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(RESEARCH ARTICLE)

Unsteady MHD Couette flow in a vertical porous channel with effect of thermal radiation and variable temperature

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Abstract

Unsteady MHD Couette flows in a vertical porous channel with effect of thermal radiation and variable temperature 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 line graphs. Significant results from this study showed that the velocity, temperature and concentration increases 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

The Unsteady MHD Couette flow in a vertical porous channel with effect of thermal radiation and variable temperature, however, amount of efforts has 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 [9].

They discuss 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. They use the Roseland approximation to describe the radiative heat flux in the energy equation. They also present the numerical solution by the implicit finite difference method and the analytical solution of the steady state by the perturbation method for the governing time-dependent partial differential equations. They have found an excellent agreement between the numerical solution at the large time and the analytical solution of the steady state was carried out [3]. The study on unsteady MHD free-convective Couette flow between vertical porous plates with thermal radiation was investigated [10]. Special attention to the combined effects of Frank-Kamenetskii, activation energy parameters and Prandtl number on an unsteady/steady natural convection flow of a viscous reactive fluid in a vertical annulus [9]. The study on 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 was conducted [6]. In view of the significance of the Soret effect as well as Hall effect, the unsteady MHD free convective flow past a vertical porous plate in porous medium

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with Hall current, thermal diffusion and heat source [2]. Here their main objectives are to study the effect of Soret number and Hall parameter on the flow and transport characteristics. Their work is an extension to the work done of [18] to consider the effect of thermal diffusion on the flow and heat and mass transfer. Considering study unsteady flow of a reactive variable viscosity fluid between two parallel porous plates acted upon by non-constant 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 [21]. However, the study motivated them to accomplish the analysis for the electrically conducting fluid inside the porous walls. To achieve the aim, the system of higher order nonlinear PDEs are solved with the manifestation of explicit Finite Difference Scheme [12].

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 [8]. The objective of their 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. Considering the effects of magnetic field which is found to be very important in controlling and regulating the fluid velocity and viscous drag at wall [20].

The study on the 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 was carried out [4]. 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 was investigated [16]. Investigating the flow formation in Couette motion in magneto hydrodynamics with time varying suction and taking into account the effects of heat and mass transfer [15]. 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. [17] investigated the radiation effects on free convection MHD Couette flow of a viscous incompressible heat generating fluid in the presence of variable temperature. [7] 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. [13] focuses on the effect of chemical reaction on unsteady MHD free convective two immiscible fluids flow. [22] considered a Couette flow of a Casson fluid in an inclined composite duct partly filled with fluid and partly filled with porous material. The velocity of the fluid through porous layers and velocity of fluid in free flow region are calculated. 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 [11]. [5] investigated 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 in the presence of a uniform transverse magnetic field is analyzed.

The effect of free convection on the unsteady Couette motion in which the resulting system of coupled linear partial differential equations was solved by Laplace transform was carried out [19]. The work studied the combined effect of radiation, joule heating and viscous dissipation on MHD Marangoni convection flow in the presence of suction or injection. [1] investigated 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. 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:

$$\frac{\partial u'}{\partial t'} = v\frac{\partial^2 u'}{\partial y'^2} + g\beta(T' - T_0) + g\beta_\infty(C' - C_0) - \frac{\sigma_1 B_0^2 u'}{\rho} \quad (1)$$

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

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial y^{'2}} \quad (3)$$

The quantity q_r appearing on the right hand side of equation (2) 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 following

$$\frac{\partial q_r}{\partial y'} = -4a^*\sigma(T_\omega'^4 - T'^4) \quad (4)$$

It is assumed that the temperature differences within the flow are sufficiently small such that T'^4. Maybe expressed as a linear function of the temperature. This is accomplished by expanding T'^4 in a Taylor's series about T_ω' and neglecting higher order terms. Thus

$$T'^4 \cong 4T_\omega'^3 T' - 3T_\omega'^4 \quad (5)$$

By substituting equation (5) into equation (4)

$$\frac{\partial q_r}{\partial y'} = -16a^*\sigma T_\omega'^3(T_\omega' - T') \quad (6)$$

