EFFECTS OF MHD FREE CONVECTIVE HEAT AND MASS TRANSPORT FLOW PAST AN INFINITE PLATE WITH VISCOUS ENERGY DISSIPATION

By

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ABSTRACT

In this paper, a theoretical analysis of steady Magnetohydrodynamics (MHD) free convective and mass transfer flow is presented past an infinite vertical porous plate under the influence of uniform transverse magnate field. A magnetic field of uniform strength is applied perpendicular to the plate and the fluid is subjected to a normal suction velocity while the heat flux at the plate is constant. The non-dimensional coupled partial differential equations were solved numerically using the Method of Lines (MOL). The velocity, the temperature and the concentration profiles of the flow were discussed and presented graphically. The result shows that an increase in thermal radiation causes increase in velocity and temperature profiles of the flow. Thus, increase in prantl number reduces the temperature of the system, whereas the resultant velocity enhances with increasing the permeability throughout the fluid region. Lowering the permeability of the porous medium lesser the fluid speed in the entire region. The presence of temperature dependent heat source has the mixed effect on the velocity and as well as on temperature.

Keywords: *Heat and mass transfer, MHD, Porous medium, vertical plates, viscous dissipation, unsteady flows.*

INTRODUCTION

The convective heat and mass transfer flows in an inclined porous plate find a number of applications in many branches of science and technology like chemical industry, cooling of nuclear reactors, etc. Convective heat and mass transfer flows in the presence of various physical properties for the cases of horizontal and vertical flat plates have been attracting the attention of many researchers nowadays. However, the boundary layer flows adjacent to inclined plates or wedges have received less attention (Raju *et al* (2014).

Magnetohydrodynamics (MHD) is of that conductive fluids whether liquids or gaseous, which can support magnetic fields. In earlier years MHD was applied to astrophysical and geophysical problems, where it is still very important. In engineering MHD is employed to study mostly the magnetic behavior of plasmas in fusion reactors, liquid- metal cooling of nuclear reactors and electromagnetic casting. Many people have extensively studied in this field with its applications.

Das *et al*. (2011) have studied the unsteady MHD flow and heat transfer of incompressible electrically conducting viscous fluid past an infinite heated porous plate. The unsteady MHD natural convection flow and mass transfer along an accelerated porous plate in a porous medium have been studied by Sattar and Maleque (2000) and Sattar *et al.* (2000).

Veera Krishna and Chamkha (2019) investigated the diffusion-thermo, radiation-absorption and Hall and ion slip effects on MHD free convective rotating flow of nano-fluids past a semi-infinite permeable moving plate with constant heat source. Ugwu *et al* (2021) studied the MHD effects on convective flow of dusty viscous fluid. The problem was solved numerically under the influence of magnetic field.

Veera Krishna *et al*. (2019) discussed the Soret and Joule effects of MHD mixed convective flow of an incompressible and electrically conducting viscous fluid past an infinite vertical porous plate taking Hall effects into account. Veera Krishna and Chamkha (2018) discussed the MHD squeezing flow of a water-based nanofluid through a saturated porous medium between two parallel disks, taking the Hall current into account. The effects of radiation and Hall current on an unsteady MHD free convective flow in a vertical channel filled with a porous medium have been studied by Veera Krishna *et al*. (2018).

The heat generation/absorption and thermo-diffusion on an unsteady free convective MHD flow of radiating and chemically reactive second grade fluid near an infinite vertical plate through a porous medium and taking the Hall current into account have been studied by Veera Krishna and Chamkha (2018). Veera Krishna *et al*. (2018) discussed the heat and mass transfer on unsteady, MHD oscillatory flow of second-grade fluid through a porous medium between two vertical plates under the influence of fluctuating heat source/sink, and chemical reaction. Ugwu *et al* (2021) studied the effects of MHD flow on convective fluids incorporating viscous dissipation energy though it was a Newtonian fluid. This problem was analysed numerically using method of lines and various fluid parameter and that of the particles were obtained.

Veera Krishna and Subba Reddy (2019) investigated the transient MHD flow of a reactive second grade fluid through a porous medium between two infinitely long horizontal parallel plates. Veera

Krishna *et al*. (2018) discussed heat and mass-transfer effects on an unsteady flow of a chemically reacting micropolar fluid over an infinite vertical porous plate in the presence of an inclined magnetic field, Hall current effect, and thermal radiation taken into account. Veera Krishna *et al*. (2019) discussed Hall effects on MHD peristaltic flow of Jeffrey fluid through porous medium in a vertical stratum. The effects of heat and mass transfer on free convective flow of micropolar fluid were studied over an infinite vertical porous plate in the presence of an inclined magnetic field with a constant suction velocity and taking Hall current into account have been discussed by Veera Krishna *et al*. (2019)

In recent times, many researchers have given considerable interest to the study of MHD in the presence of radiation. Mishra *et al*. (2020) studied the effect of radiation and non-uniform heat source on the unstable, MHD viscous fluid through a heated plate with time-dependent suction and viscous dissipation. Chiranjeevi *et al*. (2021) investigated the problem of the MHD boundary layer flow analysis in the presence of thermal absorption with heat generation and chemical reaction over a plate.

In this paper, MHD we have considered the unsteady free convective flow of a viscous incompressible electrically conducting fluid over an infinite vertical porous plate under the influence of uniform transverse magnate field with time dependent permeability and oscillatory suction embedded with viscous energy dissipation.

FORMULATION OF THE PROBLEM

We considered the unsteady MHD free convection flow of an incompressible viscous electrically conducting fluid with simultaneous heat and mass transfer over an infinite vertical plate through porous medium with time dependent permeability and oscillatory suction. The y-axis is taken along the plate and x-axis perpendicular to it and u is the velocity along the x-direction.

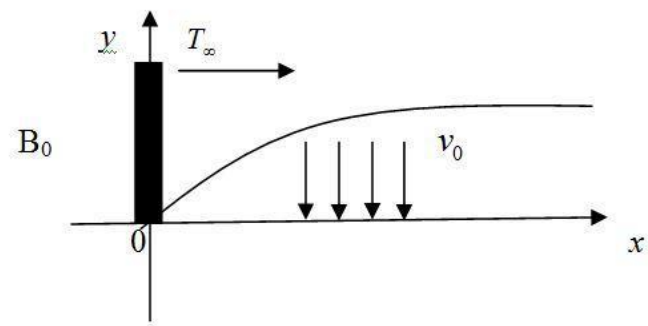

Fig. 2.1: Physical configuration of the problem

The basic assumptions are

1. All fluid proportions are constant.
2. The plate and the fluid are to be at the same temperature and the species concentration is raised or lowered.
3. The magnetic Reynolds number is so small that the induced magnetic field are neglected in comparison to the applied magnetic field.
4. The permeability of the porous medium is

$$k(t) = k\left(1+\varepsilon e^{nt}\right) \tag{1}$$

5. The suction velocity is

$$v(t) = -v_0\left(1+\varepsilon e^{nt}\right) \tag{2}$$

Where, v_0 represents the suction / injection velocity at the plate.

