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Effect of Heat and Mass Transfer on Unsteady Convective MHD Couttee Flow through Porous Medium with Oscillating Temperature.

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ABSTRACT

The effect of heat and mass transfer on unsteady free convection oscillatory flow through parallel flat plates in a porous medium with heat source and chemical reaction is investigated with free stream Velocity, temperature and concentration oscillate in time about a non-zero constant mean. A closed form analytical solution is obtained by adopting regular perturbation method to solve the momentum and energy and concentration equations. Effect of various non-dimensional parameters on velocity, temperature and concentration profiles have been analysed in detail and results are shown in graphs.

Keywords: MHD, Natural Convection, Couttee flow, Oscillatory, porous medium,heat and mass transfer.

Introduction

The study of free convective fluid flow is a classical investigation in the field offlow of fluids and thermal variations and conductions. These studies significantlyinvolved in various industrial applications like nuclear power plant, solid matrixheat transfer, porous smooth plate receivers, oil retrieval, distributing and diffusingchemical wastes in various practices, dispersing nuclear discarded material, grainspreservation and aeration and much more. Furthermore, free convective flow has agreat influence in the field of solar heating systems and is widely used in ventilatingpassive system. As there are numerous interests, research developments and analysisin free-convective flow, there are many studies in MHD free convection flows invarious surfaces with different phenomena. With the effect of heat transfer and theradiation effect of MHD flow influenced by the magnetic field also of interest invarious application areas such as space technology, nuclear power plants, temperaturechanges in transmission lines, electric transformers etc.

Heinischetal et. al. [1] studied transient free convection flow in laminarboundary layer equations using an integral technique. He arrived at a solutionby solving a system of PDE with two independent variables and ODE with twodifferent methods. Hossain et. al. [2] considered a vertical thin cylinder withthe flow of natural convection radiation interaction with boundary layer and furtherhe investigated the same for conduction radiation interaction using finite differencemethod in which the fluid is incompressible over an isothermal horizontal plate [3].Mina et. al. [4] studied unsteady free convection flow in moving sheet withambient fluid. He applied group theoretic approach in which a constant insulatedplate influenced the thermal boundary layer in a vertical layer of Boussinseq fluid.Makinde [5] investigated convective flow, energy emission and molecular transporttogether with assumption plate travels in the plane which is kept in fixed temperaturewith constant elements concentration, considered the grey fluid with absorptionand emission and found solution corresponding to the equations pertaining to nonlinear thrust, energy and deliberation. Mehmet et. al. [6] considered the verticaldown point cone to study the effect of laminar free convection flow influenced withthe magnetic field, found its energy and flow rate distribution for various parametervalues. Kassem et. al. [7] found a solution for stability in convective flow of a platemoves vertically influenced with a constant heat variation.

As micro polar fluid has a variety of applications and important in the study ofsuspended particles, Prathap et. al. [8] had taken two different regions to analyse thelaminar free convection flow in which one is occupied by micro polar fluid and theother one by a viscous fluid, found the expressions as analytic solution for velocity,temperature and the velocity corresponds to the micro rotation. Basant et. al. [9]studied the flow of hydro dynamics with thermal

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characteristics of viscous reactivefluids transient free convection flow and dimensionless parameters are employed insolving the governing equations.

MamunMollaa et. al. [10] studied with streamwise sinusoidal surfacetemperature which the viscous incompressible optically thick fluids natural convectionlaminar flow with the effect of thermal radiation in two dimension has been analysed.Ali et. al. [11] analysed it with a vertical plate influenced with Joule heating and itsthermal effect by employing dimensionless parameters with suitable transformationsusing Keller box scheme and FEM. Nazma et. al. [12] analysed with the samemethod to find the effect of energy conduction on natural convection along oscillatoryplate. Mahesha et. al. [13] had analysed the cross diffusion and double diffusiveconvection effect of a vertically spinning cone with the effect of magnetic field havingthe application in oceanography. Ruthra et. al. [14] considered the motion ofincompressible fluid with rotational cylinder to study the effect of this flow assumingthe cylinder starts spontaneously with constant acceleration corresponds to the rotatingfluid. Abdul et. al. [15] analysed the flow in a square cavity influenced by themagneticfield and with different temperature sources.

The aim of this chapter is to analyse the problem of radiating MHD oscillatoryflow. Fluid is assumed to be flowing through two parallel plates in a porous structure.When the buoyancy forces react with the flow fluid as free convective flow, the effectof magnetic field which influence the thermal radiation has been analysed with freestream velocity, concentration and temperature profiles. This problem has not been reported earlier in the literature.

Mathematical Modelling

The problem of MHD oscillatory Couette flow of a viscous incompressible fluid is considered.It is assumed that fluid is finitely conducting and flowing between two parallel plates enclosing permeable structure. One plate is suddenly moved with free stream flow rate U^*that assumed to be oscillating about mean. Choosing the coordinate axes in the directions along the plate vertically and normal to that plate respectively.

The governing equations of the flow are formulated from Navier-Stokes equation and maxwell's equation for MHD with the assumptions that magnetic force is taken normal to the boundaries and the induced magnetic field is neglected. The governing equations of the flow are:

$$\frac{\partial u^*}{\partial t^*} = \frac{\partial U^*}{\partial t^*} + \nu \frac{\partial^2 U^*}{\partial {y^*}^2} + g\beta_T(T^* - T_b^*) + g\beta_C(C^* - C_b^*) - \left(\frac{\bar{J}\times\bar{B}}{\rho}\right) - \frac{\nu u^*}{k^*} - \frac{1}{\rho}\frac{\partial p^*}{\partial x^*} \quad (1)$$

Where $\bar{J} \times \bar{B} = \sigma(\bar{v} \times \bar{B}) \times \bar{B}$, then $\left(\frac{\bar{J}\times\bar{B}}{\rho}\right) = \frac{(u^*-U^*)\sigma B^2}{\rho}$and hence equation (3.1) becomes

$$\boldsymbol{\frac{\partial u^*}{\partial t^*} = \frac{\partial U^*}{\partial t^*} + \nu \frac{\partial^2 U^*}{\partial {y^*}^2} + g\beta_T(T^* - T_b^*) + g\beta_C(C^* - C_b^*) - \left(\frac{(u^*-U^*)\sigma B^2}{\rho}\right) - \frac{\nu u^*}{k^*} - \frac{1}{\rho}\frac{\partial p^*}{\partial x^*}} \quad (2)$$

$$\frac{\partial T^*}{\partial t^*} = \alpha \frac{\partial^2 T^*}{\partial {y^*}^2} + Q^*(T^* - T_b^*) \quad (3)$$

$$\frac{\partial C^*}{\partial t^*} = D \frac{\partial^2 C^*}{\partial {y^*}^2} - K_r^*(C^* - C_b^*) \quad (4)$$

