Effects of Hall current and rotation on free convection MHD flow through a porous medium filled in a vertical plate in the presence of thermal radiation

M. Sreedhar Babu[1], B. Mallikarjuna Reddy[2*]
[1, 2*]Department of Mathematics, Yogi Vemana University, Kadapa-516005, Andhra Pradesh, India
[*]Email: mallikb2010@gmail.com
Corresponding author Email: mallikb2010@gmail.com

Received: 08-07-2024
Revised: 23-08-2024
Accepted: 25-09-2024

ABSTRACT

The effect of Hall current and rotation on MHD free convection flow in a vertical rotating plate filled with porous medium have been studies. A uniform magnetic field is applied in the direction normal to the plane of the plate. The entire system rotates about an axis normal to the planes of the plates. It is assumed that the entire system rotates with a uniform angular velocity Ω' about the normal to the plate and a uniform transverse magnetic field is applied along the normal to the plate directed into the fluid region. The magnetic Reynolds number is considered to be so small that the induced magnetic field can be neglected.
Keywords: Hall current, Radiation, Rotation, MHD, Free convection, Porous medium, Heat source

INTRODUCTION

In recent years, the effects of transversely applied magnetic field on the flows of electrically conducting viscous fluids have been discussed widely owing to their astrophysics, geophysical and engineering applications. When the strength of the magnetic field is strong, one cannot neglect the effects of Hall current. The rotating flow of an electrically conducting fluid in the presence of a magnetic field is encountered in geophysical and cosmical fluid dynamics. The study of flow in rotating porous media is motivated by practical applications in geophysics and engineering. Among the applications of rotating flow in porous media to engineering disciplines, one can find the food processing industry, chemical process industry, centrifugation filtration processes and rotating machinery. Also the hydrodynamic rotating flow of electrically conducting viscous incompressible fluids has gained considerable attention because of its numerous applications in physics and engineering. In geophysics, it is applied to measure and study the positions and velocities with respect to a fixed frame of reference on the surface of earth, which rotate with respect to an inertial frame in the presence of its magnetic field. The subject of geophysical dynamics now – a – days has become an important branch of fluid dynamics due to the increasing interest to study environment. In astrophysics, it is applied to study the stellar and solar structure, inter planetary and inter stellar matter, solar storms ect. In engineering, it finds its applications in MHD pumps, MHD boundary layer control of re-entry vehicles etc. Several researchers are studied in view of above [1-12].

There are numerous important engineering and geophysical applications of the plate flows through porous medium, for example in the fields of agricultural engineering for plate irrigation and to study the underground water resources, in petroleum technology to study the movement of natural gas, oil and water through the oil reservoirs [13-24].

The study of heat transfer with chemical reaction in the presence nanofluids is of immense realistic significance to engineers and scientists, because of its almost universal incidence in many branches of science and engineering. This phenomenon plays an important role in chemical industry, power and cooling industry for drying, evaporation, energy transfer in a cooling tower and the flow in a desert cooler, chemical vapour deposition on surfaces, cooling or nuclear reactors and petroleum industries and also there are many transport processes that are governed by the joint action of the buoyancy forces form both thermal and mass diffusion in the presence of chemical reaction effects. The effect of chemical reaction with heat radiation in presence of nanofluid over a porous vertical stretching surface [25-36].

The present study deals with the study of the effects of hall current, rotation and MHD free convection flow of a viscous, incompressible, electrically conducting fluid past an impulsively moving vertical plate in a porous medium. Exact solution of the governing equations is obtained in closed form by perturbation technique. Exact solution is also obtained in case of unit Schmidt number. The expressions for primary and secondary fluid velocity, fluid temperature, spices concentration, skin friction due to primary and secondary velocity fields at the plate are obtained.