6. If the plate is extended to infinite length, then all the physical variables are functions of y and t alone.

The governing equations are given by

$$\frac{\partial u}{\partial y} = 0 \tag{3}$$

$$\frac{\partial u}{\partial t}+\nu\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}-\frac{\sigma\mu_e^2 H_0^2}{\rho}u-\frac{\nu}{k(t)}u+g\beta(T-T_\infty)+g\beta^*(C-C_\infty) \quad (4)$$

$$\frac{\partial c}{\partial t}+\nu\frac{\partial c}{\partial y}=D\frac{\partial^2 c}{\partial y^2}-k_1(C-C_\infty) \quad (5)$$

$$\frac{\partial T}{\partial t}+\nu\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}-S_1(T-T_\infty)+\frac{\nu}{Cp}\left(\frac{\partial u}{\partial y}\right)^2 \quad (6)$$

Subject to

$$u(y,t)=T(y,t)=C(y,t)=1+\varepsilon e^{nt} \quad @\ y=0 \quad (7)$$

$$u(y,t)=T(y,t)=C(y,t)=0 \quad @\ y\to\infty$$

Using the following dimensionless variables, we dimensionalise (3) – (7)

$$u^*=\frac{u}{\nu_0};\quad y^*=\frac{\nu_0 y}{\nu};\ t^*=\frac{\nu_0{}^2 t}{\nu};\ \nu^*=\frac{\nu}{\nu_0};\ w^*=\frac{\nu w}{\nu_0{}^2};\ \theta=\frac{T-T_\infty}{T_w-T_\infty};\ \phi=\frac{C-C_\infty}{C_w-C_\infty}; \quad (8)$$

Thus we obtain,

$$\frac{\partial u}{\partial y}=0 \quad (9)$$

$$\frac{\partial u}{\partial t}-\nu_0\left(1+\varepsilon e^{nt}\right)\frac{\partial u}{\partial y}=\frac{\partial^2 u}{\partial y^2}-\left(M^2+\frac{1}{k(t)}\right)u+Gr\theta+Gm\phi \quad (10)$$

$$\frac{\partial \phi}{\partial t}-\nu_0\left(1+\varepsilon e^{nt}\right)\frac{\partial \phi}{\partial y}=\frac{1}{Sc}\frac{\partial^2 \phi}{\partial y^2}-Kc\phi \quad (11)$$

$$\frac{\partial \theta}{\partial t}-\nu_0\left(1+\varepsilon e^{nt}\right)\frac{\partial \theta}{\partial y}=\frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2}-S_1\theta+Ec\left(\frac{\partial u}{\partial y}\right)^2 \quad (12)$$

Subject to

$$u(y,t)=\theta(y,t)=\phi(y,t)=1+\varepsilon e^{nt} \quad @\ y=0 \quad (13)$$

$$u(y,t)=\theta(y,t)=\phi(y,t)=0 \quad @\ y\to\infty$$

Where,

$M^2=\frac{\sigma\beta_0{}^2\nu}{\rho v_0{}^2}$ is the Hartmann number (Magnetic field parameter), $Ec=\frac{v_0{}^2}{Cp\left(T_w-T_\infty\right)}$ is the Magnetic induction, $K=\frac{k}{\nu^2}$ is the permeability parameter (Porosity or Darcy parameter), $Gm=\frac{\upsilon g\beta^*\left(T_w-T_\infty\right)}{v_0{}^3}$ is the Prandtl number, $Sc=\frac{\upsilon}{D}$ is the Schmidt number, $Kc=\frac{k_1\upsilon}{v_0{}^2}$ is the chemical reaction parameter, $S = \frac{S_1 \upsilon}{{v_0}^2}$ is the Heat Source parameter, $Gr = \frac{\upsilon g \beta \left(T_w - T_\infty \right)}{{v_0}^3}$ is the thermal Grashof number, $Gm = \frac{\upsilon g \beta^* \left(T_w - T_\infty \right)}{{v_0}^3}$ is the mass Grashof number and $Ec = \frac{{v_0}^2}{Cp\left(T_w - T_\infty \right)}$ is the Eckert number.

METHOD OF LINES

The basic idea of the MOL is to replace the special (boundary value) derivatives in the PDE with algebraic approximations. Once this is done, only the initial value variable, typically time in a physical problem remains. Then, with only one remaining independent variable, we have a system of ODEs that approximates the original PDE. Any suitable integration algorithm for the initial value ODEs can now be used to compute an approximate numerical solution to the PDE.

Before applying the method of lines to equation (9) – (12) subject to boundary conditions (13), we adopt the approximation below to decouple and linearize equations (9) – (12). In view of the approximation adopted, equations (9) – (12) reduce to;

$$\frac{\partial u}{\partial t} = v_0 \left(1 + \varepsilon e^{nt} \right) \frac{\partial u}{\partial y} + \frac{\partial^2 u}{\partial y^2} - \left(M^2 + \frac{1}{k(t)} \right) u + Gr + Gm \tag{14}$$

$$\frac{\partial \phi}{\partial t} = v_0 \left(1 + \varepsilon e^{nt} \right) \frac{\partial \phi}{\partial y} + \frac{1}{Sc} \frac{\partial^2 \phi}{\partial y^2} - Kc\phi \tag{15}$$

$$\frac{\partial \theta}{\partial t} = v_0 \left(1 + \varepsilon e^{nt} \right) \frac{\partial \theta}{\partial y} + \frac{1}{\Pr} \frac{\partial^2 \theta}{\partial y^2} - S_1 \theta + Ec \tag{16}$$

Applying the method of lines to equation (14), we discretize the partial derivative in space variable y, to result in approximating system of ODEs in variable t, thus we have;

$$\left(\frac{\partial u}{\partial t} \right)_i = v_0 \left(1 + \varepsilon e^{nt} \right) \frac{u_{i+1} - u_{i-1}}{2h} + \frac{u_{i+1} - 2u_i + u_{i-1}}{h^2} - \left(M^2 + \frac{1}{k} \right) u_i + Gr + Gm \tag{17}$$

Simplifying the right-hand side of equation (17) gives:

$$\left(\frac{\partial u}{\partial t} \right)_i = \alpha_1 u_{i-1} + \alpha_2 u_i + \alpha_3 u_{i+1} + \alpha_4 \tag{18}$$

Where,

$$\alpha_1 = \left(\frac{1}{h^2} - \frac{\nu_0\left(1+\varepsilon e^{nt}\right)}{2h}\right);\ \alpha_2 = -\left(\frac{2}{h^2} + M^2 + \frac{1}{k\left(1+\varepsilon e^{nt}\right)}\right);\ \alpha_3 = \left(\frac{1}{h^2} + \frac{\nu_0\left(1+\varepsilon e^{nt}\right)}{2h}\right);$$

$$\alpha_4 = Gr + Gm,\ i = 1,2,3,...,N \qquad (19)$$

Equations (18) – (19) can be solved iteratively using the boundary conditions $u(0,t) = 1+\varepsilon e^{nt}$ and $u(\alpha,t) = 0$ in equations (13)