The corresponding BCs are given by

$$\left.\begin{array}{l} \text{At } y^* = 0, u^* = U_0(1 + \varepsilon e^{i\omega * t*}), T^* = T_0^* + \varepsilon(T_0^* - T_b^*)e^{i\omega * t*}, C^* = C_0^* + \varepsilon(C_0^* - C_b^*)e^{i\omega * t*}, \\ \text{At } y^* = b, u^* = 0, T_0^* = T_b^*, C_0^* = C_b^* \end{array}\right\} \quad (5)$$

Transforming the dimensional quantities as

$$\bar{y} = \frac{y*}{b}, \left.\begin{array}{l} \bar{u} = \frac{u*}{U_0}, \bar{t} = \omega * t *, \omega = \frac{\omega * b *}{\nu}, \theta = \frac{T^* - T_b^*}{T_0^* - T_b^*}, Gr = \frac{g\beta b^2 (T_0^* - T_b^*)}{\nu U_0}, Q = Q * \frac{b^2}{\alpha}, \\ Gc = \frac{g\beta_C b^2 (C_0^* - C_b^*)}{\nu U_0}, \phi = \frac{C^* - C_b^*}{C_0^* - C_b^*}, K = \frac{b^2 U_0}{\nu^2} K_r^*, Sc = \frac{\nu}{D}, M = \sqrt{\frac{\sigma B^2 b^2}{\rho \nu}}, Pr = \frac{\nu}{\alpha} \end{array}\right\} \quad (6)$$

Using equation (6), governing equations in non-dimensional form obtained as
Momentum equation:

$$\omega\left(\frac{\partial u}{\partial t} - \frac{\partial U}{\partial t}\right) = \frac{\partial^2 u}{\partial y^2} + Gr\theta + Gc\phi - (s^2 + M^2)u + M^2 U \quad (7)$$

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Energy equation:
$$\omega\, Pr \frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial y^2} + Q\theta \quad (8)$$

Concentration equation:
$$\omega\left(\frac{\partial \phi}{\partial t}\right) = \frac{1}{Sc}\frac{\partial^2 \phi}{\partial y^2} - K\phi \quad (9)$$

With the boundary conditions
$$\left.\begin{array}{l} y = 0, u = 1 + \varepsilon e^{it}, \\ y = 1, u = \theta = C = 0 \end{array}\right\} \quad (10)$$

Solution by Regular Perturbation Method

Due to small variation ε(<<1) in all the flow profiles, the solutions can be taken as :
$$u(y,t) = u_0(y) + \varepsilon u_1(y)e^{it} \quad (11)$$
$$\theta(y,t) = \theta_0(y) + \varepsilon \theta_1(y)e^{it} \quad (12)$$
$$\phi(y,t) = \phi_0(y) + \varepsilon \phi_1(y)e^{it} \quad (13)$$
and for free stream velocity
$$U = 1 + \varepsilon e^{it} \quad (14)$$
Substituting equations (11) – (14) in equations (7) – (9), the governing equations become
Temperature equation:
$$(\theta_0'' + Q\theta_0) = 0 \quad (15)$$
$$(\theta_1'' - (Q - Pr\, i\, \omega)\theta_1 = 0 \quad (16)$$
Concentration equation:
$$(\phi_1'' - (KSc - i\omega Sc)\phi_1 = 0 \quad (17)$$
$$\phi_0'' - ScK\phi_0 = 0 \quad (18)$$
Momentum equation:
$$u_0'' - (s^2 + M^2)u_0 = -(Gr\theta_0 + Gc\theta_0 + M^2) \quad (19)$$
$$u_1'' - (s^2 + M^2 + i\,\omega)u_1 = -Gr\theta_1 - Gc\theta_1 + (i\omega + M^2) \quad (20)$$
With the corresponding BCs
$$\left.\begin{array}{l} y = 0, u_0 = 1, u_1 = 1, \theta_0 = 1, \theta_1 = 1, \phi_0 = 1, \phi_1 = 1, \\ y = 1, u_0 = 0, u_1 = 0, \theta_0 = 0, \theta_1 = 0, \phi_0 = 0, \phi_1 = 0 \end{array}\right\} \quad (21)$$
Solving (15) and (16),
$$\theta_0 = a_{01}e^{n_3 y} + a_{12}e^{-n_3 y} \quad (22)$$
$$\theta_1 = a_{11}e^{n_2 y} + a_{12}e^{-n_2 y} \quad (23)$$
Solving (17) and (18),
$$\phi_0 = b_{01}e^{n_5 y} + b_{02}e^{-n_5 y} \quad (24)$$
$$\phi_1 = b_{11}e^{n_4 y} + b_{12}e^{-n_4 y} \quad (25)$$
Solving (19),
$$C.F. = c_{01}e^{n_7 y} + c_{02}e^{-n_7 y}$$
$$P.I_1 = \frac{1}{(D^2 - n_7^2)}(-Gr\,\theta_0) = \frac{1}{(n_3^2 - n_7^2)}(-Gr\,\theta_0)$$
$$P.I_2 = \frac{1}{(D^2 - n_7^2)}(-Gc\,\phi_0) = \frac{1}{(n_5^2 - n_7^2)}(-Gc\,\phi_0)$$

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$$\therefore u_0 = c_{01}e^{n_7 y} + c_{02}e^{-n_7 y} - \frac{Gr\,\theta_0}{(n_3^2-n_7^2)} - \frac{G\,c\theta_0}{(n_5^2-n_7^2)} + \left(\frac{M^2}{n_7^2}\right) \tag{26}$$

Solving (20), $C.F. = c_{11}e^{n_6 y} + c_{12}e^{-n_6 y}$

$$P.I_1 = \frac{1}{(D^2-n_6^2)}(-Gr\,\theta_1) = \frac{1}{(n_2^2-n_6^2)}(-Gr\,\theta_1)$$

$$P.I_2 = \frac{1}{(D^2-n_6^2)}(-Gc\,\phi_1) = \frac{1}{(n_4^2-n_6^2)}(-Gc\,\phi_1)$$

$$\therefore u_1 = c_{11}e^{n_6 y} + c_{12}e^{-n_6 y} - \frac{Gr\,\theta_1}{(n_2^2-n_6^2)} - \frac{Gc\,\phi_1}{(n_4^2-n_6^2)} + \left(\frac{M^2+i\omega}{s^2+M^2+i\,\omega}\right) \tag{27}$$

The velocity, temperature and concentration distributions are obtained as

$$u(y,t) = (c_{01}e^{n_7 y} + c_{02}e^{-n_7 y}) - \frac{Gr\,\theta_0}{(n_3^2-n_7^2)} - \frac{Gc\,\phi_0}{(n_5^2-n_7^2)} + \left(\frac{M^2}{n_7^2}\right)$$
$$+\varepsilon\left[(c_{11}e^{n_6 y} + c_{12}e^{-n_6 y}) - \frac{Gr\,\theta_1}{(n_2^2-n_6^2)} - \frac{Gc\,\phi_1}{(n_4^2-n_6^2)} + \left(\frac{M^2+i\omega}{s^2+M^2+i\,\omega}\right)\right]e^{it} \tag{28}$$

$$\theta(y,t) = a_{01}e^{n_3 y} + a_{02}e^{-n_3 y} + \varepsilon[a_{11}e^{n_2 y} + a_{12}e^{-n_2 y}]e^{it} \tag{29}$$

$$\phi(y,t) = b_{01}e^{n_5 y} + b_{02}e^{-n_5 y} + \varepsilon[b_{11}e^{n_4 y} + b_{12}e^{-n_4 y}]e^{it} \tag{30}$$

