

**EFFECT OF HEAT RADIATION ON MHD FREE CONVECTIVE FLOW PAST
A VERTICAL POROUS PLATE THROUGH POROUS MEDIUM WITH
GRAVITY MODULATION IN SLIP FLOW REGION**

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Abstract

The unsteady two-dimensional convective oscillatory flow of a viscous incompressible electrically conducting fluid past a vertical porous plate with time dependent suction velocity through a porous medium has been investigated. A uniform magnetic field is applied transversely in the direction of flow. The governing equations are developed by usual Boussinesq's approximation. The effects of the pertinent parameters such as velocity slip, gravity modulation parameter and the heat radiation parameter on velocity and temperature distribution, skin-friction and the rate of heat transfer are analyzed and discussed with the help of figures.

Key words: free convection, gravity modulation, heat radiation, MHD, porous medium.

Introduction

Thermal Gravitational convection is defined as the non-uniformity of temperature which causes non uniform density. Not only temperature but also due to chemical reactions or variation in the concentration of any mixture, a change in density observed. Free convection or natural convection flows can be induced or brought in existence by both gravitational and other mass forces. The practical interest includes problems related to MHD generators, reactors, geothermal energy extractions and boundary layer control in the field of aerodynamics, engineering and metallurgy many researchers follow this area for research. Space technology at higher operating temperatures such as astrophysical flows, heating and cooling of chambers and solar power technology radiation effects can be quite significant. Memine and Adigio [10] discussed the effect of thermal radiation on unsteady free convection flow on past a vertical porous plate with Newtonian heating. Pal and Talukdar[13] studied the influence of fluctuating thermal and mass diffusion unsteady MHD buoyancy-driven convection past a vertical surface with chemical reaction and Soret effects. Abdelkhalek[1] analyzed the heat and mass transfer in magnetohydrodynamics free convection from a moving permeable vertical surface by a perturbation technique. Mohamed et.al[11] examined the combined radiation and free convection effect from a vertical wavy surface embedded in porous media. Ibrahim et. al. [5] investigated the effect of the chemical reaction and radiation absorption on the unsteady magnetohydrodynamics free convection flow past a semi-infinite vertical permeable moving plate with heat source and suction. Raptis[15] examined the effect of radiation and free convection on the flow of fluid through a porous medium. Alagoa and Tay[2] investigated radiative and free convective effects of a magnetohydrodynamics flow through a porous medium between infinite parallel plates with time-dependent suction. Das et.al.[18] have studied the effects of radiation on free convection MHD couette flow started exponentially with variable wall temperature in presence of heat generation. Kumar et. al. [7] examined the three dimensional MHD couette flow past a porous plate with heat transfer. Manna et. al. [8] studied and explained the effects of radiation on unsteady magnetohydrodynamics free convective flow past an oscillating vertical porous plate embedded in a

porous medium with oscillatory heat flux. The heat transfer to magnetohydrodynamics oscillatory viscoelastic flow in a channel filled with porous medium was explained by Choudhury and Das[3].

Navier proposed the slip at boundary which can be expressed as $u_{\text{slip}} = \beta \frac{\partial u}{\partial y}$, where $\frac{\partial u}{\partial y}$ represents the shear rate at the wall and β the slip length (non-zero taken to be $1 \mu\text{m}$ for an octadecyltrichlorosilan (OTS)-coated hydrophobic surface). The slip wall condition is for cases where viscous effects are negligible. Due to its applications in nanofluidic systems, forming semiconductor device fabrication techniques, or for manufacturing small devices (microphones) many scientists used slip conditions in their physical problems. Mehmood and Ali[9] assumed the effect of Slip at one of the plate of planar channel on unsteady magnetohydrodynamics oscillatory flow of viscous fluid. Rao and Rajagopal[14] examined the effect of the slip boundary conditions on the flow of fluids in channel. Beavers and Joseph[3] have studied the various boundary conditions at a naturally permeable wall.

During typical space shuttle flights astronauts' small disturbances or variation in the component of acceleration due to gravity (popularly known as microgravity environment denoted as μg) is named as g-jitter forces which may arise due to mechanical vibration, attitude differences, atmospheric drag or earth's gravity gradient. Numerically investigation helps in providing the basic understanding of behavioral physics governing the modulation in acceleration due to gravity during space experiments as limited instrumentation precision. Microgravity is also used for weightlessness or zero gravity, but actually g-jitter forces are not exactly zero. The symbol μg for microgravity was firstly used in STS-87 space shuttle flight, which is made for mainly microgravity research, for denoting the presence of small gravity in space. G-jitter forces are now getting attention. Shu Y, Li. Q. B and Groh de H. C. have studied numerically about the g- Jitter induced double diffusive convection. Norsarahaida A.[12] studied the effect of g-Jitter on heat transfer. Kalra M. and Verma D[6] have examined the effect of constant suction on transient free convective gelatinous incompressible flow past a perpendicular plate with cyclic temperature variation in slip flow regime. Verma D. and Kalra M.[19] have studied the free convection magnetohydrodynamics flow past a vertical plate with constant suction. Rajvanshi and Saini[16] studied the free convective magnetohydrodynamics flow past a moving vertical porous surface with gravity modulation at constant heat flux.

