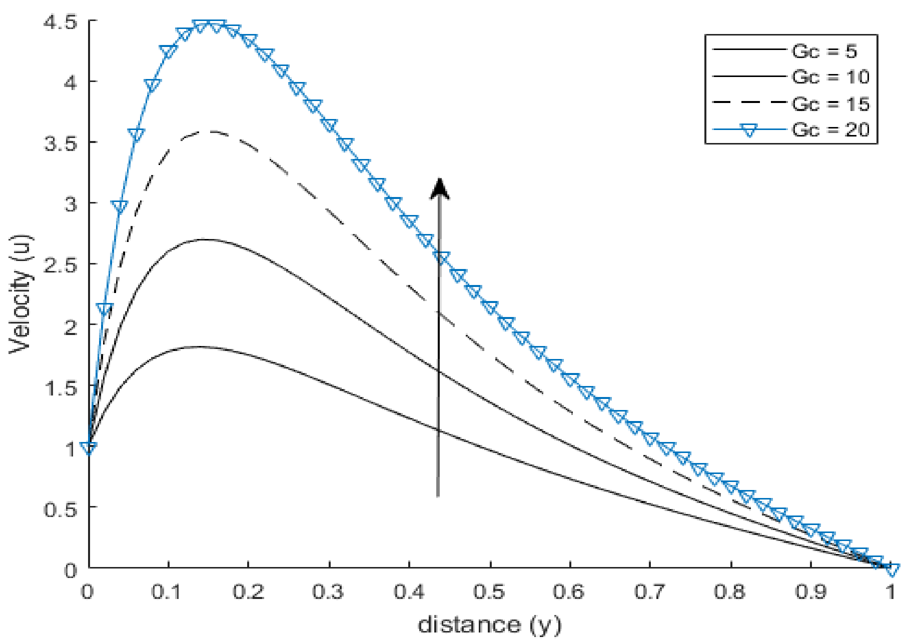


Figure-4: Velocity profile for difference value of Gm, effect of Mass Grashoft number on velocity when M = 1, Pr = 0.70, dt = 0.002, dy = 1/m, y = 0: dy: 1, dy2 = 2.0*dy, Gr = 5, Sc = 0.57, and R = 2.

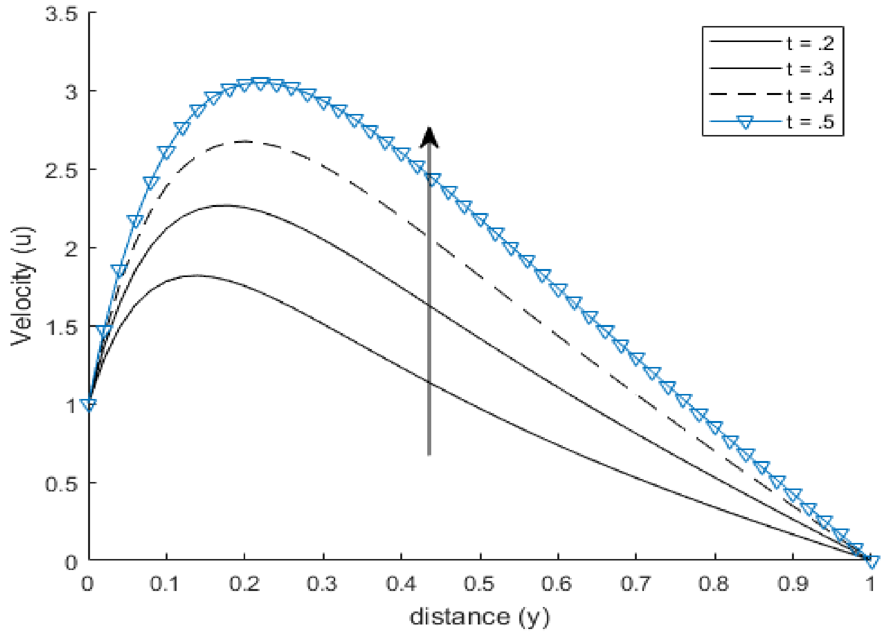


Figure-5: Velocity profile for difference value of t, effect of time on velocity when M = 1, Pr = 0.70, dt = 0.002, dy = 1/m, y = 0: dy: 1, dy2 = 2.0*dy, Gr = 5, Gm = 5, R = 2, and Sc = 0.57