For $i = 1,2,3,...,N;\ u(0,t) = u(y,t) = 1+\varepsilon e^{nt};$ & $u(\infty,t) \approx u(N+1,t) = 0;$ in equation (18) can be written as;

$$\begin{aligned} \dot{u}_1 &= \alpha_1 + \alpha_2 u_1 + \alpha_3 u_2 + \alpha_4 \\ \dot{u}_2 &= \alpha_1 u_1 + \alpha_2 u_2 + \alpha_3 u_3 + \alpha_4 \\ \dot{u}_3 &= \alpha_1 u_2 + \alpha_2 u_3 + \alpha_3 u_4 + \alpha_4 \\ \dot{u}_4 &= \alpha_1 u_3 + \alpha_2 u_4 + \alpha_3 u_5 + \alpha_4 \\ \dot{u}_N &= \alpha_1 u_{N-1} + \alpha_2 u_N + \alpha_4 \end{aligned} \qquad (20)$$

The system in equation (20), in matrix form is given as

$$\begin{bmatrix} \dot{u}_1 \\ \dot{u}_2 \\ \vdots \\ \dot{u}_{N-1} \\ u_N \end{bmatrix} = \begin{bmatrix} \alpha_1 & \alpha_2 & \alpha_3 & 0 & 0 & ... & 0 & 0 \\ 0 & \alpha_1 & \alpha_2 & \alpha_3 & 0 & ... & 0 & 0 \\ 0 & 0 & \alpha_1 & \alpha_2 & \alpha_3 & ... & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & ... & \alpha_1 & \alpha_2 \end{bmatrix} \begin{bmatrix} 1+\varepsilon e^{nt} \\ u_1 \\ u_2 \\ \vdots \\ u_{N-1} \\ u_N \end{bmatrix} + \begin{bmatrix} \alpha_4 \\ \alpha_4 \\ \alpha_4 \\ \vdots \\ \alpha_4 \\ \alpha_4 \end{bmatrix} \qquad (21)$$

Where the coefficient of α_1, α_2, α_3 and α_4 are given by (19) and $\dot{u}_i = \left(\frac{\partial u}{\partial t}\right)_i$

In a similar way, equation (15) becomes;

$$\left(\frac{\partial \phi}{\partial t}\right)_i = \nu_0\left(1+\varepsilon e^{nt}\right)\frac{\phi_{i+1} - \phi_{i-1}}{2h} + \frac{1}{Sc}\left(\frac{\phi_{i+1} - 2\phi_i + \phi_{i-1}}{h^2}\right) - Kc\phi_i \qquad (22)$$

Simplifying the right hand side, we obtain;

$$\left(\frac{\partial \phi}{\partial t}\right)_i = \beta_1\phi_{i-1} + \beta_2\phi_i + \beta_3\phi_{i+1} + \beta_4 \qquad (23)$$

Where,

$$\beta_1 = \left(\frac{1}{h^2 Sc} - \frac{\nu_0\left(1+\varepsilon e^{nt}\right)}{2h}\right);\ \beta_2 = -\left(\frac{2}{h^2 Sc} + Kc\right);\ \beta_3 = \left(\frac{1}{h^2 Sc} + \nu_0\left(1+\varepsilon e^{nt}\right)\right); \qquad (24)$$

Equations (23) – (24) can be solved iteratively using the boundary conditions $\phi(0,t)=1+\varepsilon e^{nt}$ and $\phi(\infty,t)=0$ in equations (13).

For $i=1,2,3,...,N;$ $\phi(0,t)=1+\varepsilon e^{nt};$ & $\phi(\infty,t)\approx\phi(N+1,t)=0;$ in equation (23) can be written in matrix form as;

$$\begin{bmatrix} \dot{\phi}_1 \\ \dot{\phi}_2 \\ \vdots \\ \dot{\phi}_{N-1} \\ \dot{\phi}_N \end{bmatrix} = \begin{bmatrix} \beta_1 & \beta_2 & \beta_3 & 0 & 0 & \dots & 0 & 0 \\ 0 & \beta_1 & \beta_2 & \beta_3 & 0 & \dots & 0 & 0 \\ 0 & 0 & \beta_1 & \beta_2 & \beta_3 & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & \dots & \beta_1 & \beta_2 \end{bmatrix} \begin{bmatrix} 1+\varepsilon e^{nt} \\ \phi_1 \\ \phi_2 \\ \vdots \\ \phi_{N-1} \\ \phi_N \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ \vdots \\ 0 \\ 0 \end{bmatrix} \tag{25}$$

Where the coefficient β_1, β_2, and β_3 are given in equation (24) and $\dot{\phi}_i=\left(\frac{\partial\phi}{\partial t}\right)_i$.

Similarly, equation (16) becomes;

$$\left(\frac{\partial\theta}{\partial t}\right)_i=\left(\frac{1}{h^2\Pr}-\frac{\nu_0\left(1+\varepsilon e^{nt}\right)}{2h}\right)\theta_{i-1}-\left(\frac{2}{h^2\Pr}+S\right)\theta_i+\left(\frac{1}{h^2\Pr}+\nu_0\left(1+\varepsilon e^{nt}\right)\right)\theta_{i+1}+Ec \tag{26}$$

$$\left(\frac{\partial\theta}{\partial t}\right)_i=\gamma_1\theta_{i-1}+\gamma_2\theta_i+\gamma_3\theta_{i+1}+\gamma_4 \tag{27}$$

Where;

$$\gamma_1=\left(\frac{1}{h^2\Pr}-\frac{\nu_0\left(1+\varepsilon e^{nt}\right)}{2h}\right);\ \gamma_2=-\left(\frac{2}{h^2\Pr}+S\right);\ \gamma_3=\left(\frac{1}{h^2\Pr}+\nu_0\left(1+\varepsilon e^{nt}\right)\right);\ \gamma_4=Ec \tag{28}$$

Equations (26) – (28) can be solved iteratively using the boundary conditions $\theta(0,t)=1+\varepsilon e^{nt}$ and $\theta(\infty,t)=0$ in equations (13).

For $i=1,2,3,...,N;$ $\theta(0,t)=1+\varepsilon e^{nt};$ & $\theta(\infty,t)\approx\theta(N+1,t)=0;$ in equation (27) can be written in matrix form as;

$$\begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \\ \vdots \\ \dot{\theta}_{N-1} \\ \dot{\theta}_N \end{bmatrix} = \begin{bmatrix} \gamma_1 & \gamma_2 & \gamma_3 & 0 & 0 & \dots & 0 & 0 \\ 0 & \gamma_1 & \gamma_2 & \gamma_3 & 0 & \dots & 0 & 0 \\ 0 & 0 & \gamma_1 & \gamma_2 & \gamma_3 & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & \dots & \gamma_1 & \gamma_2 \end{bmatrix} \begin{bmatrix} 1+\varepsilon e^{nt} \\ \theta_1 \\ \theta_2 \\ \vdots \\ \theta_{N-1} \\ \theta_N \end{bmatrix} + \begin{bmatrix} \gamma_4 \\ \gamma_4 \\ \gamma_4 \\ \vdots \\ \gamma_4 \\ \gamma_4 \end{bmatrix} \quad (29)$$

Where the coefficient $\gamma_1, \gamma_2, \gamma_3$ and γ_4 are given by the equation (28) and $\dot{\theta}_i = \left(\frac{\partial\theta}{\partial t}\right)_i$

RESULT AND DISCUSSION

We have considered the unsteady free convective flow of a viscous incompressible electrically conducting fluid over an infinite vertical porous plate under the influence of uniform transverse magnate field with time dependent permeability and oscillatory suction.