Modern technology requires the need of understanding fluid flow studies with interaction of several phenomenon. One of such study is presented to analyze the effect of heat radiation on MHD free convective flow past a vertical porous plate through porous medium with gravity modulation in slip flow region.

Formulation of the problem

We consider MHD incompressible, viscous fluid past a uniformly moving infinite vertical porous plate. Plate is bounded by a porous medium with time dependent suction velocity. We take the x^* -axis along the plate upwards and the y^* -axis perpendicular to it directed into the fluid region. A uniform magnetic field normal to the direction of flow is introduced. The magnetic Reynolds number is taken to be very small so that the induced magnetic field ' B_0 ' can be neglected in comparison to the applied magnetic field. The temperature difference between the wall and the medium develops buoyancy force which induces basic flow. Initially the plate as well as fluid is assumed to be at the same temperature and the concentration of species is very low.

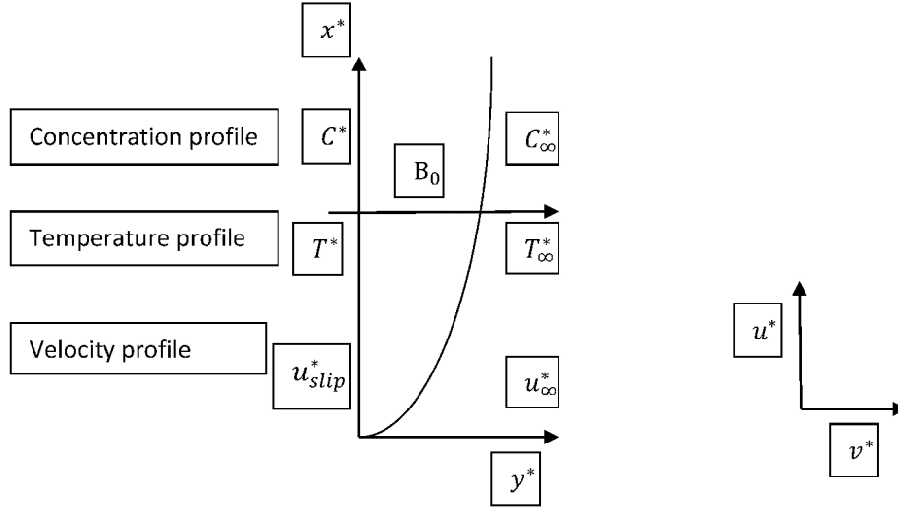


Figure 1. Schematic diagram of Physical problem.

Since the plate is considered infinite in the x^* - direction, all physical quantities are independent of x^* and are function of y^* and t^* only. Under these assumptions flow is governed by the following set of equations

Equation of Continuity:

$$\frac{\partial v^*}{\partial y^*} = 0. \quad (1)$$

Equation of Momentum:

$$\frac{\partial u^*}{\partial t^*} + v^* \frac{\partial u^*}{\partial y^*} = v \frac{\partial^2 u^*}{\partial y^{*2}} - \frac{\sigma B_0^2 u^*}{\rho} + g\beta(T^* - T_\infty) + g\beta_c(C^* - C_\infty) - \frac{vu^*}{k_0^*}. \quad (2)$$

Equation of Energy:

$$\frac{\partial T^*}{\partial t^*} + v^* \frac{\partial T^*}{\partial y^*} = \frac{k}{\rho c_p} \frac{\partial^2 T^*}{\partial y^{*2}} + \frac{\mu}{\rho c_p} \frac{\partial T^*}{\partial y^*}. \quad (3)$$

Equation of Concentration:

$$\frac{\partial C^*}{\partial t^*} + v^* \frac{\partial C^*}{\partial y^*} = D \frac{\partial^2 C^*}{\partial y^{*2}} - K_c^*(C^* - C_\infty). \quad (4)$$

Where u^* and v^* are the components of the velocities along x^* and y^* directions respectively. The (*) stands for dimensional quantities and the subscript (∞) denotes the free stream condition. The time dependent gravitational acceleration is assumed in the form $g = g_0 + g_1 e^{i\omega^* t^*}$, where ' g_0 ' the constant of gravity level in the environment and ' $g_1 = \epsilon \alpha g_0$ ' is the amplitude of oscillating component of acceleration, α is the gravity modulation parameter, F is the radiation parameter, ω^* is the frequency of oscillation, ρ is the density of the medium, v is the kinematic viscosity, σ is the fluid electrical conductivity, β volumetric coefficient of thermal expansion and β_c volumetric coefficient of thermal expansion with concentration, k_0^* is the permeability of porous medium, T^* is the dimensional temperature of the fluid near the plate, T_∞ is the dimensional free stream temperature, k is the thermal conductivity, c_p is the specific heat at constant pressure, D is chemical diffusivity and K_c^* is chemical reaction parameter.