The skin friction, rate of heat transfer and mass transfer are obtained as

$$\tau = \left\{\frac{\partial u}{\partial y}\right\}_{y=h_1,h_2}$$

$$\tau = \varepsilon[e^{ti+n_6 y}c_{11}n_6 - e^{ti-n_6 y}c_{12}n_6] + c_{01}n_7 e^{n_7 y} + c_{02}n_7 e^{-n_7 y}$$
$$-\left[\frac{Gr}{(n_3^2-n_7^2)\frac{\partial\theta_0}{\partial y}\frac{G\,c}{(n_5^2-n_7^2)}\frac{\partial\phi_0}{\partial y}\frac{Gr}{(n_2^2-n_6^2)\frac{\partial\theta_1}{\partial y}\frac{G\,c}{(n_4^2-n_6^2)}\frac{\partial\phi_1}{\partial y}}}\right]$$

(31)

$$Nu = -\left(\frac{\partial\theta}{\partial y}\right)_{y=h_1,h_2} = -\varepsilon[e^{ti}(a_{11}n_2)e^{n_2 y} - (a_{12}n_2)e^{-n_2 y}] + (a_{01}n_3)e^{n_3 y} - (a_{02}n_3)e^{-n_3 y} \tag{32}$$

$$Sh = -\left(\frac{\partial\phi}{\partial y}\right)_{y=h_1,h_2} = -\varepsilon[e^{ti}(b_{11}n_4)e^{n_4 y} - (b_{12}n_4)e^{-n_4 y}] + b_{01}n_5 e^{n_5 y} - b_{02}n_5 e^{-n_5 y} \tag{33}$$

All the constants appearing in the above solutions are given below:

$$n_2^2 = Q + i\,Pr\,\omega\,;\, n_3^2 = Q;\, n_4^2 = KSc - i\omega Sc;\, n_5^2 = KSc;$$
$$n_6^2 = s^2 + M^2 + i\,\omega\,;\, n_7^2 = s^2 + M^2;$$
$$a_{01} = \frac{-e^{-2n_3}}{1-e^{-2n_3}};\, a_{02} = \frac{1}{1-e^{-2n_3}};\, a_{11} = \frac{-e^{-2n_2}}{1-e^{-2n_2}};\, a_{12} = \frac{1}{1-e^{-2n_2}};$$
$$b_{01} = \frac{-e^{-2n_5}}{1-e^{-2n_5}};\, b_{02} = \frac{1}{1-e^{-2n_5}};\, b_{11} = \frac{-e^{-2n_4}}{1-e^{-2n_4}};\, b_{12} = \frac{1}{1-e^{-2n_4}};$$
$$c_{01} = \left\{1 + \frac{Gr}{(n_3^2-n_7^2)\frac{G\,c}{(n_5^2-n_7^2)}\frac{M^2}{n_7^2}}\{\}\left(1-\frac{e^{n_7}}{A}\right)\frac{M^2}{An_7^2}\right\}$$

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$$c_{02} = \left\{1 + \frac{Gr}{(n_3^2 - n_7^2)\frac{G\,c}{(n_5^2-n_7^2)}\frac{M^2}{n_7^2}}\{\}\left(\frac{e^{n_7}}{A}\right)\frac{M^2}{An_7^2}\right\}$$

$$c_{11} = \left\{1 + \frac{Gr}{(n_2^2 - n_6^2)\frac{G\,c}{(n_2^2-n_6^2)}\frac{M^2+i\omega}{n_6^2}}\{\}\left(1 - \frac{e^{n_6}}{B}\right)\frac{M^2+i\omega}{Bn_6^2}\right\}$$

$$c_{12} = \left\{1 + \frac{Gr}{(n_2^2 - n_6^2)\frac{G\,c}{(n_2^2-n_6^2)}\frac{M^2+i\omega}{n_6^2}}\{\}\left(\frac{e^{n_6}}{B}\right)\frac{M^2+i\omega}{Bn_6^2}\right\}$$

$$A = 2\,sinh(n_7); \quad B = 2\,sinh(n_6)$$

Results and Discussion

The results of the above problem discussed with the graphs drawn for the impactof parameters on various profiles offlow field.

Velocity Profiles

In fig.1, the impact of Grashoff number (Gr) on velocity (u) is presented. AsGr increases velocity increases.
From fig.2, the mutual effect of three parameters (ω,Gr) and K oscillationfrequency (ω), Grashoff number (Gr) and chemical reaction parameter (K), onvelocity (u) can be observed.

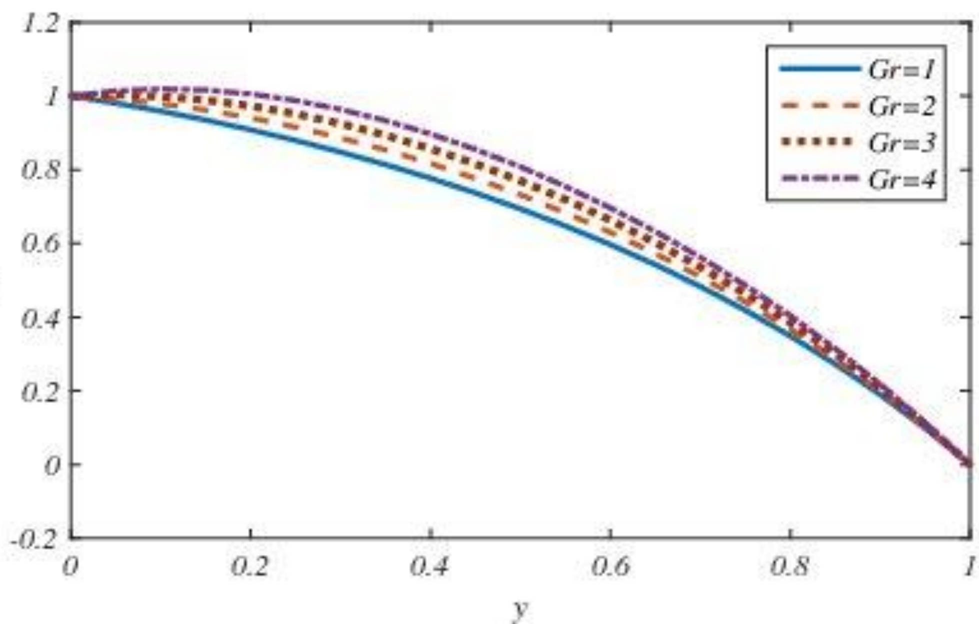

Figure 1. Influence of Grashoff number (Gr) on velocity for ω = 2, Pr = 0.71,t = π/2, ϙ = 0.1, K = 1, Sc = 0.6, M = 2, s = 1, Gc = 1, Q = 1