The result for the temperature profile were obtained and presented in figure 6 to 9. In figure 6 illustrate the effect of Pr in temperature, it is observed that the temperature decreases as the Pr increased for the fixed value of other parameters. Figure 7 we observed that the temperature increases when the value of R (radiative parameter) increased for the fixed value of other parameters. While in figure 8 it is observed that the temperature increases as the value of Temperature ratio difference increased for the fixed value of other parameters and figure 9 it is observed that the temperature increases as the value of t increased for the fixed value of other parameters.

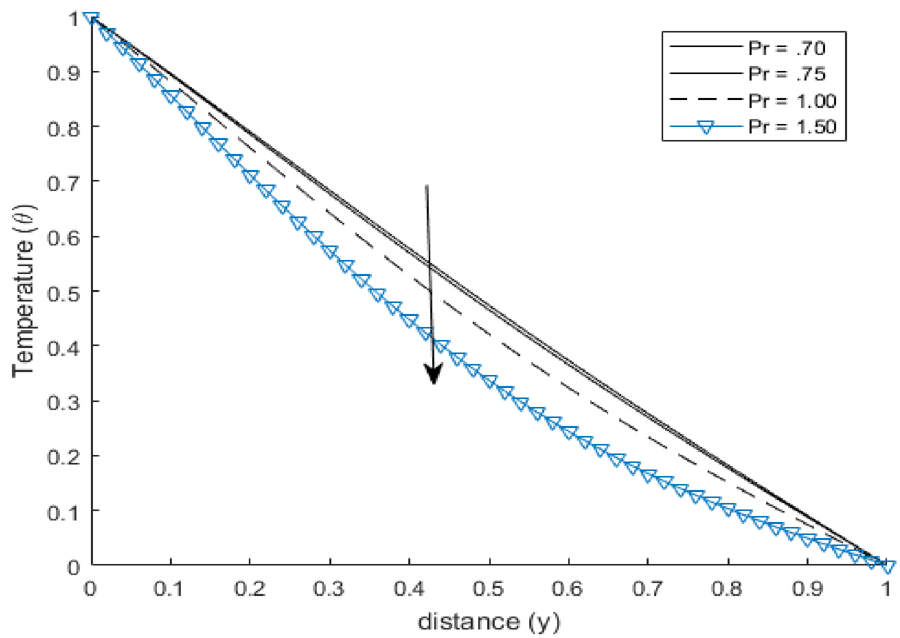


Figure-6: Temperature profile for difference value of Pr, effect of Prandtl number on temperature when M = 1, dt = 0.002, dy = 1/m, y = 0: dy: 1, dy2 = 2.0*dy, Gr = 5, Gm = 5, R = 2, and Sc = 0.57