FORMULATION OF THE PROBLEM

Consider unsteady MHD natural convection flow heat and mass transfer of an electrically conducting, viscous, incompressible fluid past an infinite vertical plate embedded in a uniform porous medium in a rotating system taking Hall current into account. Assuming Hall currents, the generalized Ohm's la [38] may be put in the following form:

$$\vec{j} = \frac{\sigma}{1+m^2}\left(\vec{E} + \vec{V}\times\vec{B} - \frac{1}{\sigma n_e}\vec{j}\times\vec{B}\right)$$

where $\vec{V}$ represent the velocity vector, $\vec{E}$ is the intensity vector of the electric field, $\vec{B}$ is the magnetic induction vector, $\vec{j}$ is the electric current density vector, m is the Hall current parameter, is the electrical conductivity and is the number density of the electron. A very interesting fact that the effect of Hall current gives rise to a force in the z' direction which in turn produces a cross flow velocity in this direction and thus the flow becomes three-dimensional.

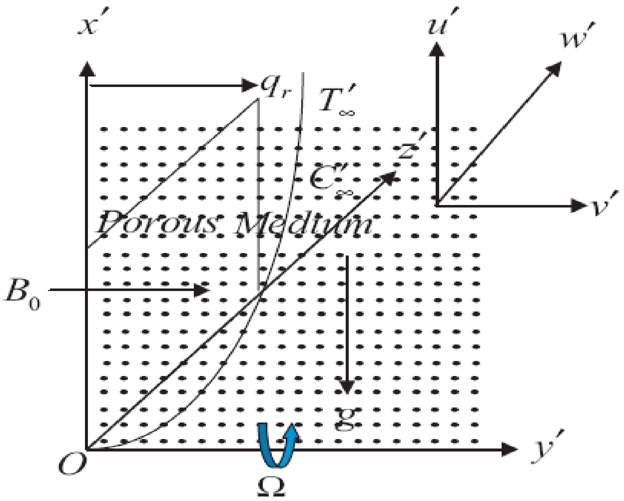

Figure (1): Geometry of the problem

Coordinate system is chosen in such a way that $x'-$is considered along the plate in upward direction and $y'-$axis normal to plane of the plate in the fluid. A uniform transverse magnetic field B_0 is applied in a direction which is parallel to $y'-$axis. The fluid and plate rotate in unison with uniform angular velocity Ω' about $y'-$axis. Initially, i.e. at time $t' \le 0$, both the fluid and plate are at rest and are maintained at a uniform temperature, both the fluid and plate are at rest and are maintained at a uniform temperature T'_∞. Also species concentration at the surface of the plate as well as at every point within the fluid is maintained at uniform concentration C'_∞. At the time $t' > 0$, plate starts moving in $x'-$ direction with a velocity $u'' = U t'$ in its plane. The temperature at the surface of the plate is raised to uniform temperature T'_w and the spices concentration at the surface of the plate is raised to uniform species concentration C'_w and is maintained thereafter. Geometry of the problem is presented in figure (1). Since plate is of infinite extent in x' and z' directions and is electrically non-conducting, all physical quantities except pressure depend on y' and t' only. Also no applied or polarized voltage exists so the effect of polarization of fluid is negligible. This correspondence to the case where no energy is added or extracted from the fluid by electrical means [39]. It is assumed that the induced magnetic field generated by fluid motion is negligible in comparison to the applied one. This assumption is justified because magnetic Reynolds number is very small for liquid metals and partially ionized fluids which are commonly used in industrial applications.

Keeping in view the assumptions made above, governing equations for natural convection flow with heat and mass transfer of an electrically conducting, viscous, incompressible fluid past an infinite vertical plate embedded in a uniform porous medium in a rotating system taking Hall current, radiation and chemical reaction effect into account, are given by

Conservation of momentum

$$\frac{\partial u'}{\partial t'} + 2\Omega w' = \nu \frac{\partial^2 u'}{\partial y'^2} + \frac{\sigma B_0^2}{\rho\left(1+m^2\right)}\left(u' + m w'\right) + g\beta\left(T' - T'_\infty\right) + g\beta^*\left(C' - C'_\infty\right) - \frac{\nu}{K'_1} u' \quad (1)$$

$$\frac{\partial w'}{\partial t'} + 2\Omega u' = \nu \frac{\partial^2 w'}{\partial y'^2} + \frac{\sigma B_0^2}{\rho\left(1+m^2\right)}\left(m u' - w'\right) - \frac{\nu}{K'_1} w' \quad (2)$$