The suction velocity on the vertical plate is of the form

$$v^* = -V_0 (1 + \epsilon e^{i\omega^* t^*}). \quad (5)$$

The relevant boundary conditions are

$$u^* = u_{slip}^* = \varphi_1^* \frac{\partial u^*}{\partial y^*}, T^* = T_w + \epsilon (T_w - T_\infty) e^{i\omega^* t^*}, C^* = C_w + \epsilon (C_w - C_\infty) e^{i\omega^* t^*} \text{ at } y^* = 0, \left. \begin{aligned} u^* \rightarrow 0, T^* \rightarrow T_\infty, C^* \rightarrow C_\infty \text{ as } y^* \rightarrow \infty, \end{aligned} \right\} \quad (6)$$

where T_w is the dimensional temperature at the wall.

Now, we introduce the dimensionless variables as follows

$$\left. \begin{aligned} u = \frac{u^*}{V_0}, v = \frac{v^*}{V_0}, y = \frac{V_0 y^*}{\nu}, t = \frac{V_0^2 t^*}{4\nu}, \theta = \frac{T^* - T_\infty}{T_w - T_\infty}, \omega = \frac{4\nu\omega^*}{V_0^2}, C = \frac{C^* - C_\infty}{C_w - C_\infty}, K_0 = \frac{K_0^* V_0^2}{\nu^2}, \varphi_1 = \varphi_1^* \frac{V_0}{\nu}, \\ P_r = \frac{\mu C_p}{k}, M^2 = \frac{\sigma B_0^2 \nu}{\rho V_0^2}, G_r = \frac{\nu g_0 \beta (T_w - T_\infty)}{U_0 V_0^2}, G_c = \frac{\vartheta g_0 \beta_c (C_w - C_\infty)}{U_0 V_0^2}, S_c = \frac{\nu}{D}, K_c = \frac{\nu K_c^*}{V_0^2}, F = \frac{4\nu I^*}{\rho C_p V_0^2} \end{aligned} \right\}. \quad (7)$$

Equations (1) to (6) get transformed to following set of equations

$$\frac{\partial v}{\partial y} = 0, \quad (8)$$

$$\frac{1}{4} \frac{\partial u}{\partial t} - (1 + \epsilon e^{i\omega t}) \frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + (1 + \epsilon \alpha e^{i\omega t}) (G_r \theta + G_c C) + M^2 u - \frac{u}{k_0}, \quad (9)$$

$$\frac{1}{4} \frac{\partial \theta}{\partial t} - (1 + \epsilon e^{i\omega t}) \frac{\partial \theta}{\partial y} = \frac{1}{P_r} \frac{\partial^2 \theta}{\partial y^2} - F \theta, \quad (10)$$

$$\frac{1}{4} \frac{\partial C}{\partial t} - (1 + \epsilon e^{i\omega t}) \frac{\partial C}{\partial y} = \frac{1}{S_c} \frac{\partial^2 C}{\partial y^2} - K_c C. \quad (11)$$

The boundary conditions in non-dimensional form are

$$u = \varphi_1 \frac{\partial u}{\partial y}, \theta = 1 + \epsilon e^{i\omega t}, C = 1 + \epsilon e^{i\omega t} \text{ at } y^* = 0 \left. \begin{aligned} u \rightarrow 0, \theta \rightarrow 0, C \rightarrow 0 \text{ at } y^* \rightarrow \infty \end{aligned} \right\}. \quad (12)$$

Solution of the governing equations

For small amplitude oscillation ($0 < \epsilon < 1$) the velocity u , the temperature θ and concentration C are expressed as

$$(u, \theta, C)(y, t) = (u_0, \theta_0, C_0)(y) + \epsilon (u_1, \theta_1, C_1)(y) e^{i\omega t}. \quad (13)$$

Substituting (13) in (9) to (12) and separating steady and unsteady components, we have

Zeroth order equations in ' ϵ '

$$\frac{\partial^2 u_0}{\partial y^2} + \frac{\partial u_0}{\partial y} - \left(M^2 + \frac{1}{k_0} \right) u_0 = -\theta_0 G_r - C_0 G_c, \quad (14)$$

$$\frac{\partial^2 \theta_0}{\partial y^2} + P_r \frac{\partial \theta_0}{\partial y} - F P_r \theta_0 = 0, \quad (15)$$

$$\frac{\partial^2 C_0}{\partial y^2} + S_c \frac{\partial C_0}{\partial y} - K_c S_c C_0 = 0. \quad (16)$$

First order equations in ' ϵ '

$$\frac{\partial^2 u_1}{\partial y^2} + \frac{\partial u_1}{\partial y} - \left(M^2 + \frac{1}{k_0} + \frac{i\omega}{4} \right) u_1 = -(\theta_1 + \alpha\theta_0)G_r - (C_1 + \alpha C_0)G_c - \frac{\partial u_0}{\partial y}, \quad (17)$$

$$\frac{\partial^2 \theta_1}{\partial y^2} + P_r \frac{\partial \theta_1}{\partial y} - P_r \left(F + \frac{i\omega}{4} \right) \theta_1 = -P_r \left(\frac{\partial \theta_0}{\partial y} \right), \quad (18)$$

$$\frac{\partial^2 C_1}{\partial y^2} + S_c \frac{\partial C_1}{\partial y} - \left(K_c + \frac{i\omega}{4} \right) S_c C_1 = -S_c \left(\frac{\partial C_0}{\partial y} \right), \quad (19)$$