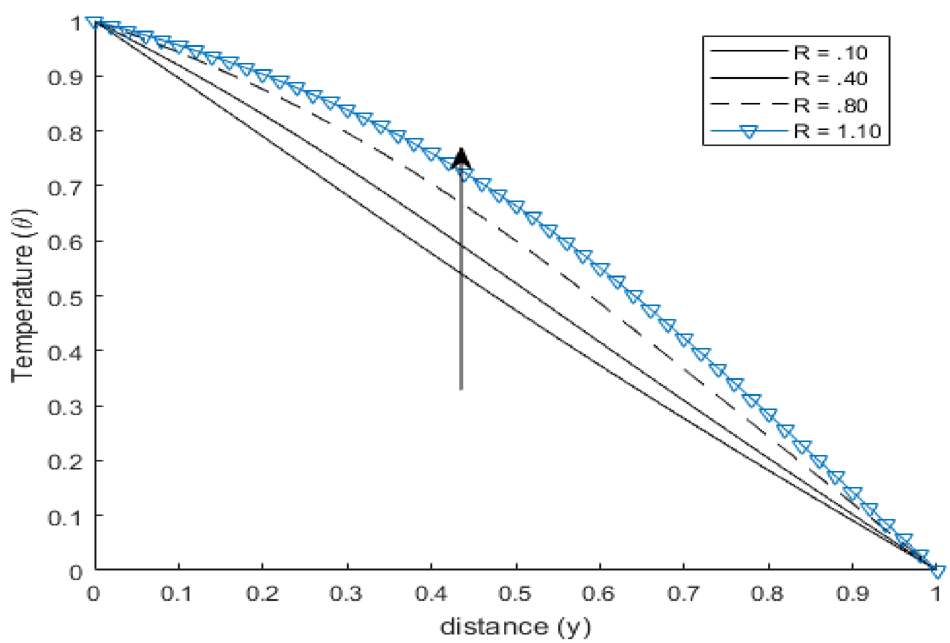


Figure-7: Temperature profile for difference value of R, effect of Radiative parameter on temperature when M = 1, dt = 0.002, dy = 1/m, y = 0: dy: 1, dy2 = 2.0*dy, Gr = 5, Gm = 5, and Sc = 0.57

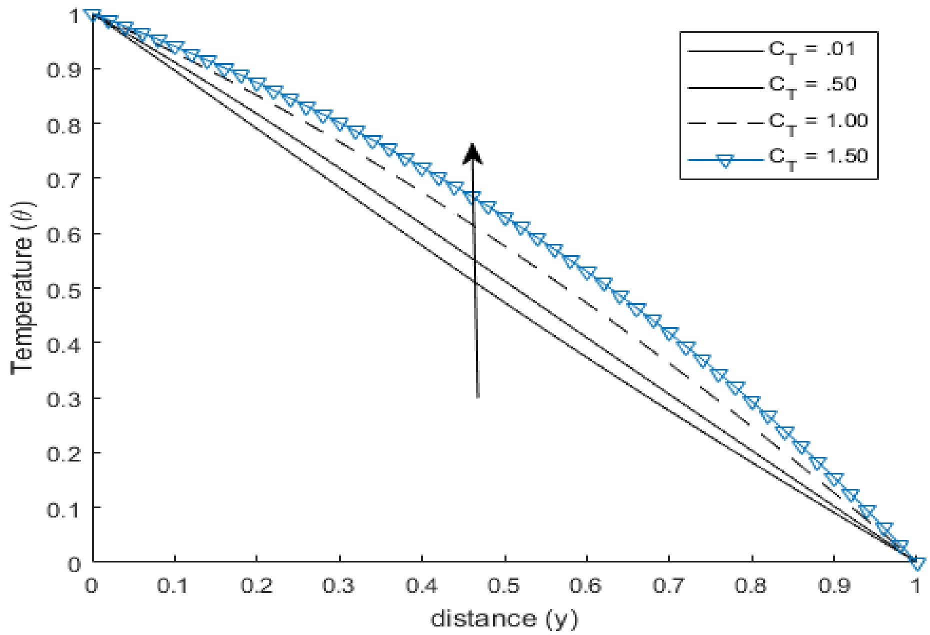


Figure-8: Temperature profile for difference value of Pr, effect of Temperature ratio difference on temperature when M = 1, dt = 0.004, dy = 1/m, y = 0:dy:1, dy2 = 2.0*dy, Gr = 5, Gm = 5, R = 0.10, and Sc = 0.57.