Conservation of energy

$$\frac{\partial T'}{\partial t'} = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y'} \quad (3)$$

$$\frac{\partial C'}{\partial t'} = D_M \frac{\partial^2 C'}{\partial y'^2} - Kr'\left(C' - C'_\infty\right) \quad (4)$$

where $u', w', g, \rho, \beta, \beta', k, C_p, \sigma, \nu, m = \omega_e \tau_e, \omega_e, \tau_e, K_T, T', C', Kr'$ and K_1' are, respectively, the fluid velocity in the x' direction, fluid velocity in z' direction acceleration due to gravity, the fluid density, the volumetric coefficient of thermal expansion, the volumetric coefficient of expansion for concentration, thermal conductivity, specific heat at constant pressure, electrical conductivity, the kinematic viscosity, Hall current parameter, cyclotron frequency, electron collision time, the coefficient of mass diffusivity, the thermal diffusion ratio, the mean fluid temperature, the temperature of the fluid, species concentration, chemical reaction parameter, radiative heat flux vector and permeability of the porous medium.

Initial and boundary conditions for the fluid flow problem are given below

$$u' = w' = 0, T' - T'_\infty, C' = C'_\infty \quad \text{for all} \quad y' \quad \text{and } t' \le 0$$
$$u' = Ut', w' = 0, T' - T'_w, C' = C'_w \quad \text{at} \quad y' = 0 \quad \text{and } t' > 0 \qquad (5)$$
$$u' \to 0,\ w \to 0,\ T' \to T'_\infty,\quad C' \to C' \ \ as\ \ y' \to \infty \text{ for } t' > 0$$

The following dimensionless variables and parameters of the problem are

$$u = \frac{u'}{U_0}, w = \frac{w'}{U_0},\ y = \frac{y'U_0}{\nu}, t = \frac{t'U_0{}^2}{\nu}, \theta = \frac{T' - T'_\infty}{T'_w - T'_\infty}, \phi = \frac{C' - C'_\infty}{C'_w - C'_\infty}$$
$$Gr = \frac{g\beta\nu\left(T'_w - T'_\infty\right)}{U_0^3}, \qquad Gm = \frac{\beta' g\nu\left(C'_w - C'_\infty\right)}{U_0^3}, \qquad \lambda = \frac{3N+4}{3N}$$
$$\Pr = \frac{\mu C_p}{k}, \quad Sc = \frac{\nu}{D}, \quad K^2 = \frac{\nu\Omega}{U_0^2}, \qquad Kr = \frac{Kr'\nu}{U_0^2}, \quad M^2 = \frac{\sigma B_0^2 \nu}{\rho U_0^2} \qquad (6)$$
$$K_1 = \frac{K_1' U_0^2}{\nu^2}, \qquad N = \frac{kk_1}{4\sigma_1 T_\infty'^3}, \qquad U = \frac{U_0^3}{\nu}, \qquad \omega = \frac{\nu\omega'}{U^2}$$

where $Gr, Gm, M^2, K_1, \Pr, Sc, K^2$ and Q are, respectively, the thermal Grashof number, the solutal Grashof number, the magnetic parameter, Permeability parameter, the Prandtl number, the Schmidt number,, the Soret number, the rotation parameter and heat source parameter.
Using (6) into (1) to (4) yield the following

$$\frac{\partial u}{\partial t} + 2K^2 w = \frac{\partial^2 u}{\partial y^2} - \frac{M^2}{1+m^2}\left(u + mw\right) + Gr\,\theta + Gm\,\phi - \frac{u}{K_1} \qquad (7)$$
$$\frac{\partial w}{\partial t} + 2K^2 u = \frac{\partial^2 w}{\partial y^2} + \frac{M^2}{\left(1+m^2\right)}\left(mu - w\right) - \frac{w}{K_1} \qquad (8)$$
$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2} - \frac{N}{\Pr}\theta \qquad (9)$$
$$\frac{\partial \phi}{\partial t} = \frac{1}{Sc}\frac{\partial^2 \phi}{\partial y^2} - Kr\,\phi \qquad (10)$$