And the corresponding initial and boundary conditions are:

$$t' \leq 0: \{u' = 0, T' = T_0', C' = C_0', 0 \leq y' \leq H\}$$

$$t' >: \begin{cases} u' = U, T' = T_\omega, C' = C_\omega \; at \; y' = 0 \\ u' = 0, T' = T_0, C' = C_0 \; at \; y' = \mathrm{H} \end{cases} \quad (7)$$

To obtain the solution of equation (1), (2) and (3) subject to the initial and boundary condition (7) in dimensionless form, the following appropriate dimensionless quantities are introduced.

$$t = \frac{vt'}{H^2}, y = \frac{y'}{H}, u = \frac{u'}{U}, \mathrm{Pr} = \frac{v}{\alpha}, R = \frac{16a^*\sigma H^2 T_\omega'^3}{k}, M^2 = \frac{\sigma_1 B_0^2 H^2}{\rho}, Gr = \frac{g\beta H^2(T_\omega' - T_0')}{vU}, Gm = \frac{g\beta_\infty H^2(C_\omega' - C_0')}{vU}, \theta = \frac{T' - T_0'}{T_\omega' - T_0'}, C = \frac{C' - C_0'}{C_\omega' - C_0'}, \quad (8)$$

Using the dimensionless quantities introduced in equation (6), the dimensionless form of equations (1), (2) and (3) are:

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

$$Pr\frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial y^2} + R\theta \quad (10)$$

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

While the dimensionless initial and boundary conditions are

$$t \leq 0: \{u = 0, \theta = 1, c = 1 \; at \; 0 \leq y$$

$$t > 0: \begin{cases} u = 1, \theta = 1, c = 1 \; at \; y = 0 \\ u = 0, \theta = 0, c = 0 \; at \; y = 1 \end{cases} \quad (12)$$

Substituting the non-dimensional quantities in the boundary condition

$$t' = \frac{tH^2}{v} \leq 0: \{u' = uU = 0, T' = T_0' + \theta(T_\omega' - T_0') = T_0', C' = C_0' + \theta(C_\omega' - C_0') = C_0', 0 \leq y' \leq H\}$$

$$t' = \frac{tH^2}{v} >: \{u' = uU = U, T' = T_0' + \theta(T_\omega' - T_0') = T_\omega', C' = \theta(C_\omega' - C_0') = C_\omega' \; at \; y' = yH = 0\}$$

$$t' = \frac{tH^2}{v} >: \{u' = uU = 0, T' = T_0' + \theta(T_\omega' - T_0') = T_0, C' = \theta(C_\omega' - C_0') = C_0 \; at \; y' = yH = 0\} \quad (13)$$

3. Numerical Solution

The velocity, temperature and concentration equations given in equations (1), (2) and (3) 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

$$\frac{U_i^{j+1} - U_i^j}{Dt} = \frac{U_{i-1}^{j+1} - 2U_i^{j+1} + U_{i+1}^{j+1}}{(Dy)^2} + Gr\theta_i^j + GmC_i^j - M^2u_i^j \quad (15)$$

$$Pr\frac{\theta_i^{j+1} - \theta_i^j}{Dt} = \frac{\theta_{i-1}^{j+1} - 2\theta_i^{j+1} + \theta_{i+1}^{j+1}}{(Dy)^2} + R\theta_i^j \quad (16)$$

$$\frac{C_i^{j+1} - C_i^j}{Dt} = \frac{1}{Sc}\frac{C_{i-1}^{j+1} - 2C_i^{j+1} + C_{i+1}^{j+1}}{(Dy)^2} \quad (17)$$

Solving the finite difference solution with respective boundary condition using 3- point formula then the characteristic equations are obtained.

$$\left(\frac{-4r1}{3} + (1 + 2r1)\right)U_1^{j+1} + \left(\frac{r1}{3} - r1\right)U_2^{j+1} - \frac{2Dyr1}{S} = (1 - DtM^2)U_1^j + Dt\,Gr\theta_1^j + DtGmC_1^j \quad (18)$$

$$\left(\frac{-4r2}{3} + (\mathrm{Pr} + 2r2)\right)\theta_i^{j+1} + \left(\frac{r2}{3} - r2\right)\theta_2^{j+1} - \frac{2r2Dy}{3} = (Pr + DtR)\theta_1^j \quad (19)$$

$$\left(\frac{-4r3}{3} + (1 + 2r3)\right)C_1^{j+1} + \left(\frac{r3}{3} - r3\right)C_2^{j+1} - \frac{2r3Dy}{3} = C_1^j \quad (20)$$

Where$r1 = r2 = \frac{Dt}{(Dy)^2}$., $r3 = \frac{Dt}{Sc(Dy)^2}$

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, Magnetic number M.