And the corresponding boundary conditions are

$$\left. \begin{aligned} u_0 &= \varphi_1 \frac{\partial u_0}{\partial y}, u_1 = \varphi_1 \frac{\partial u_1}{\partial y}, \theta_0 = 1, \theta_1 = 1, C_0 = 1, C_1 = 1 \text{ at } y=0 \\ u_0 &\rightarrow 0, u_1 \rightarrow 0, \theta_0 \rightarrow 0, \theta_1 \rightarrow 0, C_0 \rightarrow 0, C_1 \rightarrow 0 \text{ as } y \rightarrow \infty \end{aligned} \right\}. \quad (20)$$

Solving equations (14) and (19) under the boundary conditions (20) we get

$$C_0 = e^{-R_3 y}, \quad (21)$$

$$C_1 = (1 - K_{12})e^{-R_5 y} + K_{11}e^{-R_3 y}, \quad (22)$$

$$u_0 = C_{10}e^{-R_{10} y} + A_1 e^{-R_7 y} + A_2 e^{-R_3 y}, \quad (23)$$

$$u_1 = C_{12}e^{-R_{12} y} + A_3 e^{-R_{10} y} + A_4 e^{-R_7 y} + A_5 e^{-R_3 y} - G_r(A_6 e^{-R_9 y} + B_1 e^{-R_7 y}) - G_c(A_9 e^{-R_5 y} + B_2 e^{-R_3 y}), \quad (24)$$

$$\theta_0 = e^{-R_7 y}, \quad (26)$$

$$\theta_1 = (1 - K_{11})e^{-R_9 y} + K_{11}e^{-R_7 y}. \quad (27)$$

Finally, we have

$$u(y, t) = u_0(y) + u_1(y)e^{i\omega t}, \quad (28)$$

$$\theta(y, t) = \theta_0(y) + \theta_1(y)e^{i\omega t}, \quad (29)$$

$$C(y, t) = C_0(y) + C_1(y)e^{i\omega t}. \quad (30)$$

Some important characteristic of flow field:

The Skin friction at the wall is given by

$$C_{fx} = \left. \frac{\partial u}{\partial y} \right|_{y=0} = -R_{10}C_{10} - R_7 A_1 - R_3 A_2 + (-R_{12}C_{12} - R_{10}A_3 - R_7 A_4 - R_3 A_5 - G_r(-R_9 A_6 - R_7 B_1) - G_c(-R_5 A_9 - R_3 B_2))e^{i\omega t}. \quad (31)$$

The rate of heat transfer coefficient is as follows:

$$\phi = -\left. \frac{\partial \theta}{\partial y} \right|_{y=0} = -R_7 + (-R_9(1 - K_{11}) - R_7 K_{11})e^{i\omega t}. \quad (32)$$

The mass diffusion coefficient in terms of Sherwood number is as follows:

$$S_h = -\left. \frac{\partial C}{\partial y} \right|_{y=0} = -R_3 + (-R_5(1 - K_{12}) - R_3 K_{11})e^{i\omega t}. \quad (33)$$

The physical variables used herein are defined in Appendix.

Graphs and discussion

In order to point out the effects of various parameters on flow characteristic, the following discussion is set out. The values of Prandtl number are chosen $Pr=7$ (convection in water) and $Pr=1$ (convection in air), value of Schmidt number are chosen $Sc=0.22$ (Hydrogen) and $Sc= 0.66$ (Oxygen). Velocity profiles are presented in figures 2 and 3 which is of convex type. From figure 2 we depicted that the convexity of velocity profile increases with increase of Grashoff number, Slip parameter, and permeability of porous medium and decreases with increase of Prandtl number and Magnetic field parameter. Figure 3 exhibits the variation of velocity field for different values of frequency of oscillation, modified Grashoff number, Radiation parameter, Schmidt number and Gravity modulation parameter and frequency of oscillation. It is found that when thermal and modified Grashoff numbers were increased, the thermal and concentration buoyancy effects were enhanced and thus, the fluid velocity increased. Figure 4 shows the temperature variation with Prandtl number, Radiation parameter and frequency of oscillation. Temperature decreases with increase of Prandtl number and radiation parameter. We observed that with increase of frequency of oscillation temperature shows slight decrease near to the plate. Figure 5 illustrates concentration profile with change in Schmidt number and chemical reaction parameter. It is observed that concentration profile decreases with increase of either of the parameters. In figure 6, effect on real part of skin friction with various non dimensional parameters has been observed and found that skin friction increases with increase of Grashoff number, modified Grashoff number, Gravity modulation parameter and with decrease of slip parameter. It decreases with increase of Prandtl number and Schmidt number while the radiation parameter has insignificant effect. Figure 6 and 7 shows the effects of non dimensional parameters on rate of heat transfer and Sherwood number respectively. It has been observed that the real part of rate of heat transfer decreases with increase of both Prandtl number and radiation parameter. And Sherwood number increases with increase of Schmidt number as well as chemical reaction parameter.