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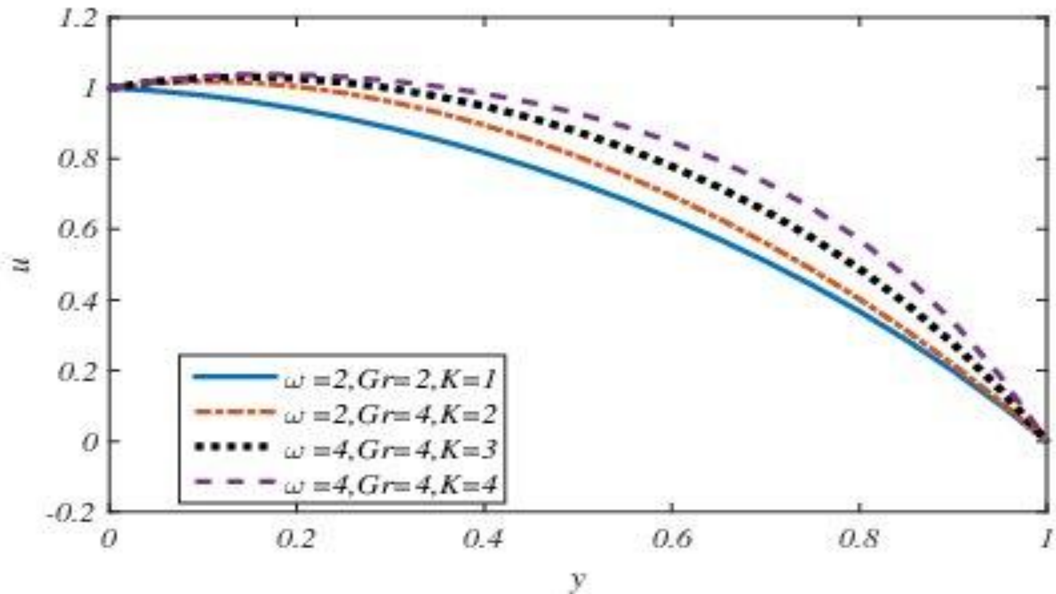

Figure 2. Influence of Gr,K, ω on velocity for M = 2, Pr= 0.71, t = π/2, ε= 0.1, K = 1, Sc = 0.6, M = 2, s = 1, Gc = 1, Q = 1

When ω = 2 ,Gr increasing from 2 to 4 and increasing from 1 to 2 simultaneously, velocity increases. But for ω = 4,Gr= 4 and chemical reaction K increases from 3 to 4, only little variation in velocity has been observed. As the parameter M increases, velocity decreases as shown in fig.3.

The combined effect of parameters Gr, ω and M on velocity is depicted in thefig.4. For M = 2, when ω increasing from 1 to 2 and Gr increasing for 2 to 4,velocity increases. When M = 4, each of ω and Gr increasing from 2 to 4, velocityshowing only marginal increase.

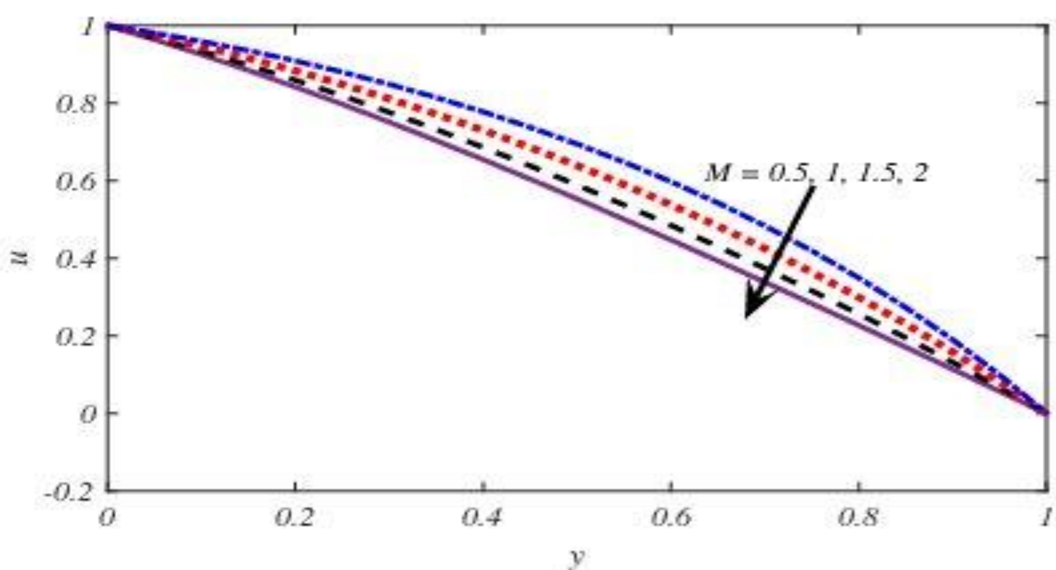

Figure 3. Influence of M on velocity for ω = 2, Pr= 0.71, t = π/2, ε= 0.1,K = 1, Sc = 0.6, s = 1, Gc = 1, Q = 1

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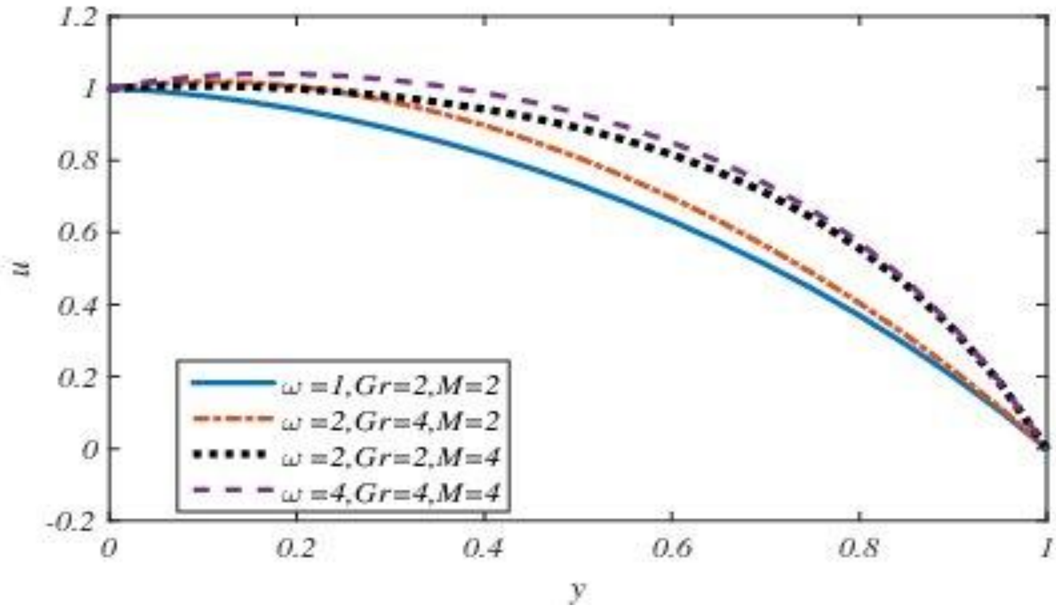

Figure 4. Influence of Gr,M, ω on velocity for Pr = 0.71, t = π/2, ε = 0.1, K = 1, Sc = 0.6, s = 1, Gc = 1, Q = 1

Temperature Profiles

In fig.5, influence of ω on temperature (θ) is presented. As ω increases,temperature (θ) also increases.
As Prandtl number (Pr) increases from 0.7 to 3.7, temperature (θ) decreasesas shown in fig.6. In fig.3.8, as (Q) increases, it is observed that temperature (θ)also increases.