The relevant initial and boundary conditions in non- dimensional form are given by

$$u = w = 0, \theta = 0, \phi = 0 \quad \text{for all} \quad y \quad \text{and } t \le 0$$
$$u = t, w = 0, \theta = 1, \phi = 1 \quad \text{at} \quad y = 0 \quad \text{and } t > 0 \qquad (11)$$
$$u \to 0,\ w \to 0,\ \theta \to 0_\infty, \quad \phi \to 0 \ \ as\ \ y \to \infty \text{ for } t > 0$$

Equations (7) and (8) are presented, in complex form, as

$$\frac{\partial F}{\partial t} = \frac{\partial^2 F}{\partial y^2} - \alpha F + Gr\,\theta + Gm\,\phi \qquad (12)$$

where $F = u + iv$ and $\alpha = \dfrac{M^2(1-im)}{1+m^2} + \dfrac{1}{K_1 - 2iK^2}$

The initial and boundary conditions (11) in compact form, become

$$F = 0, \theta = 0, \phi = 0 \quad \text{for all} \quad y \quad \text{and } t \le 0$$
$$F = t, \theta = 1, \phi = 1 \quad \text{at} \quad y = 0 \quad \text{and } t > 0 \qquad (13)$$
$$F \to 0, \quad \theta \to 0_\infty, \quad \phi \to 0 \quad as\ \ y \to \infty \text{ for } t > 0$$

The system of differential Equations (9), (10) and (12) together with the initial and boundary conditions (13) describes our model for the MHD free convective heat and mass transfer flow of a viscous, incompressible, electrically conducting fluid past an infinite vertical plate embedded in a porous medium taking Hall current, rotation and Soret effect into consideration.

METHOD OF SOLUTION

In order to reduce the above system of partial differential equations (9), (10) and (12) under the boundary conditions given equations (13) we assume in complex form the solution of the problems as

$$\begin{aligned} F(y,t) &= F_0(y)\, e^{i\omega t} \\ \theta(y,t) &= \theta_0(y)\, e^{i\omega t} \\ \phi(y,t) &= \phi_0(y) e^{i\omega t} \end{aligned} \qquad (14)$$

Substitute equation (14) in to the equations (9), (10) and (12) the set of ordinary differential equations are the following form

$$F_0'' - (i\omega + \alpha) F_0 = -Gr\theta_0 - Gm\phi_0 \qquad (15)$$

$$\theta_0'' - (i\omega + N)\Pr\theta_0 = 0 \qquad (16)$$

$$\phi_0'' - (i\omega + Kr) Sc\,\phi_0 = 0 \qquad (17)$$

The initial and boundary conditions (13) in compact form, become

$$\begin{aligned} &F = 0, \theta = 0, \phi = 0 && \text{for all } y \text{ and } t \le 0 \\ &F_0 = t, \theta_0 = 1, \phi_0 = 1 && \text{at } y = 0 \text{ and } t > 0 \\ &F_0 \to 0,\ \theta_0 \to 0_\infty,\ \phi_0 \to 0 && as\ y \to \infty \text{ for } t > 0 \end{aligned} \qquad (18)$$

The exact solution for the fluid temperature $\theta(y,t)$, species concentration $\phi(y,t)$ and fluid velocity $F(y,t)$ are obtained under the boundary conditions of (18) and expressed from equations from (15) - (17) in the following form:

$$F(y,t) = \left(L_1 + L_2\, e^{-\sqrt{KrSc}\, y} + L_3\, e^{-\sqrt{\alpha}\, y}\right) e^{i\omega t}$$

$$\theta(y,t) = e^{i\omega t}$$

$$\phi(y,t) = \left(e^{-\sqrt{Kr\ Sc}\ y}\right) e^{i\omega t}$$

Skin-friction

$$\left(\frac{\partial F}{\partial y}\right)_{y=0} = -\left(L_1 \sqrt{KrSc} + L_3\alpha\right)\cos\omega t$$

Sherwood number

$$\left(\frac{\partial \phi}{\partial y}\right)_{y=0} = -\left(\sqrt{Kr\ Sc}\right)\cos\omega t$$