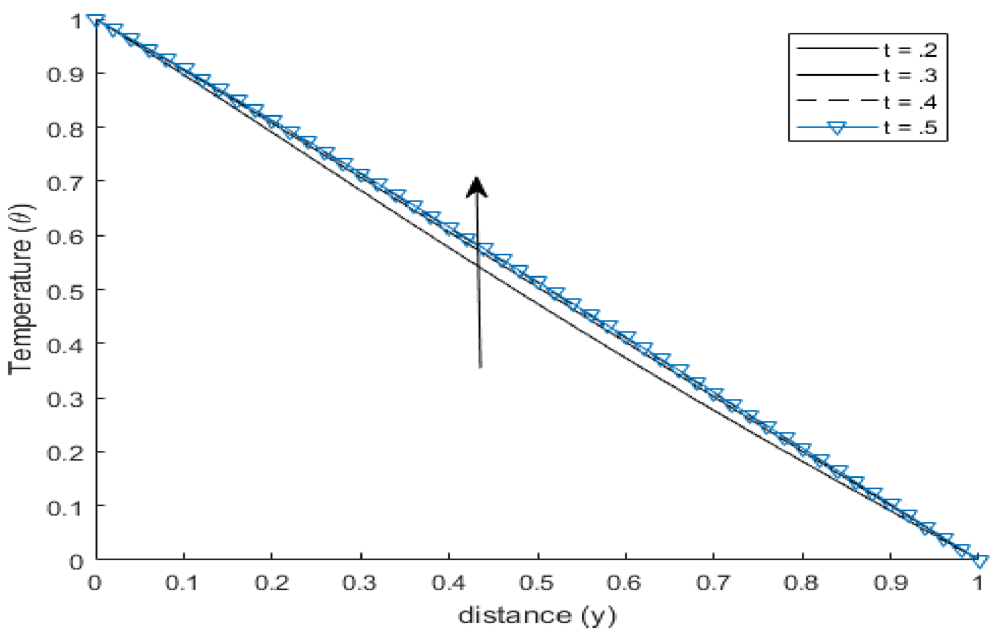


Figure-9: Temperature profile for difference value of t, effect of time on temperature when M = 1, dt = 0.002, dy = 1/m, y = 0: dy: 1, dy2 = 2.0*dy, Gr = 5, Gm = 5, R = 2, and Sc = 0.57

The result for the Concentration profile were obtained and presented in figure 10 to 11. Figure 10 illustrate the effect of Sc in concentration, it is observed that the concentration decreases as the value of *Sc* increased. Figure 11 the t (time) in concentration increases as the value of t increased for the fixed value of other parameters.

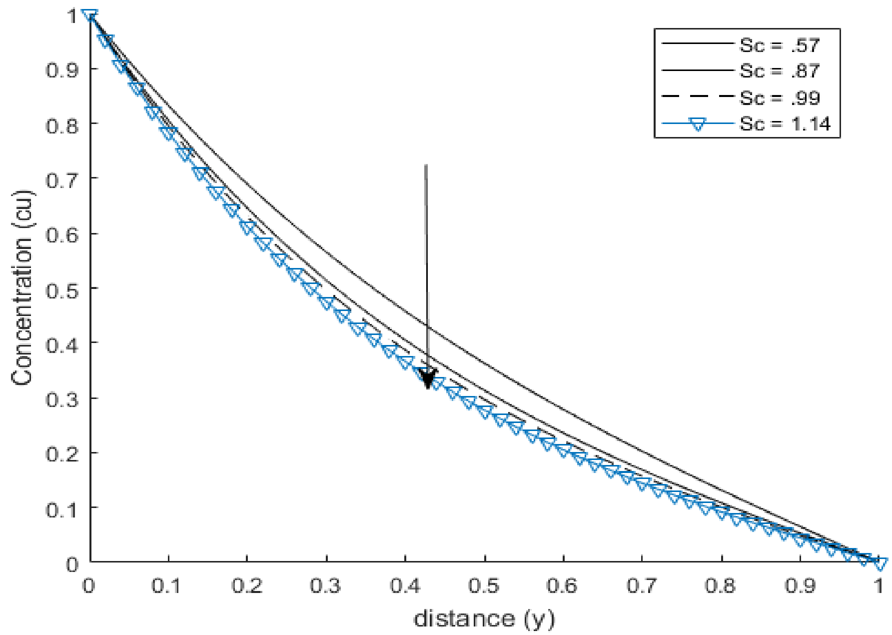


Figure-10: Concentration profile for difference value of Sc, effect of Schmidt number on Concentration when M = 1, dt = 0.002, dy = 1/m, y = 0: dy: 1, dy2 = 2.0*dy, Gr = 5, Gm = 5 and R = 2