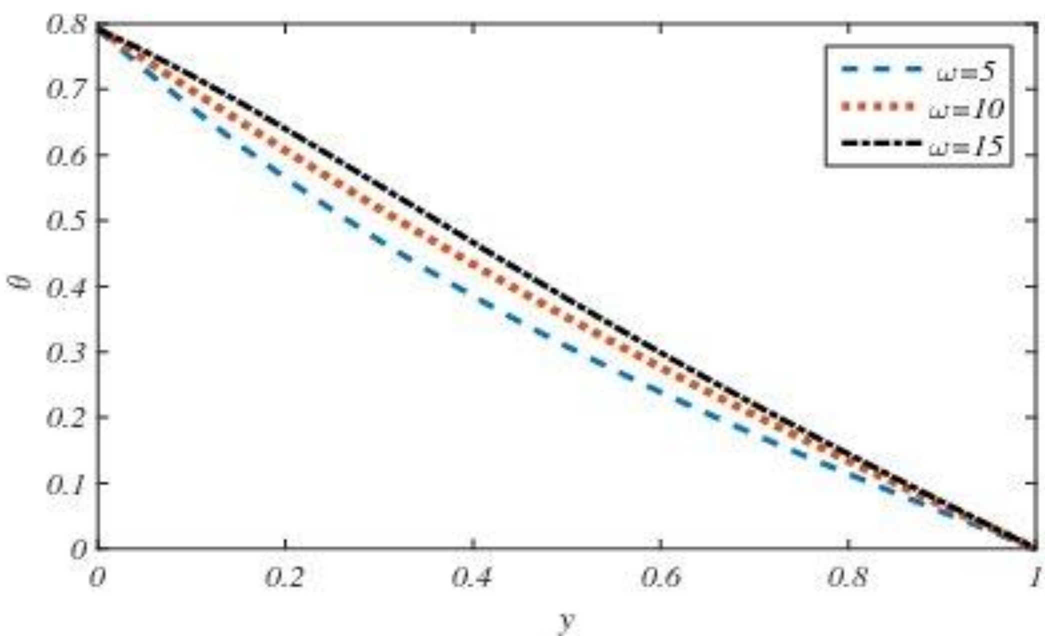

Figure 5. Influence of oscillation frequency (ω) on Temperature for Q = 4, ε= 0.1, Pr= .7, t = 2

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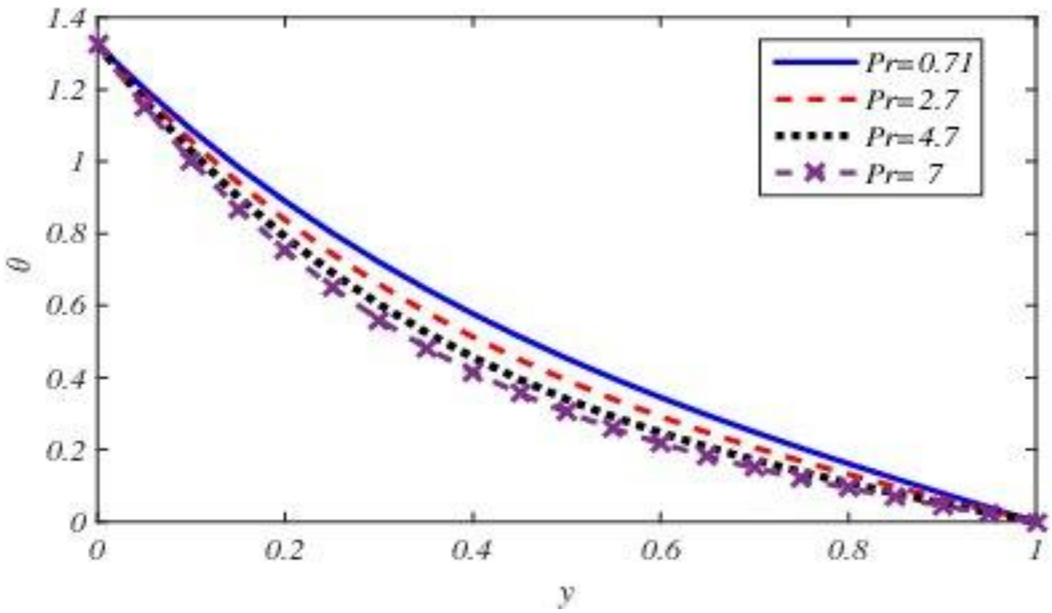

Figure 6. Impact of Pron θ for Q = 3, t = 1.6, ω = 3, ε= 0.1

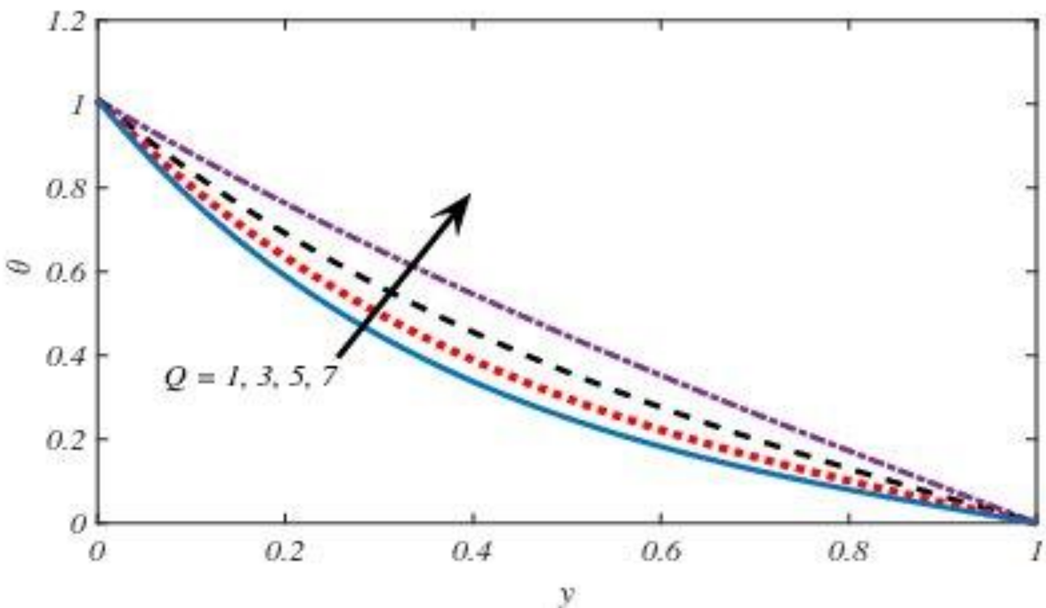

Figure 7. Influence of Q on Temperature for ω = 2, Pr= 2.7, t = .2, ε= 0.1

Concentration Profiles

Fig.8 – fig.9 reveal that concentration (φ) decreases when the chemicalreaction parameter (K) and oscillation frequency (ω) increases.