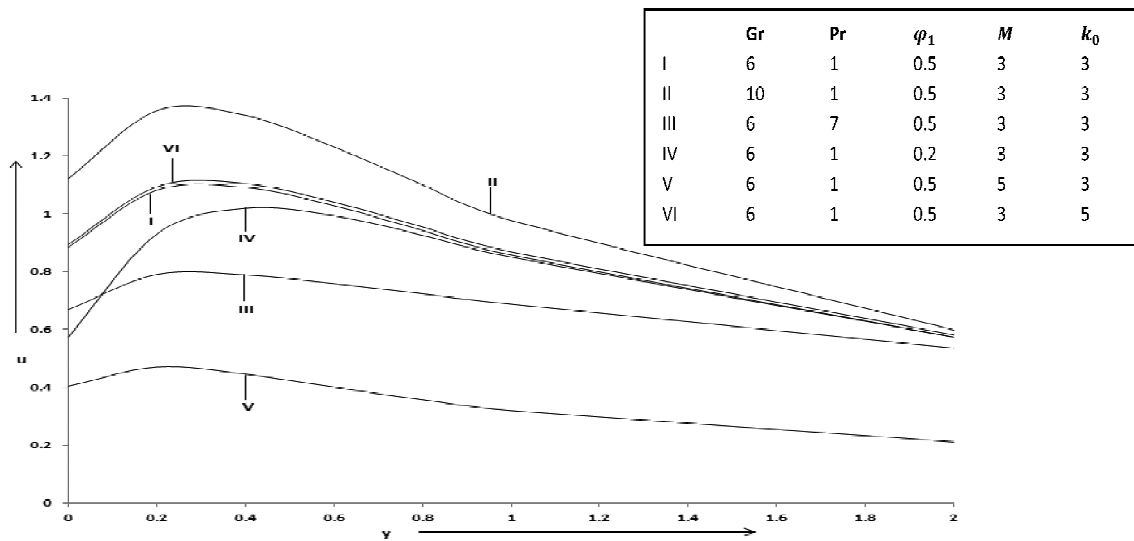


Figure 2. Velocity for different values of Gr, Pr, ϕ_1, M and k_0 with fixed values of other non-dimensional parameter against the distance.

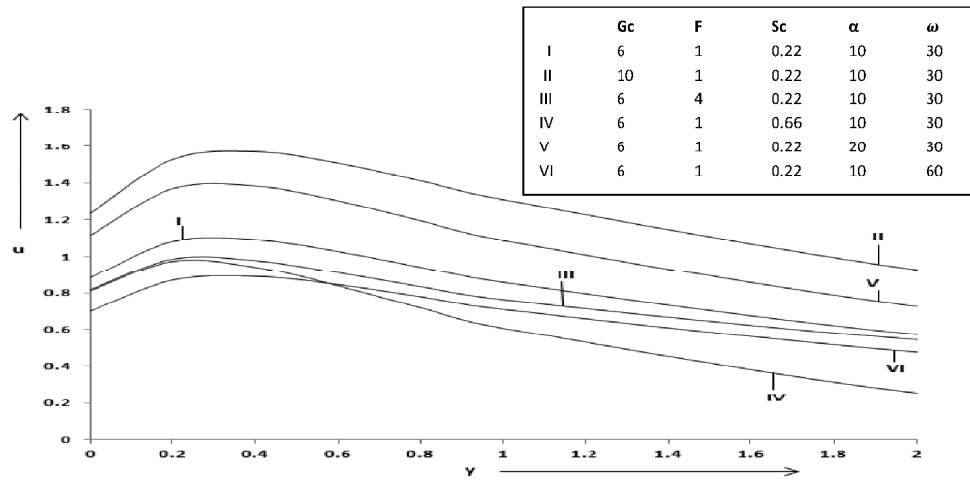


Figure 3. Velocity for different values of ω , G_c , F , Sc , α with fixed values of other non-dimensional parameter.

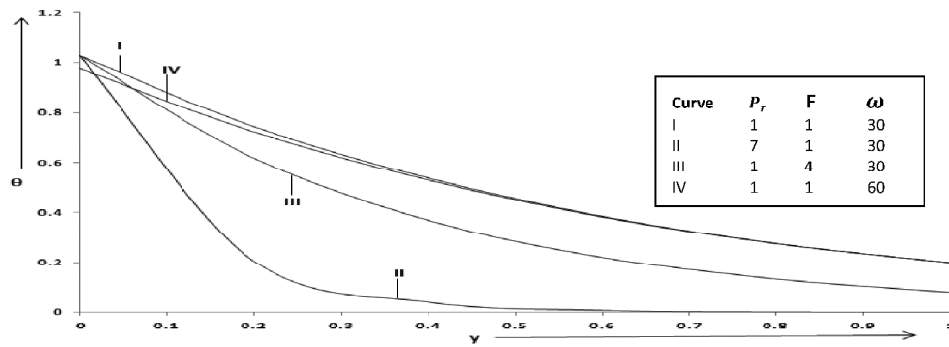


Figure 4. Temperature for different values of P_r , F , ω with fixed values of other non-dimensional parameter.