The results for the velocity profile are obtained and presented in figure 1 to 4. In figure 1 it is observed that the fluid velocity decreased as the M increases for fixed value of other parameters. In figure 2 it is observed that the fluid velocity significantly increases as Gr increase 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 3 that the velocity of the flow increases as Gm increase for fixed value of other parameters. In figure 4 that the velocity of the flow increases as t increase for the fixed value of other parameters.

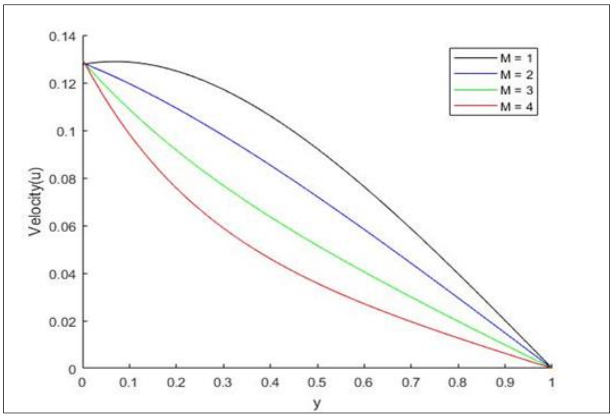

Figure 1 Velocity profile for difference value of M, effect of magnetic parameter on velocity when Pr = 0.70, dt = 0.03, dy = 1/m, y = 0: dy: 1, dy2 = 2.0*dy, Gr = 5, Gm = 5, Sc = 0.57, and R = 2

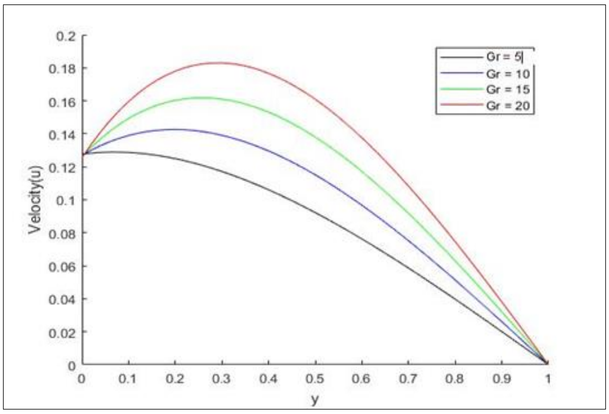

Figure 2 Velocity profile for difference value of Gr, effect of Grashoft number on velocity when M = 1, Pr = 0.70, dt = 0.03, dy = 1/m, y = 0: dy: 1, dy2 = 2.0*dy, Gm = 5, Sc = 0.57, and R = 2

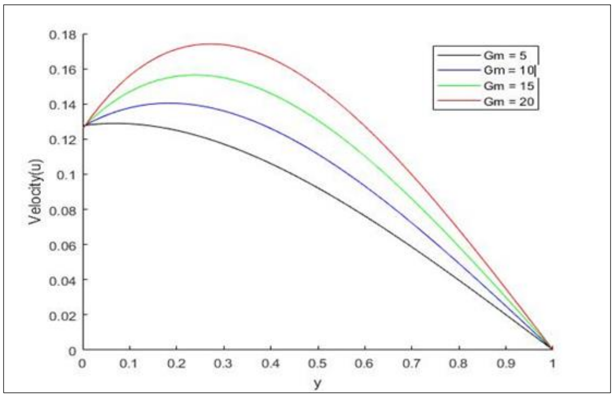

Figure 3 Velocity profile for difference value of Gm, effect of Mass Grashoft number on velocity when M = 1, Pr = 0.70, dt = 0.03, dy = 1/m, y = 0: dy: 1, dy2 = 2.0*dy, Gr = 5, Sc = 0.57, and R = 2