RESULTS AND DISCUSSION

The variations of the velocity profiles with Grashof number and thermal Grashof number are shown in figure (2) and (3), the velocity increases with increasing Grashof number and thermal Grashof number. The maximum of the velocity profiles shifts towards right half of the plate due to the grater buoyancy force in this part of the plate due to the presence of hotter plate. Figure (4) shows the variation of velocity profiles under the influence of the rotation parameter. The velocity increases when rotation parameter increased. The variation of the velocity with permeability of the porous medium is shown in figure (5). It is observed from figure (5) that in rotating plate the velocity increases with increasing permeability of the porous medium. It is expected physically also because the resistance posed by the porous medium to the decelerated flow due to rotation reduces with increasing permeability which lead to decrease in the velocity. Figure (6) demonstrate the influence of chemical reaction parameter on the variations of fluid velocity respectively. As can be seen, an increase in the chemical reaction parameter leads to an increase in the thickness of the velocity boundary layer; this shows that diffusion rate can be tremendously altered by chemical reaction. A temporal maximum of velocity profiles is clearly seen for increasing values of chemical reaction parameter. It should be mentioned here that physically positive values of chemical reaction parameter imply destructive reaction and negative values of chemical reaction parameter imply generative reaction. Figure (7) displays the effect of Hall current on the variations of velocity. It is evident from this figure that the velocity increases with increasing of Hall current parameter. This implies that Hall current tends to accelerate the fluid flow directions throughout the boundary layer region. The variation of velocity profiles with radiation parameter is shown in figure (8). The velocity decreases with increase of radiation parameter. The influences of the Schmidt number Sc on concentration profiles are plotted in figures (9) respectively. It is noticed decrease the concentration on increasing Sc. The Schmidt number embodies the ratio of the momentum to the mass diffusivity. The Schmidt number therefore quantifies the relative effectiveness of momentum and mass transport by diffusion in the hydrodynamic concentration (species) boundary layers. As the Schmidt number increases the concentration decreases. This causes the concentration buoyancy effects to decrease yielding a reduction in the fluid velocity. The reductions in the velocity and concentration profiles are accompanied by simultaneous reductions in the velocity and concentration boundary layers. The temperature profiles for peclet number and radiation parameter are shown in figure (10) and (11). It is interesting to note that the flow of heat decreases with increasing peclet and radiation parameter. The influences of the Schmidt number Sc on concentration profiles are plotted in figures (12) respectively. It is noticed decrease the concentration on increasing Sc. The Schmidt number embodies the ratio of the momentum to the mass diffusivity. The Schmidt number therefore quantifies the relative effectiveness of momentum and mass transport by diffusion in the hydrodynamic concentration (species) boundary layers. As the Schmidt number increases the concentration decreases. This causes the concentration buoyancy effects to decrease yielding a reduction in the fluid velocity. The reductions in the velocity and concentration profiles are accompanied by simultaneous reductions in the velocity and concentration boundary layers. Figure (13) shows the influence of a chemical reaction on concentration profiles. In this study, we are analyzing the effects of a destructive chemical reaction parameter. It is noticed that concentration distribution decrease when the chemical reaction increases. Physically, for a destructive case, chemical reaction takes place with many disturbances. This, in turn, causes high molecular motion, which results in an increase in the transport phenomenon, thereby reducing the concentration distribution in the fluid flow.

REFERENCES

1. P. Ramesh Babu, G. Balreddy, D. Chenna Kesavaiah, Lavanya Srinathuni (2024): Variable temperature, radiation absorption and chemical reaction effects on unsteady MHD flow through porous medium past an oscillating inclined plate, Journal of Computational Analysis and Applications, Vol. 33 (2), pp. 925-941
2. G. Balreddy, Y. V. Seshagiri Rao, D. Chenna Kesavaiah, Lavanya Srinathuni (2024): Radiation absorption and chemical reaction effects on MHD flow through porous

medium past an Exponentially accelerated inclined plate with variable temperature, Nanotechnology Perceptions, Vol. 20 (3), pp. 346–362