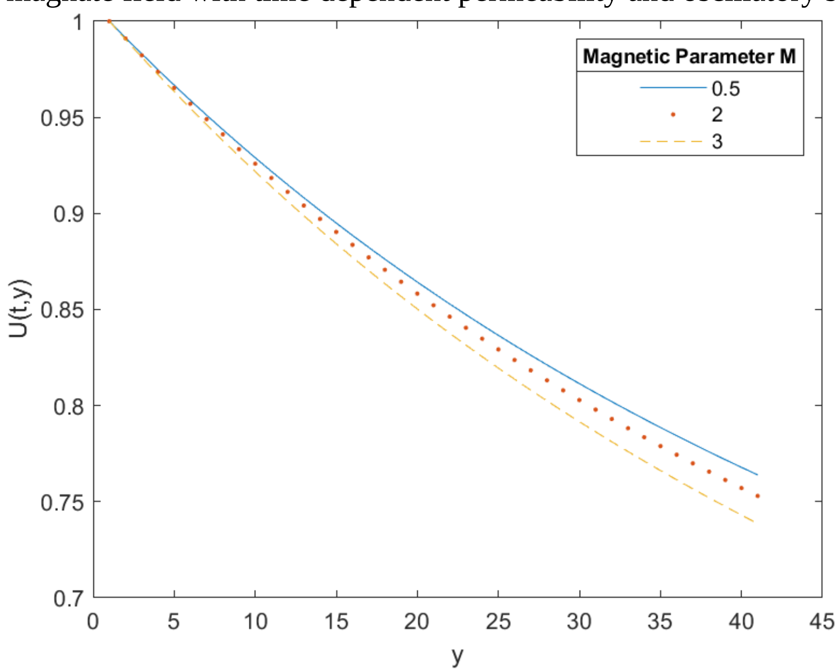

Figure.2: Effects of Magnetic Parameter on the velocity profile.