Variation in concentration (φ) observed to be small for values of K around 2,compared to the variations for values of K , around 1.

In fig. 10, as Schmidth number (Sc) increases concentration (φ) decreases.

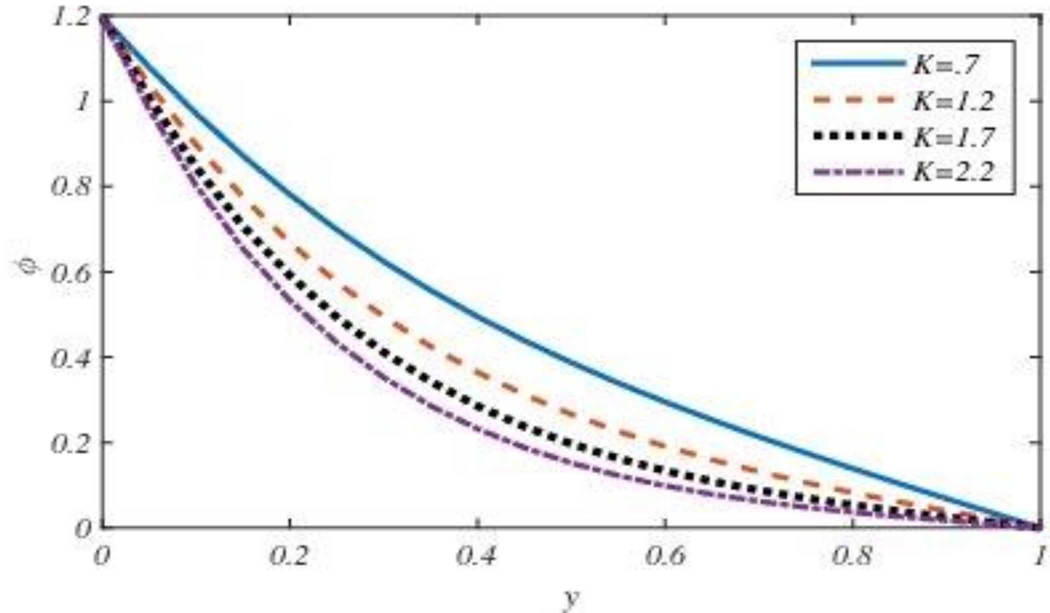

Figure 8. Influence ofK on Concentration for ω = 6, t = .2, ε = 0.1, Sc = 4

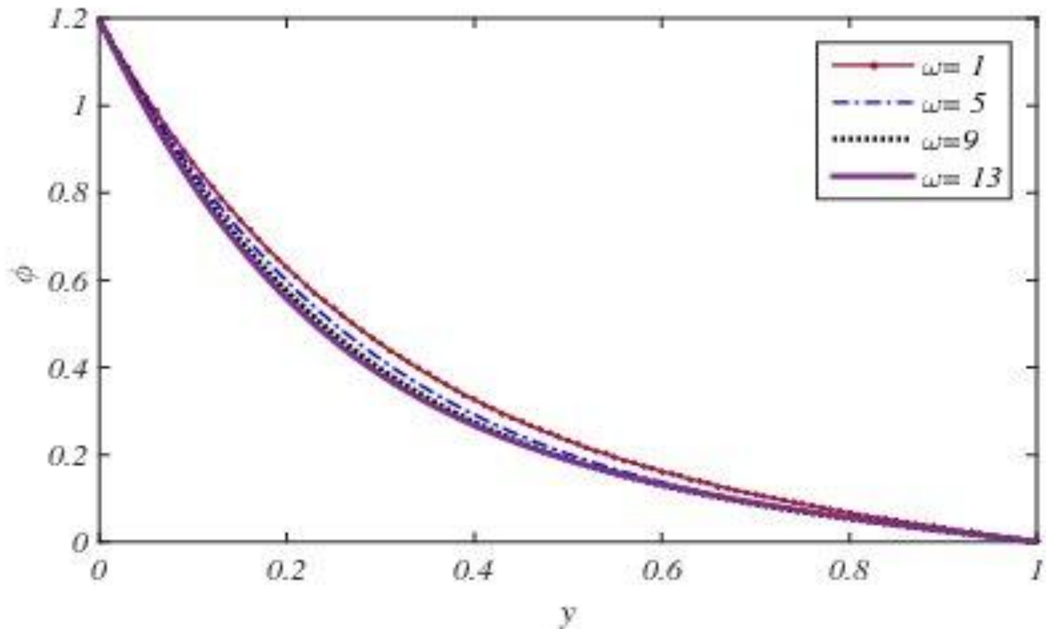

Figure 9. Influence of oscillation frequency (ω) on Concentration for K = 2, t = .1, ε= 0.1, Sc = .74

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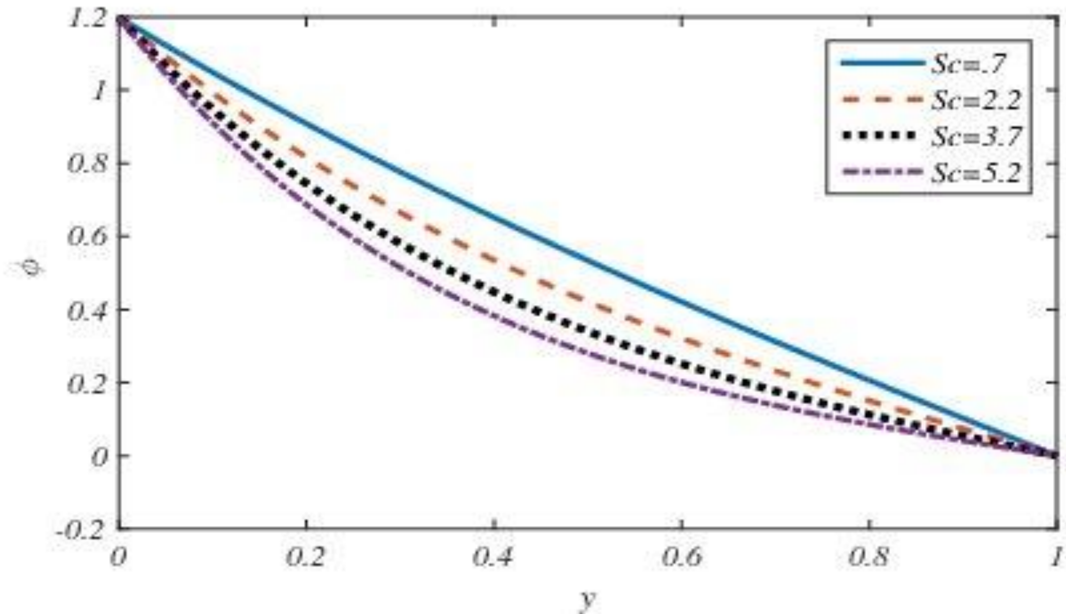