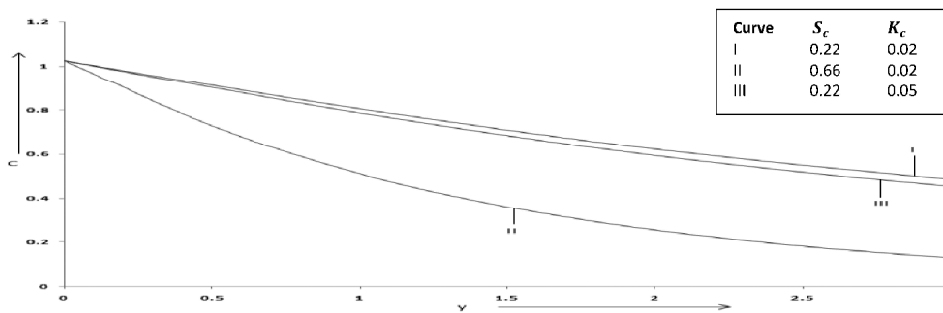


Figure 5. Concentration for different values of Sc and K_c with fixed values of other non-dimensional parameter.

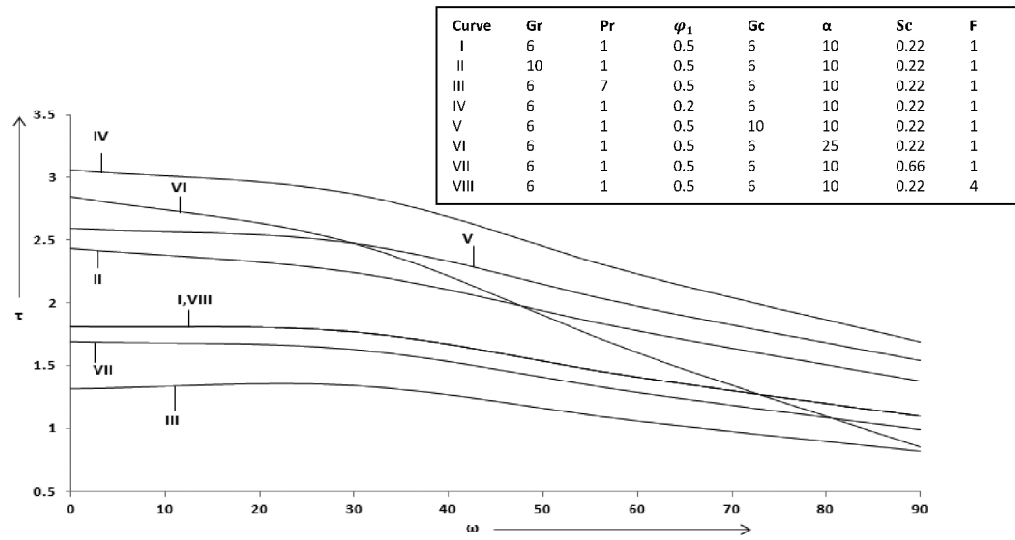


Figure 6. Skin friction for different values of Gr, Pr, ϕ_1 , Gc, Sc, F and α with fixed values of other non-dimensional parameters.

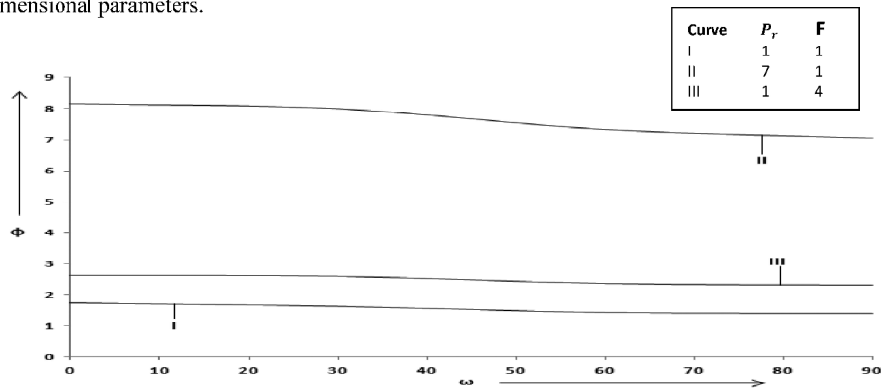


Figure 7. Rate of heat transfer for different values of P_r , F with fixed values of other non-dimensional parameter.