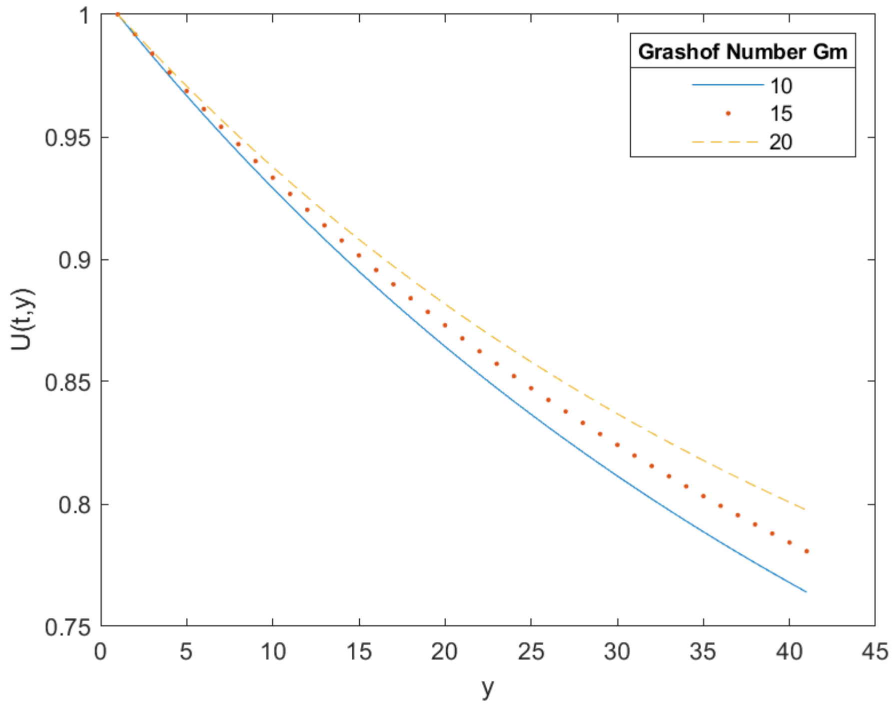

Figure.3: Effects of Mass Grashof Number on the velocity profile

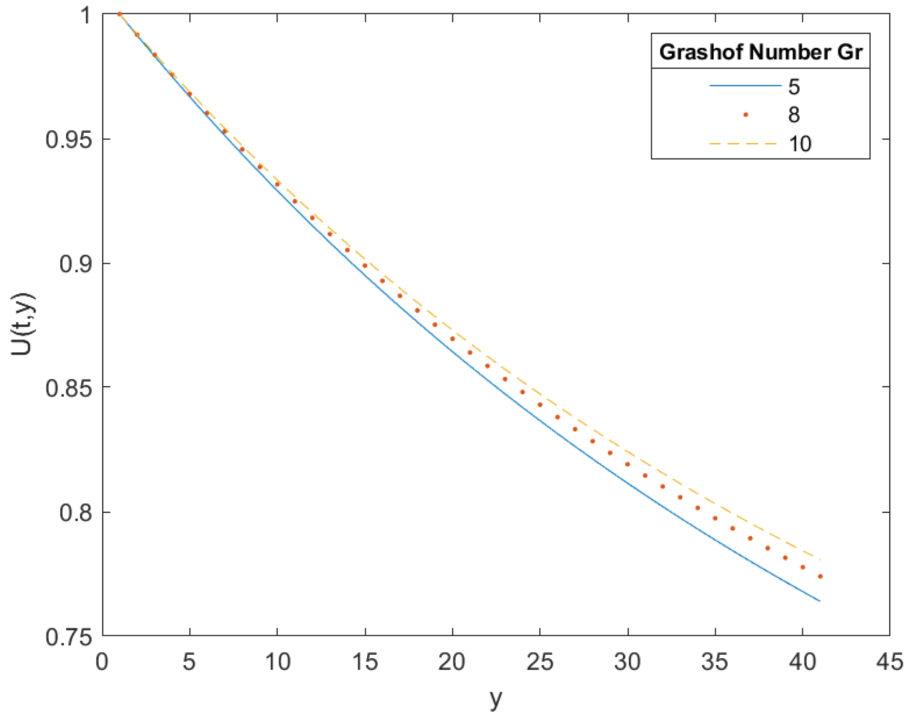

Figure.4: Effects of Thermal Grashof Number on the velocity profile

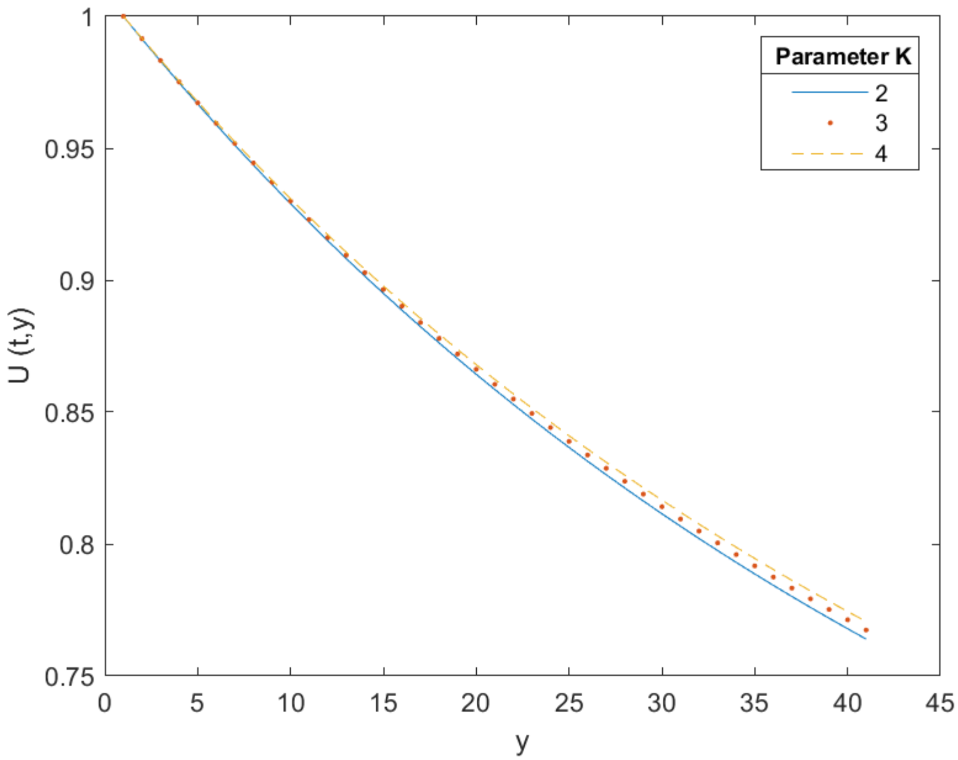

Figure.5: Effects of Permeability (Porosity) on the velocity profile

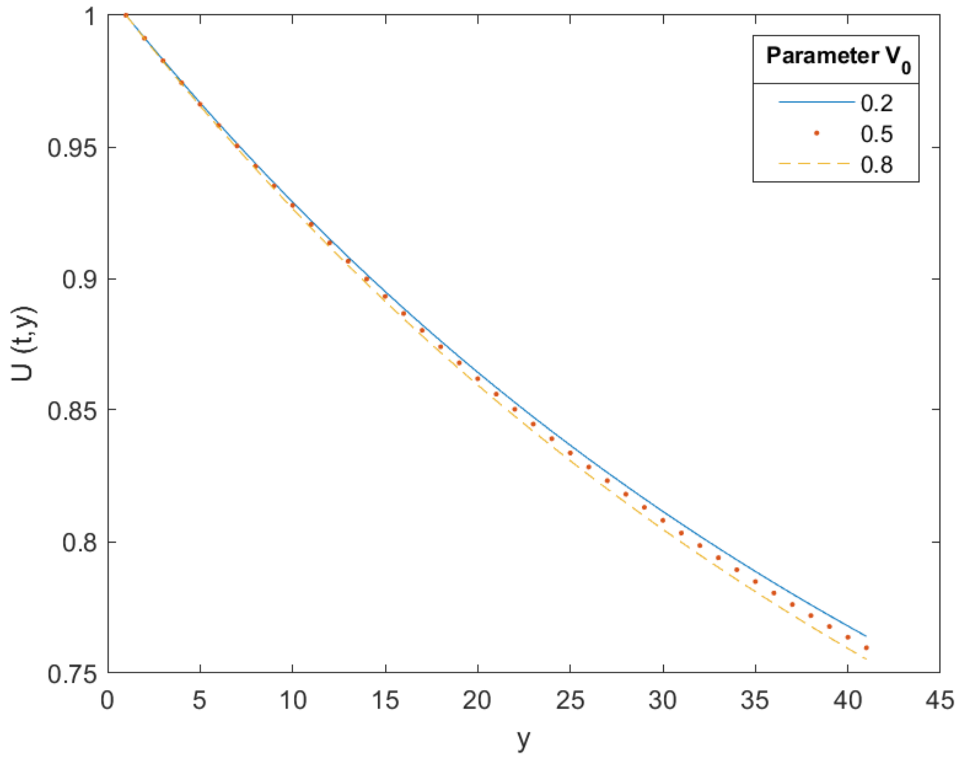

Figure.6: Effects of Parameter V_0 on the velocity profile

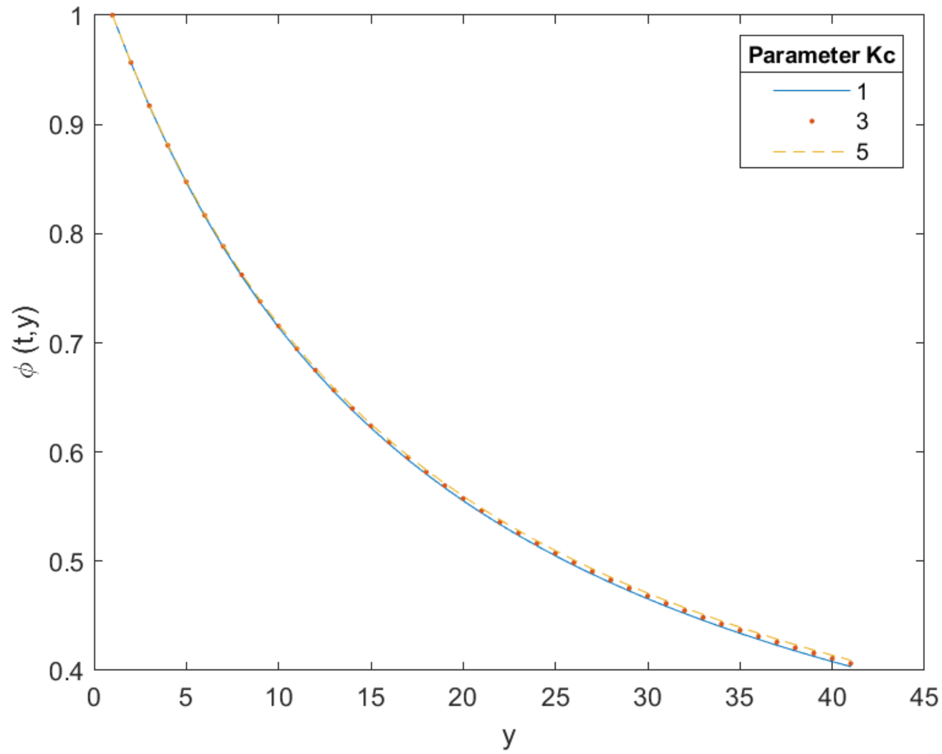

Figure.7: Effects of Parameter Kc on the Concentration profile

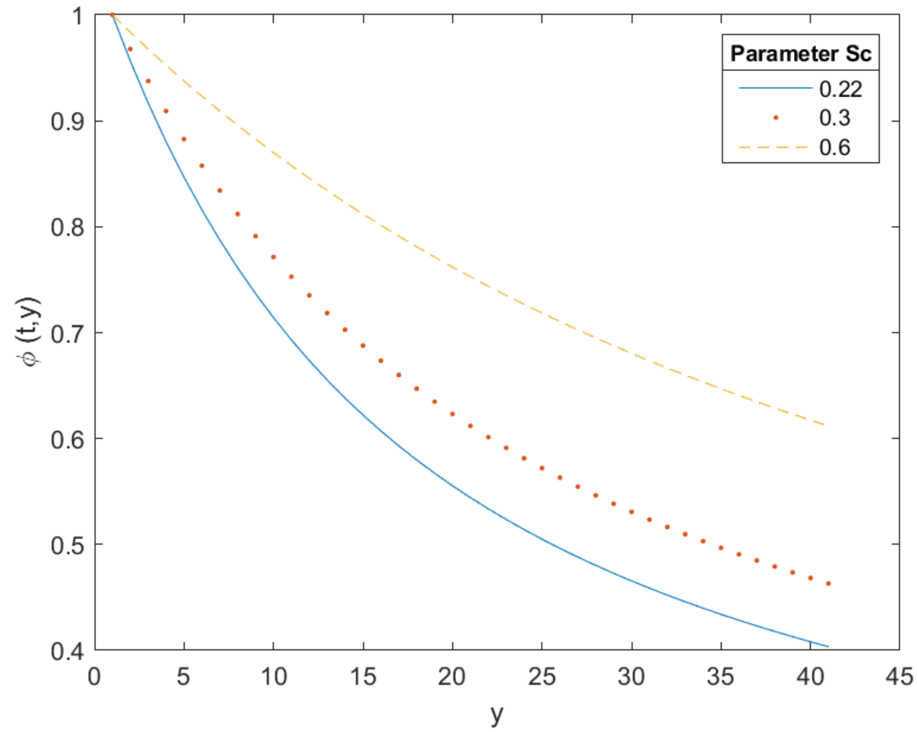

Figure.8: Effects of Schmidt Number, Sc on the Concentration profile