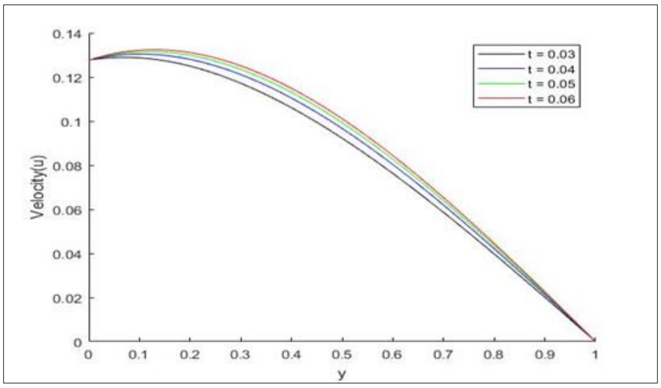

Figure 4 Velocity profile for difference value of t, effect of time on velocity when M = 1, Pr = 0.70, dt = 0.03, dy = 1/m, y = 0: dy: 1, dy2 = 2.0*dy, Gr = 5, Gm = 5, R = 2, and Sc = 0.57

The result for the temperature profile were obtained and presented in figure 5 to 7. In figure 5 illustrate the effect of Pr in temperature, it is observed that the temperature increases as the Pr increase for fixed value of other parameters. Figure 6 we observed that the temperature increase when the value of R (radiative parameter) increases for the value of other parameters. While in figure 7 it is observed that the temperature increases as the value of t increase for the fixed value of other parameters.

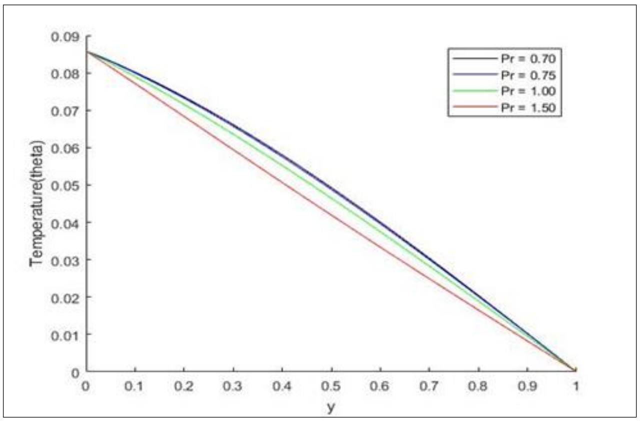

Figure 5 Temperature profile for difference value of Pr, effect of Prandtl number on temperature when M = 1, dt = 0.03, dy = 1/m, y = 0: dy: 1, dy2 = 2.0*dy, Gr = 5, Gm = 5, R = 2, and Sc = 0.57

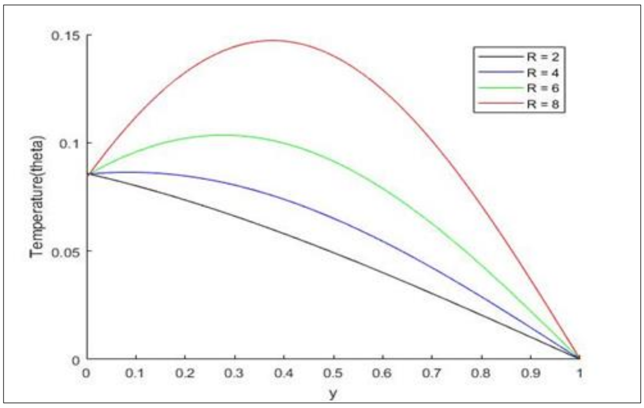

Figure 6 Temperature profile for difference value of R, effect of Radiative parameter on temperature when M = 1, dt = 0.03, dy = 1/m, y = 0: dy: 1, dy2 = 2.0*dy, Gr = 5, Gm = 5, and Sc = 0.57