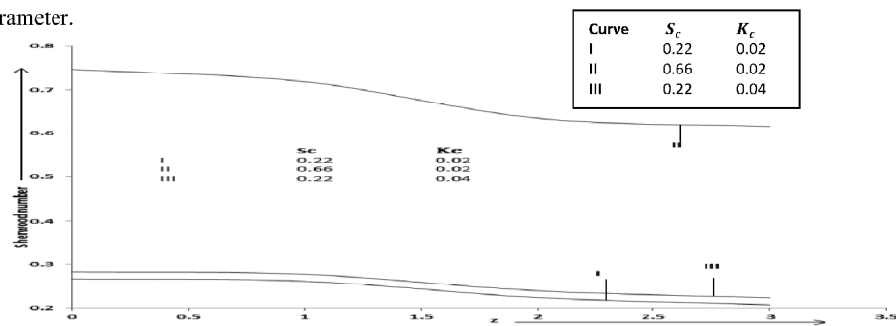


Figure 8. Sherwood number for different values of K_c and S_c with fixed values of other non-dimensional parameter against z .

Conclusion

This paper studied the effect of heat radiation on MHD free convective flow past a vertical porous plate through porous medium with gravity modulation in slip flow region. The governing equations are solved by using usual perturbation technique. Numerical calculations are carried out for various values of the dimensionless parameters of the problem. The conclusions are listed below:

1. Velocity increases with the increase of thermal and modified Grashof number due to the enhanced concentration buoyancy effects.
2. Velocity and skin friction increased by an increase of gravity modulation parameter as the positive increment in the gravity has been taken under consideration.
3. Lorentz force (drag force), which came into existence due to imposition of magnetic field applied on the conducting fluid in the opposite direction of fluid flow, reduced the velocity and skin friction.
4. Temperature gets decreased by increase of radiation parameter as it decreases the rate of energy transport to the fluid, thereby decreasing the temperature of the fluid.
5. Concentration decreases with increase of coefficient of first order destructive chemical reaction parameter and Schmidt number. When the Schmidt number was increased, there is decrease in concentration level which in turn reduces the fluid velocity.
6. It also has been noted that for large values of Prandtl number both the temperature and velocity profiles decreased due to the thinning of the thermal boundary layer thickness.
7. With the increase of radiation parameter, the rate of heat transfer decreases and Sherwood number is the ratio of convective mass transfer to the diffusive mass transfer, hence if convectivity of the fluid increases with increase of Schmidt number, it enhances the mass transfer rate.
8. With increase of permeability k_0 (which increases the porosity and reduces the drag force), velocity and skin friction increases which asserts the fact that with increase of permeability of the porous material through which the fluid particles can pass through increases and hence enhances the velocity.

Appendix

$$\begin{aligned}
 A_1 &= \frac{-G_r}{R_7^2 - R_7 - \left(M^2 + \frac{1}{k_0}\right)} & A_2 &= \frac{-G_c}{R_3^2 - R_3 - \left(M^2 + \frac{1}{k_0}\right)} & A_3 &= \frac{R_{10}C_{10}}{R_{10}^2 - R_{10} - \left(M^2 + \frac{1}{k_0} + \frac{i\omega}{4}\right)} & A_4 &= \frac{R_7A_1}{R_7^2 - R_7 - \left(M^2 + \frac{1}{k_0} + \frac{i\omega}{4}\right)} \\
 A_5 &= \frac{R_3A_2}{R_3^2 - R_3 - \left(M^2 + \frac{1}{k_0} + \frac{i\omega}{4}\right)} & A_6 &= \frac{(1-K_{11})}{R_9^2 - R_9 - \left(M^2 + \frac{1}{k_0} + \frac{i\omega}{4}\right)} & A_7 &= \frac{K_{11}}{R_7^2 - R_7 - \left(M^2 + \frac{1}{k_0} + \frac{i\omega}{4}\right)} & A_8 &= \frac{\alpha}{R_7^2 - R_7 - \left(M^2 + \frac{1}{k_0} + \frac{i\omega}{4}\right)} \\
 A_9 &= \frac{(1-K_{12})}{R_5^2 - R_5 - \left(M^2 + \frac{1}{k_0} + \frac{i\omega}{4}\right)} & A_{10} &= \frac{K_{12}}{R_3^2 - R_3 - \left(M^2 + \frac{1}{k_0} + \frac{i\omega}{4}\right)} & A_{11} &= \frac{\alpha}{R_3^2 - R_3 - \left(M^2 + \frac{1}{k_0} + \frac{i\omega}{4}\right)} & B_1 &= A_7 + A_8 \\
 B_2 &= A_{10} + A_{11} & R_3 &= \frac{S_c + \sqrt{S_c^2 + 4K_cS_c}}{2} & R_5 &= \frac{S_c + \sqrt{S_c^2 + 4\left(K_c + \frac{i\omega}{4}\right)S_c}}{2} & R_7 &= \frac{P_r + \sqrt{P_r^2 + 4FP_r}}{2} \\
 R_9 &= \frac{P_r + \sqrt{P_r^2 + 4\left(K_c + \frac{i\omega}{4}\right)P_r}}{2} & R_{11} &= \frac{1 + \sqrt{1 + 4\left(M^2 + \frac{1}{k_0}\right)}}{2} & K_{11} &= \frac{R_7P_r}{R_7^2 - P_rR_3 - \left(F + \frac{i\omega}{4}\right)P_r} & K_{12} &= \frac{R_3S_c}{R_3^2 - S_cR_3 - \left(K_c + \frac{i\omega}{4}\right)S_c} \\
 C_{10} &= \frac{-(1+R_7\varphi_1)A_1 - (1+R_3\varphi_1)A_2}{1+R_{10}\varphi_1} \\
 C_{12} &= \frac{-(1+R_{10}\varphi_1)A_3 - (1+R_7\varphi_1)A_4 - (1+R_3\varphi_1)A_5 + G_r((1+R_9\varphi_1)A_6 + (1+R_7\varphi_1)B_1) + G_c((1+R_5\varphi_1)A_9 + (1+R_3\varphi_1)B_2)}{1+R_{12}\varphi_1}
 \end{aligned}$$