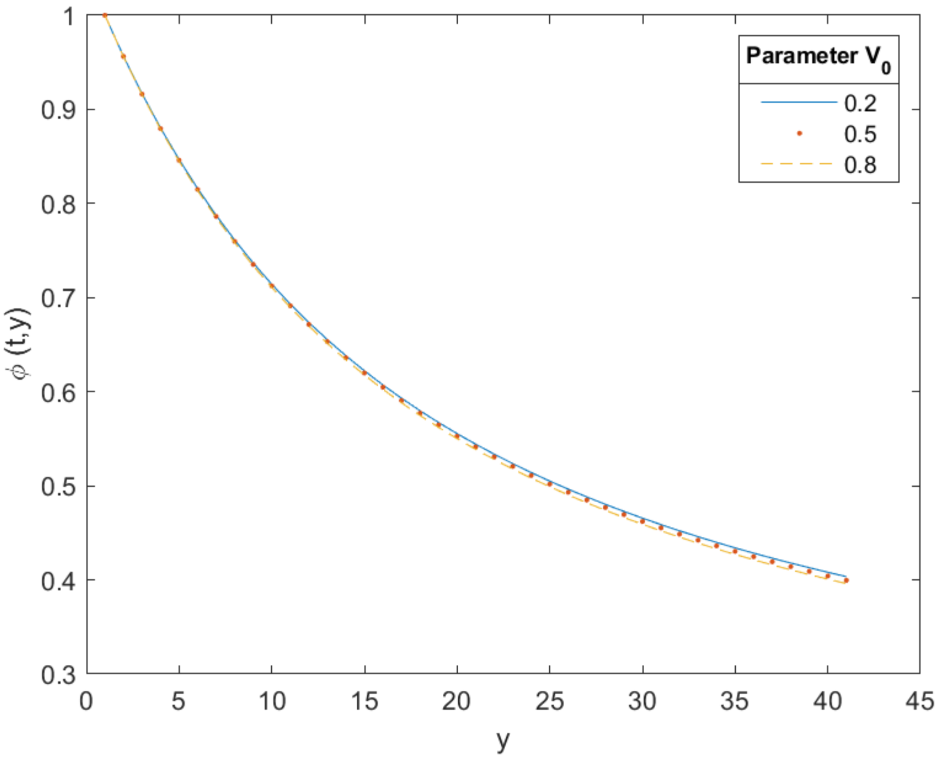

Figure.9: Effects of Parameter V_0 on the Concentration profile

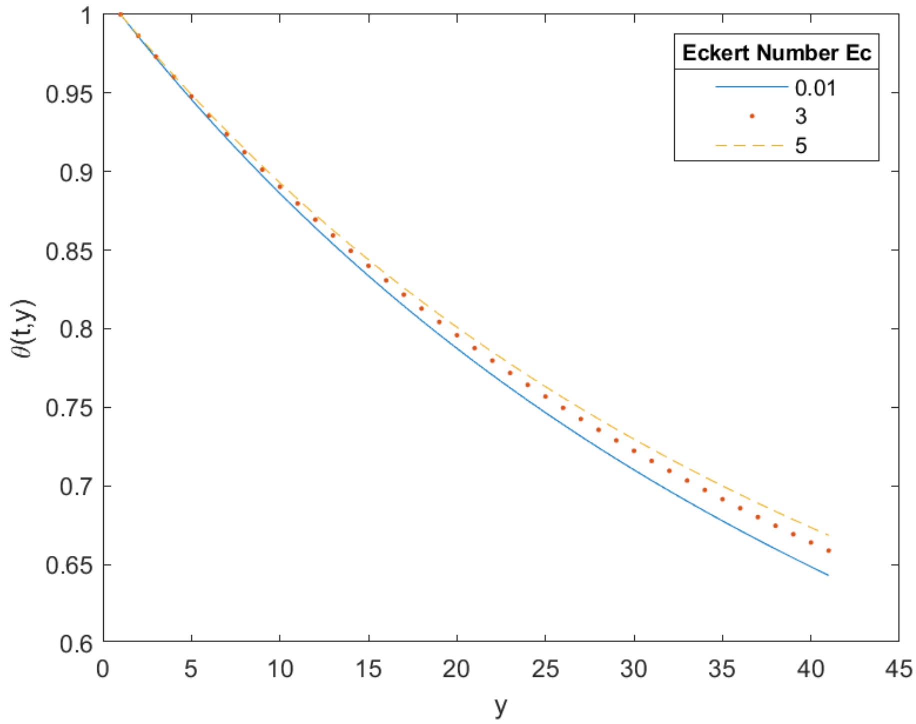

Figure.10: Effects of Eckert Number on the Temperature profile

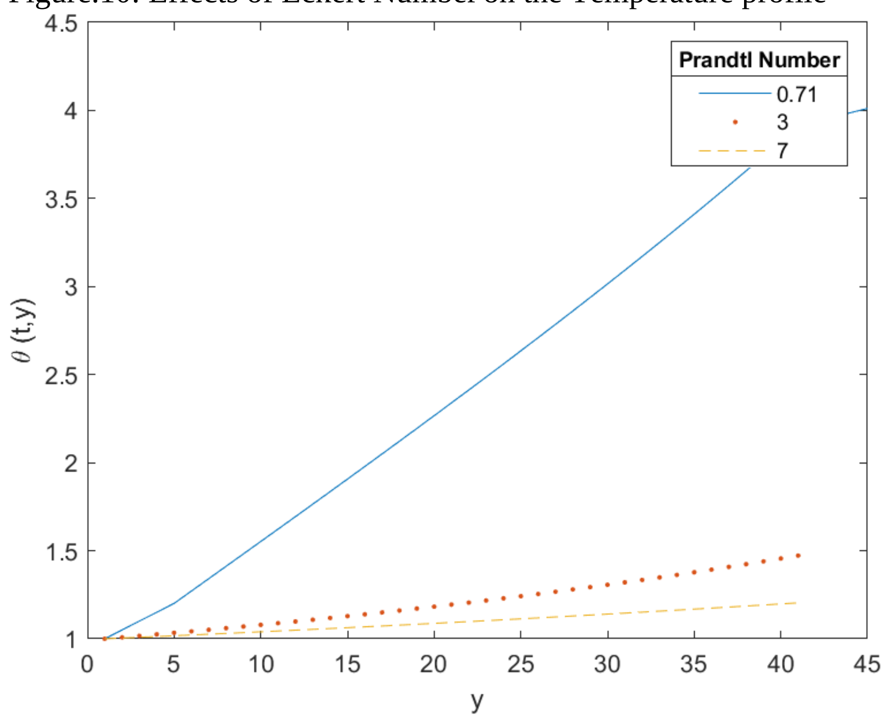

Figure.11: Effects of Prantl number on the Temperature profile

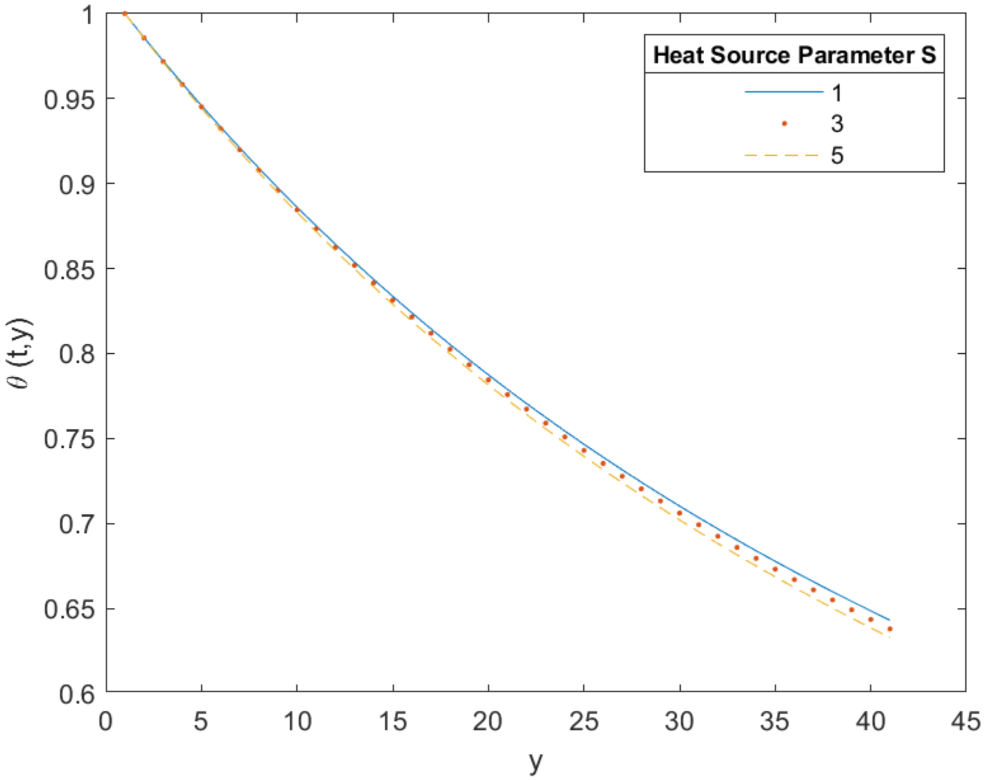

Figure.12: Effects of Heat Source on the Temperature profile

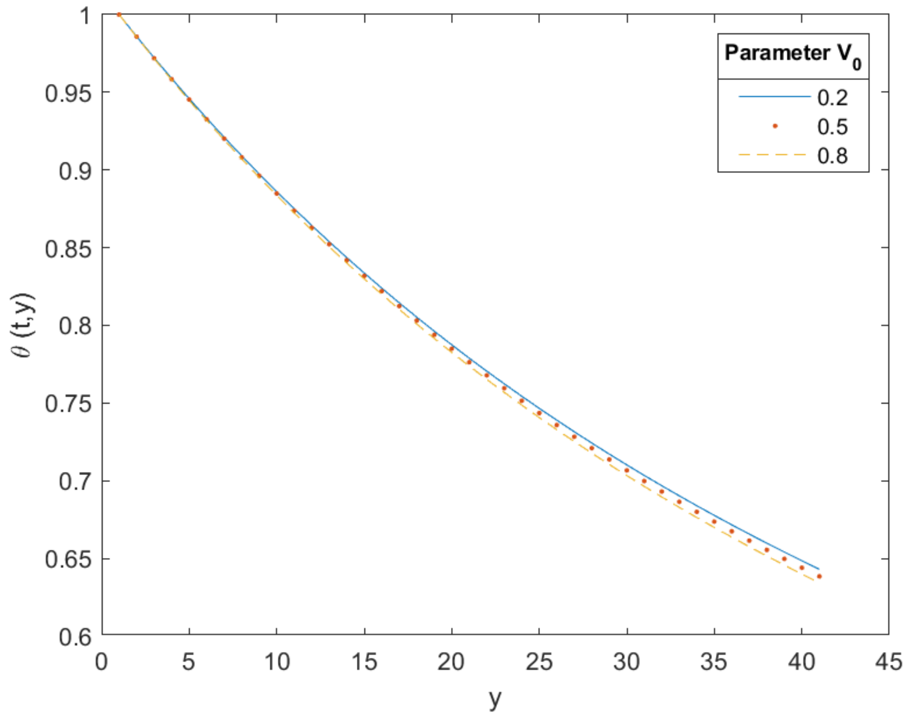

Figure.13: Effects of Parameter V_0 on the Temperature profile

Figures (2) – (6) represent the effects of Magnetic Parameter, Mass Grashof number, Thermal Grashof number, Permeability (Porosity) and Suction/ injection parameter on the velocity denoted by M, Gm, Gr, K and V_0 respectively, figures (7) – (9) represent the effects of chemical reaction, Schmidt number and Suction parameter on the Concentration denoted by Kc, Sc and V_0 respectively, whereas figures (10) – (13) denotes the effects of Eckert number, Prantl number, Heat source and Suction parameter on the temperature of the system denoted by Ec, Pr, S and V_0. Fixing the parameters $t := 0.2 : h := 0.1 : \nu[0] := 0.2 : \varepsilon := 0.001 : n := 0.01 : S := 1 : M := 0.5 :$ $K := 2 : Gr := 5 : Gm := 10 : Sc := 0.22 : Kc := 1 : Pr := 0.71 : Ec := 0.001 :$

We then draw the profiles varying for each parameters being fixed.