Figure 10. Influence ofSc on Concentration for K = 1.3, ω = 2, t = .1, ε = 0.1

Skin Friction

Fig.11, reflects the influence of Grashoff number (Gr) on skin friction (τ)along the boundaries. As Gr increases, skin friction (τ) increases at both the platesy = 0 and y = 1 . Fig.12 shows the influence of Hartmann number (M) on skinfriction (τ.) As M increases, skin friction (τ) decreases uniformly at both the platesy = 0 and y = 1 .

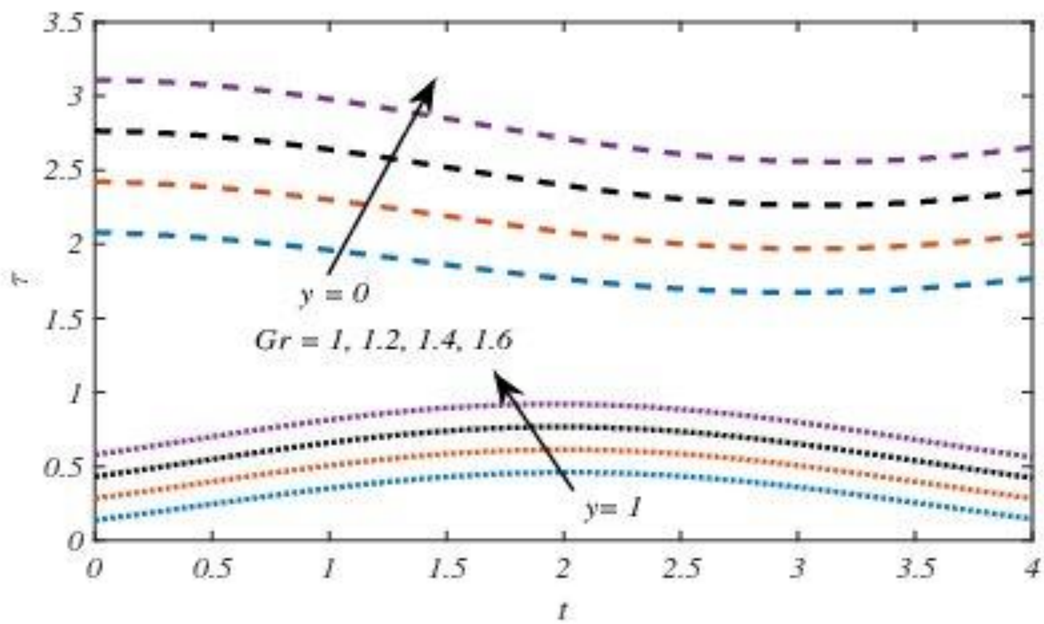

Figure 11. Influence ofGr on τ for Q = 1, ω = 4, ε = 0.1, K = 1, Sc = 0.9, M = 1, s = 1, Pr = 0.71, Gc = 1

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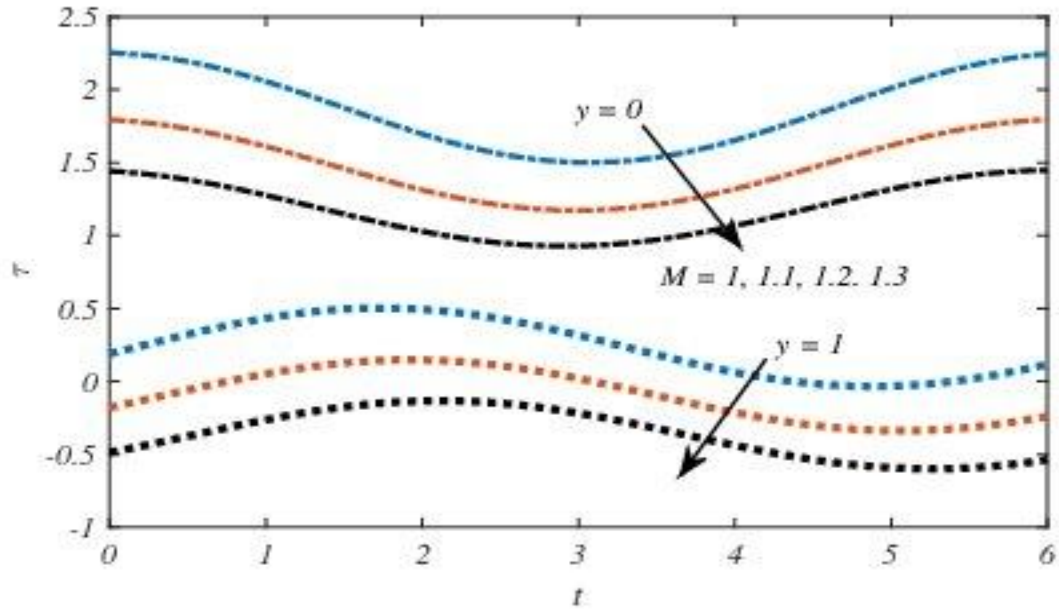

Figure 12. Influence ofM on τ for Q = 1, ω = 2, ε = 0.1, K = 1, sc = 0.9, s = 1, Gr = 1, Gc = 1, Pr = 0.71

Heat Transfer

As oscillation frequency (ω) increases, the Nu decreases for the range y = 0(left plate) to y = 0.4 (nearer to half the distance) and then for y = 0.4 to y = 1(right plate), Nu increases, as shown in fig.13.