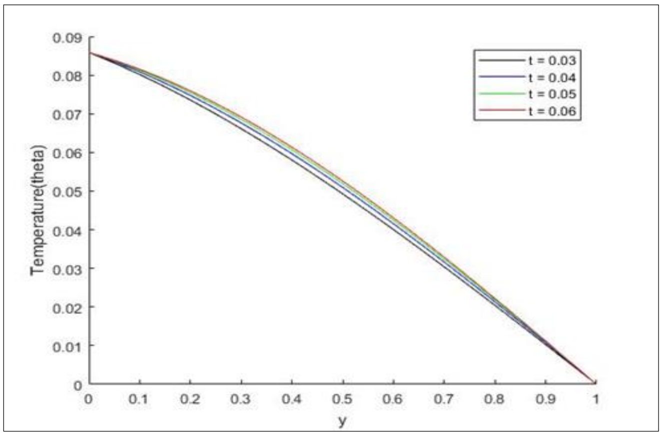

Figure 7 Temperature profile for difference value of t, effect of time on temperature when M = 1, dt = 0.03, dy = 1/m, y = 0: dy: 1, dy2 = 2.0*dy, Gr = 5, Gm = 5, R = 2, and Sc = 0.57

The result for the Concentration profile were obtained and presented in figure 8 to 9. Figure 8 illustrate the effect of Sc in concentration, it is observed that the concentration increases as the value of Sc increased. Figure 9 the t (time) in concentration profile as the value of t increases concentration decreases.

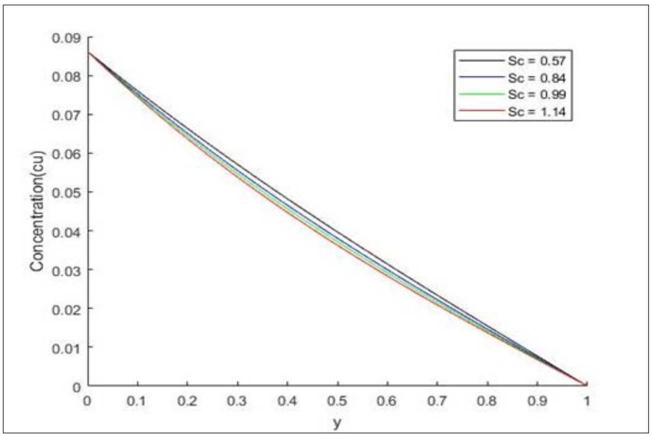

Figure 8 Concentration profile for difference value of Sc, effect of Schmidt number on Concentration when M = 1, dt = 0.03, dy = 1/m, y = 0: dy: 1, dy2 = 2.0*dy, Gr = 5, Gm = 5, R = 2, and Sc = 0.57

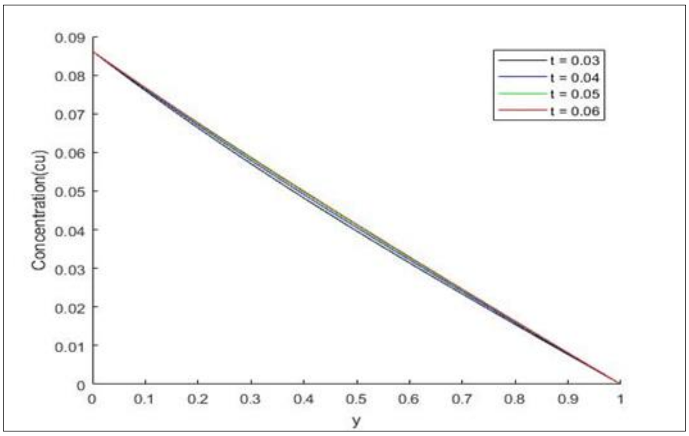

Figure 9 Concentration profile for difference value of t, effect of time on temperature when M = 1, dt = 0.03, dy = 1/m, y = 0: dy: 1, dy2 = 2.0*dy, Gr = 5, Gm = 5, Pr = 0.70, R = 2, and Sc = 0.57

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 MHD Gr in both problems, in the first problem the velocity profile decreases with rise in MHD value Gm in the second problem Gr and Gm are the same they are all increasing as the MHD Gr and Gm were increasing, the velocity profile increases with increase in MHD dt in both problems.

The temperature profiles for the different value of Pr it was observed that the temperature decreases with increase in MHD Pr in both problems, while the temperature profiles for different value R it was noticed that the temperature increases with increase in MHD thermal radiation R in both problems, as well as time t increases in both problems.

It is also observed that in the concentration profiles with different value of Schmidt number (Sc) the concentration decrease as the Schmidt value Sc rise. A reverse flow of is also recognized due to suction as demonstrated on concentration profile, also the concentration profiles with different value of chemical reaction (Kc) the concentration decrease as the chemical value rise, while the concentration increase 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

Compliance with ethical standards

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