Reference

1. Abdelkhalek M.M. 'Heat and mass transfer in MHD free convection from a moving permeable vertical surface by a perturbation technique.' *Communications Nonlinear Science and Numerical Simulation*. **14**, 2091–2102, (2009).
2. Alagoa K.D. and Tay G. 'Radiative and free convective effects of a MHD flow through a porous medium between infinite parallel plates with time-dependent suction.' *Astrophysics and Space Science* **260**, 455–468, (1999).
3. Beavers G. S. and Joseph D. D. 'Boundary conditions at a naturally permeable wall.' *Journal of Fluid Mechanics* **30** (1), 197-207, (1967).
4. Choudhury R. and Das U. J. 'Heat transfer to MHD oscillatory viscoelastic flow in a channel filled with porous medium. Hindawi Publishing Corporation Physics Research International. Volume **2012**, Article ID 879537, 5 pages doi: 10. 1155/2012/879537
5. Ibrahim F.S., Elaiw A.M. and Bakr A.A. 'Effect of the chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate with heat source and suction'. *Communications Nonlinear Science and Numerical Simulation*. **13**, 1056–1066, (2008).
6. Kalra M. and Verma D. 'Effect of Constant Suction on Transient Free Convective Gelatinous Incompressible Flow past a Perpendicular Plate with Cyclic Temperature Variation in Slip Flow Regime.' *International Journal of Innovative Technology and Exploring Engineering*. **2** (4) 42-44(2013)
7. Kenneth D. K. 'Near-field Characterization of micro/Nano-scaled fluid flows.' Scientific Publishing Services Pvt. Ltd. Chennai. India (2011).
8. Kumar R. V., Raju M.C. and Raju G.S.S. 'MHD Three Dimensional Couette Flow past a Porous Plate with Heat Transfer.' *IOSR Journal of Mathematics*. **1** (3) 03-09, (2012).
9. Manna S. S., Das S and Jana R. N. 'Effects of radiation on unsteady MHD free convective flow past an oscillating vertical porous plate embedded in a porous medium with oscillatory heat flux.' *Advances in Applied Science Research*, 2012, **3** (6):3722-3736.
10. Mehmood A. and A-Ali. 'The effect of Slip condition on unsteady MHD oscillatory flow of viscous fluid in a planar channel. *Romania journal of Physics* **52** (1-2) 85-91, (2007).
11. Memine P. and Adigio M. E. 'Unsteady free convection flow with thermal radiation past a vertical porous plate with Newtonian heating.' *Turkish Journal of Physics*. **33** 109-119, (2009).
12. Mohamed R. A., Mahdy A., and Hady F. M. 'Combined radiation and free convection from a vertical wavy surface embedded in porous media.' *International Journal of Applied Mathematics and Mechanics*. **4** (1) 49-58, 2008.
13. Norsarahaida A. 'The effect of g-Jitter on heat transfer' *Proceedings of Royal Society of London A*. **419**, 151-172 (1988).
14. Pal D. and Talukdar B. 'Influence of fluctuating thermal and mass diffusion unsteady MHD buoyancy-driven convection past a vertical surface with chemical reaction and Soret Effects. *Communications Nonlinear Science and Numerical Simulation*. **17**(4) 1597-1614 (2012).
15. Rao I. J. and Rajagopal K. R. 'The effect of the slip boundary conditions on the flow of fluids in channel.' *Acta Mechanica* **135**, 113- 126 (1999).
16. Raptis A. 'Radiation and free convection flow through a porous medium.' *International Communications in Heat and mass Transfer*. **25** 289–95 (1998).
17. Rajvanshi C. S. and Saini S B. 'Free convective MHD flow past a moving vertical porous surface with gravity modulation at constant heat flux.' *International journal of Theoretical and Applied Sciences*, **2**(1) 29-33 (2010).

18. Sanatan Das, Sarkar C. B. and Jana N. R. 'Radiation Effects on free convection MHD Couette flow started exponentially with variable wall temperature in presence of Heat generation.' Open journal of Fluid dynamics. **2**, 14-27 (2012).
19. Shu. Y, Li. Q. B and Groh de H. C. ' Numerical study of g- Jitter Induced double diffusive convection.' Numerical Heat Transfer, Part A, **39** 245-265, (2001).
20. Verma D. and Kalra M. 'Free convection MHD flow past a vertical plate with constant suction. International Journal of Innovative Technology and Exploring Engineering. **2**,(3) 154-157,(2013).