Figure (2) shows that the magnitude of the velocity component reduces with increasing the intensity of the magnetic field, M. This is due to the Lorentz force the velocity retards continuously throughout the fluid region. Figure (3) shows that the velocity component increases with increase in mass Grashof number. Figure (4) shows that the velocity component also increases with increase in thermal Grashof number. Figure (5) depicts that lowering the permeability of the porous medium lesser the fluid speed in the entire region. Figure (6) depicts that the velocity component experiences retardation in the flow field with increasing suction parameter. Figure (7) and (8) shows that the Concentration distribution decreases with increase in chemical reaction or Schmidt number respectively, thus causing a retardation in the fluid flow. Also figure (9) shows that increasing the suction parameter leads to reduction in the concentration distribution. These results in the concentration distribution show that the heavier diffusing species have a greater retarding effect on the concentration distribution of the flow field. Figure (10) show that the temperature of the system increases with an increase in Eckert number. Figure (11) shows that the temperature of the flow field diminishes as the Pr increases. This is consistent with the fact that the thermal boundary layer thickness decreases with increasing Prantl number. Figure (12) depicts that with increasing heat source, the temperature of the flow field reduces. This may be as a result of the elastic property of the fluid. It is observed that in figure (13) increasing the suction parameter reduces the temperature of the system.

CONCLUSION

In this paper, we investigated the MHD free convective flow of an incompressible fluid over an infinite vertical porous plate under the influence of uniform transverse magnate field with time dependent permeability and oscillatory suction incorporating the viscous energy dissipation. We presented the results to illustrate the flow characteristics for the velocity, temperature, and concentration and the effects of the physical parameters of the flow. Therefore, we conclude that fluid velocity increases with the increase in Grashof number or porosity of the medium, while it decrease with increase in Magnetic and Suction parameter. The concentration distribution reduces with increase in chemical reaction, Schmidt number and Suction parameter while the temperature of the system increases with increase in Eckert number and decreases with increase in prantl number or suction parameter.

REFERENCES

[1]. Chiranjeevi, B.; Valsamy, P.; Vidyasagar, G. Radiation absorption on MHD free convective laminar flow over a moving vertical porous plate, viscous dissipation and chemical reaction with suction under the influence of transverses magnetic field. Materials Today: Proceedings 2021, 42, 1559-1569, https://doi.org/10.1016/j.matpr.2020.01.488.

[2]. M.A. Sattar and M.A. Maleque, Unsteady MHD Natural Convection Flow along an Accelerated Porous Plate with Hall Current and Mass Transfer in a Rotating PorousMedium, Journal of Energy, Heat and Mass Transfer, 22 (2000), 67-72.

[3]. M.A. Sattar, M.M. Rahman and M.M. Alam, Free Convection Flow and Heat Transferthrough a Porous Vertical Flat Plate Immersed in a Porous Medium, Journal of Energy Research, 22 (2000), no. 1, 17-21.

[4] M. C. Raju, N. A. Reddy, and S. V. K. Varma, "Analytical study of MHD free convective, dissipative boundary layer flow past a porous vertical surface in the presence of thermal radiation, chemical reaction and constant suction," 2014.

[5]. Mishra, P.; Tripathi, S.: Effect of non-uniform heat source and radiation on unsteady MHD free convection flow past an infinite heated vertical plate in porous medium. E-Jurnal Matematika 2020, 9, 219-228, https://doi.org/10.24843/mtk.2020.v09.i04.p302. 24.

[6]. S. Das, S.K. Guchhait, R.N. Jana, Unsteady MHD flow and heat transfer past a porous plate in a rotating system, International Journal of Computer Applications, 33 (2011), no. 2.

[7]. Ugwu U.C, Cole A.T and Olayiwola R.O. Analysis of Magnetohydrodynamics effects on convective flow of dusty viscous fluid. *Science World Journal* 2021; 16(2) : 85-89

[8]. Ugwu U. C. , Cole A. T. , Olayiwola R. O. and Kazeem J. A. Method of Lines Analysis of Mhd Effect on Convectve Flow of Dusty Fluid In The Presence of Viscous Energy Dissipation. Journal *of Science, Technology, Mathematics and Education (JOSTMED)* 2021; 17(1):140-151.

[9]. Veera Krishna, M., Chamkha, A.J., Hall and ion slip effects on MHD rotating boundary layer flow of nanofluid past an infinite vertical plate embedded in a porous medium, Results in Physics, 15, 102652, DOI: https://doi.org/10.1016/j.rinp.2019.102652

[10]. Veera Krishna, M., Swarnalathamma, B.V., Chamkha, A.J., Investigations of Soret, Joule and Hall effects on MHD rotating mixed convective flow past an infinite vertical porous plate, Journal of Ocean Engineering and Science, 4(3), pp. 263-275, 2019. DOI: https://doi.org/10.1016/j.joes.2019.05.002.

[11]. Veera Krishna.M., Chamkha, A.J., Hall effects on MHD Squeezing flow of a water based nano fluid between two parallel disks, Journal of Porous media, 22(2), pp. 209-223, 2019. **DOI:** https://doi.org/10.1615/JPorMedia.2018028721

[12]. Veera Krishna.M, G.Subba Reddy, A.J.Chamkha, "Hall effects on unsteady MHD oscillatory free convective flow of second grade fluid through porous medium between two vertical plates," Physics of Fluids, vol. **30**, 023106 (2018); doi: https://doi.org/10.1063/1.5010863

[13]. Veera Krishna.M, A.J.Chamkha, Hall effects on unsteady MHD flow of second grade fluid through porous medium with ramped wall temperature and ramped surface concentration, Physics of Fluids **30**, 053101 (2018), doi: https://doi.org/10.1063/1.5025542

[14]. Veera Krishna.M., K.Jyothi, A.J.Chamkha, Heat and mass transfer on unsteady, magnetohydrodynamic, oscillatory flow of second-grade fluid through a porous medium between two vertical plates, under the influence of fluctuating heat source/sink, and chemical reaction, *Int. Jour. of Fluid Mech. Res.*, vol. 45, no. 5, pp. 459-477, 2018b. DOI: 10.1615/InterJFluidMechRes.2018024591.

[15]. Veera Krishna.M., Subba Reddy.G., Unsteady MHD reactive flow of second grade fluid through porous medium in a rotating parallel plate channel, *J. Anal*., vol. 27, no. 1, pp. 103-120, 2019. DOI: https://doi.org/10.1007/s41478-018-0108-3.
[16]. Veera Krishna.M., B.V.Swarnalathamma, Ali.J.Chamkha, Heat and mass transfer on magnetohydrodynamic chemically reacting flow of micropolar fluid through a porous medium with Hall effects, *Special Topics & Reviews in Porous media – An International Journal*, vol. 9, no. 4, pp. 347-364, 2018. **DOI:** 10.1615/SpecialTopicsRevPorousMedia.2018024579.
[17]. Veera Krishna, M., K.Bharathi, Ali.J.Chamkha, Hall effects on MHD peristaltic flow of Jeffrey fluid through porous medium in a vertical stratum, Interfacial Phenomena and Heat transfer, vol. 6, no. 3, pp. 253-268, 2019. DOI: 10.1615/InterfacPhenomHeatTransfer.201903021
[18]. Veera Krishna, M., P.V.S. Anand, Ali.J.Chamkha, Heat and mass transfer on free convective flow of a micropolar fluid through a porous surface with inclined magnetic field and Hall effects, Special Topics & Reviews in Porous media – An International Journal, vol. 10, no. 3, pp. 203-223, 2019. DOI: 10.1615/SpecialTopicsRevPorousMedia.2018026943