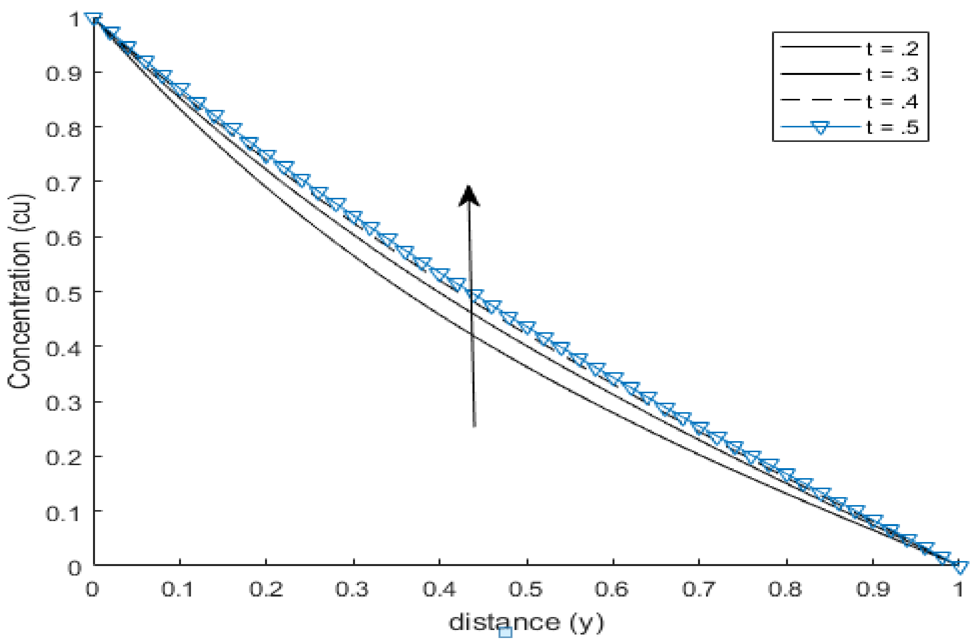


Figure-11: Concentration profile for difference value of t, effect of time on temperature when M = 1, dt = 0.002, dy = 1/m, y = 0: dy: 1, dy2 = 2.0*dy, Gr = 5, Gm = 5, Pr = 0.70, R = 2, and Sc = 0.57

5. CONCLUSION

The effect of MHD Couette flow investigates on the velocity profile shows that the velocity decreases with increased or rises in MHD Couette flow value (M). The result of velocity profile increases with increase in *Gr* in the problem, in the problem the velocity profile increases with rise in value *Gc* in the second problem *Gr* and *Gc* are the same they are all increasing as the *Gr* and *Gc* were increasing, the velocity profile increases with increase in dt in both problems. The temperature profiles for the different value of *Pr* it was observed that the temperature decreases with increase in *Pr* in the problem, while the temperature profiles for different value *R* it was noticed that the temperature increases with increase in thermal radiation *R* in the problem, the temperature profile increases with increased in temperature ratio difference C_T as well as time t increases in the problem. It is also observed that in the concentration profiles with different value of Schmidt number (Sc) the concentration decreases as the Schmidt value *Sc* rise. while the concentration increases as the time value rise.

6. NOMENCLATURE

- MHD: Magneto-hydrodynamic
- M: Magnetic number
- R: Thermal radiation parameter
- Pr: Prandtl number
- u': Dimensional velocities
- u: Dimensionless velocities
- U: Velocity of the plate at $y' = 0$
- x': Vertical co-ordinate, direction of the fluid
- y': Dimensional co-ordinate perpendicular to the plate
- t': Dimensional time
- t: Dimensionless time
- T': Dimensional temperature of the fluid
- v: Ratio of Kinematics' viscosity to
- Sc: Schmidt number, is the ratio of shear component for
- D: Diffusivity Viscosity Density for Mass Transfer
- Gr: Grashof number
- Gm: Modify Grashof number
- dr : Radiative heat flux q
- k: Permeability
- K: Thermal conductivity
- D_m : Coefficient of Mass Diffusivity

List of Greek Letters

- β Co-efficient of thermal expansion
- α Thermal diffusivity
- k^* Mean n abs
- σ Stefan-Boltzmann constant
- K Thermal conductivity
- θ Dimensionless temperature
- v Kinematic viscosity

- ρ Density of the fluid 0
- σ_1 Fluid electrical conductivity

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