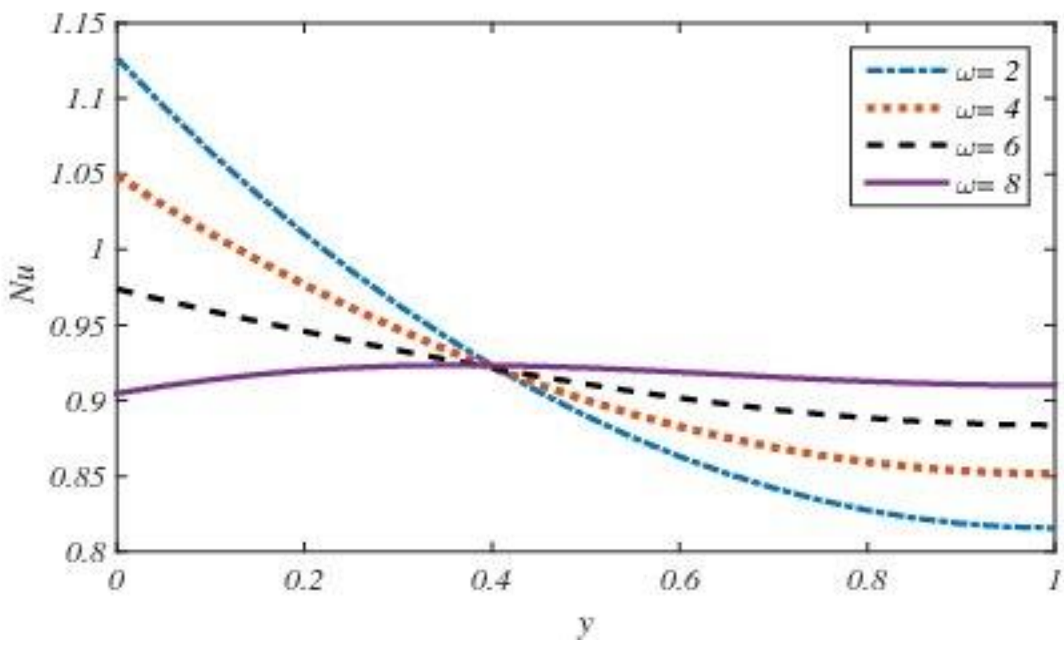

Figure 13. Influence of oscillation frequency (ω) on Heat transfer for Q = 1, Pr= .7, ε= 0.1, K = 1, Sc = .5, s = 0.2, Gr = 1, Gc = 1, M = 3, t = 2

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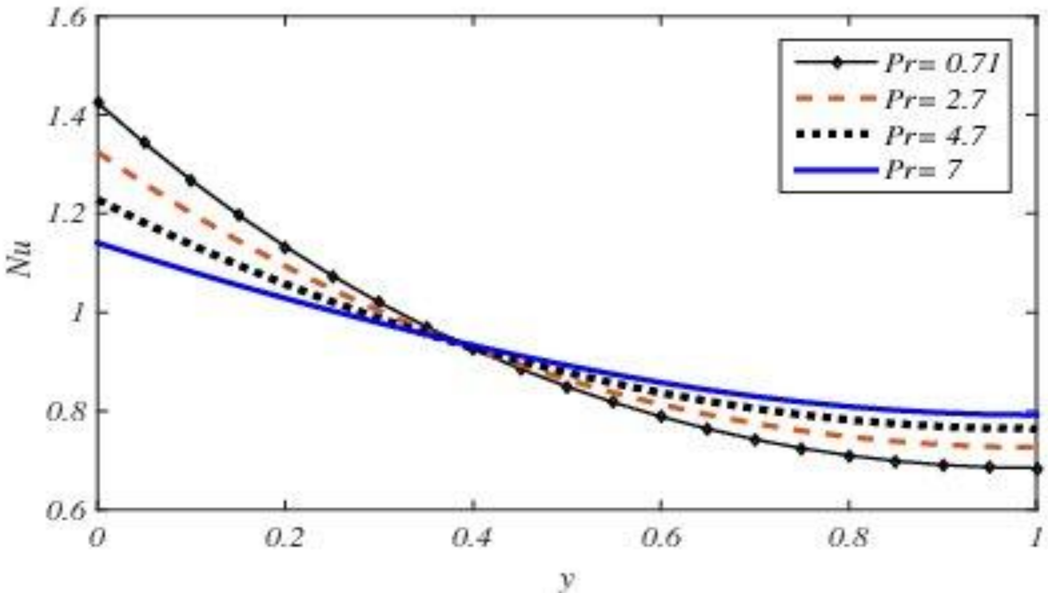

Figure 14. Influence ofPrandtl number (Pr) on Heat transfer for Q = 1, ε= 0.1, K = 1, Sc = .5, s = 0.2, Gr = 1, Gc = 1, M = 3, t = 2

Mass Transfer

In fig.14, for the increase in chemical reaction parameter (K), Sherwoodnumber (Sh) initially increases for y = 0 to y = 0.4 and then for y = 0.4 to y = 1,the pattern is reversed.

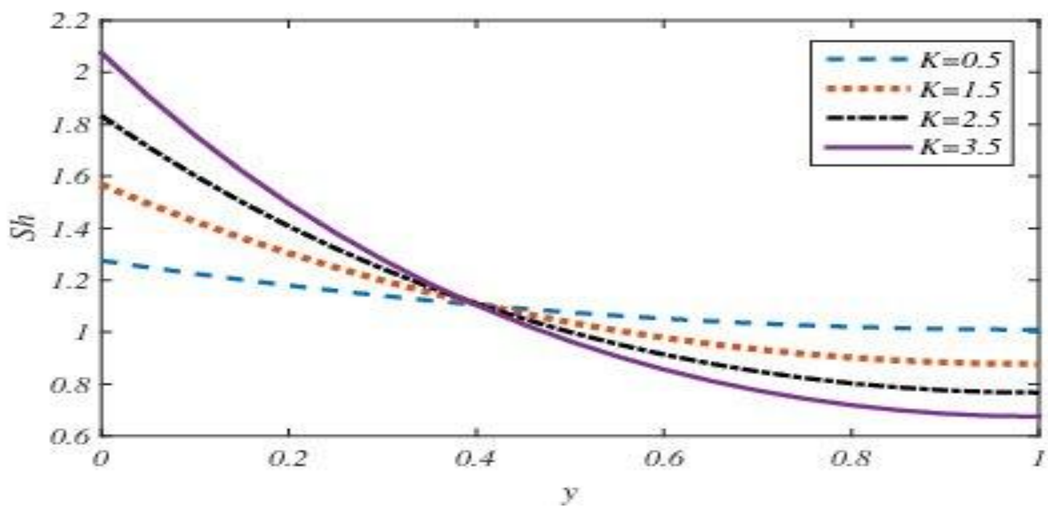

Figure 15. Influence ofK on Mass Transfer for ω = 2, t = .2, ε = 0.1, Sc = 0.9

Conclusion

Analysis of this problem involves exploring the influence of chemicalreaction(K) and heatsource (Q) on various profiles of MHD oscillatory couttee flow ashighlighted below.

1. The mutual impact of Grashoff number (Gr), frequency of oscillation (ω) andchemical reaction (K) results in the enhancement of velocity (u). Values of Gr, ωand K with high magnitude reduces variation in velocity (u).
2. Increase in Hartmann number (M) reduces velocity (u) as well as skin friction(τ) at the walls.

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3. Increment in Grashoff number (Gr) results in the enhancement of velocity (u)between the walls and skin friction (τ) rise at both the walls.
4. Increase in Q (or) ω , increases the temperature (θ).
5. Impact of Prandtl number (Pr) diminishes the temperature (θ).
6. Concentration reduces due to the impact of each of the parameters K, ω and Sc.
7. Nusselt number (Nu) oscillates for the increase in frequency of oscillation (ω)and Sherwood number (Sh) oscillating for increase in chemical reaction (K).

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