3. D. Chenna Kesavaiah, B Venkateswarlu, N. Nagendra and O.D. Makinde (2024): Magneto-Compound Reaction of Convective Flow via a Porous Inclined Plate with Heat Energy Absorption, Journal of Nonlinear Modeling and Analysis, Vol. 6 (1), pp. 88–106
4. Damala Chenna Kesavaiah, Vellanki Nagaraju, Bhumarapu Venkateswarlu (2023): Investigating the Influence of Chemical Reaction on MHD-Casson Nanofluid Flow via a Porous Stretching Sheet with Suction/Injection, Science, Engineering and Technology, Vol.3, No.2, pp. 47-62
5. K. Venugopal Reddy, B. Venkateswarlu, D. Chenna Kesavaiah, N. Nagendra (2023): Electro-Osmotic Flow of MHD Jeffrey Fluid in a Rotating Microchannel by Peristalsis: Thermal Analysis, Science, Engineering and Technology, Vol. 3, No. 1, pp. 50-66
6. G. Balreddy, Y. V. Seshagiri Rao, D. Chenna Kesavaiah, Lavanya Srinathuni (2023): Effects of hall current and rotation, heat generation on MHD free convection heat and mass transfer flow past an accelerated vertical plate, Journal of Computational Analysis and Applications, Vol. 31 (4), pp. 775-789
7. P. Ramesh Babu, D. Chenna Kesavaiah, Y. V. Seshagiri Rao (2022): Chemical reaction and hall effects on unsteady flow past an isothermal vertical plate in a rotating fluid with variable mass diffusion with heat source, Eur. Chem. Bull. Vol. 11 (11), pp. 1432–1446
8. G. Balreddy, D. Chenna Kesavaiah, Y. V. Seshagiri Rao (2022): Analytical solution for transient free convection MHD flow through a porous medium between two vertical plates with heat source, Eur. Chem. Bull. Vol. 11(10), 653 –661
9. D. Chenna Kesavaiah, G. Rami Reddy, Y. V. Seshagiri Rao (2022): Impact of thermal diffusion and radiation effects on MHD flow of Walter's liquid model-B fluid with heat generation in the presence of chemical reaction, International Journal of Food and Nutritional Sciences, Vol. 11,(12), pp. 339- 359
10. D. Chenna Kesavaiah, G. Rami Reddy, G. Maruthi Prasada Rao (2022): Effect of viscous dissipation term in energy equation on MHD free convection flow past an exponentially accelerated vertical plate with variable temperature and heat source, International Journal of Food and Nutritional Sciences, Vol. 11,(12), pp. 165- 183
11. Dr. Pamita, D. Chenna Kesavaiah, Dr. S. Ramakrishna (2022): Chemical reaction and Radiation effects on magnetohydrodynamic convective flow in porous medium with heat generation, International Journal of Food and Nutritional Sciences, Vol. 11, (S Iss 3), pp. 4715- 4733
12. Chenna Kesavaiah DAMALA, Venkateswarlu BHUMARAPU, Oluwole Daniel MAKINDE (2021): Radiative MHD Walter's Liquid-B Flow Past a Semi-Infinite Vertical Plate in the Presence of Viscous Dissipation with a Heat Source, Engineering Transactions, Vol. 69(4), pp. 373–401
13. G Rami Reddy , D Chenna Kesavaiah , Venkata Ramana Musala and G Bkaskara Reddy (2021): Hall Effect on MHD Flow of a Visco-Elastic Fluid through Porous Medium Over an Infinite Vertical Porous Plate with Heat Source, Indian Journal of Natural Sciences, Vol. 12 (68), pp. 34975-34987
14. D Chenna Kesavaiah, T. Ramakrishna Goud, Y. V. Seshagiri Rao, Nookala Venu (2019): Radiation effect to MHD oscillatory flow in a channel filled through a porous medium with heat generation, Journal of Mathematical Control Science and Applications, Vol. 5 (2), pp. 71-80

15. B Mallikarjuna Reddy, D Chenna Kesavaiah and G V Ramana Reddy (2018): Effects of radiation and thermal diffusion on MHD heat transfer flow of a dusty viscoelastic fluid between two moving parallel plates, ARPN Journal of Engineering and Applied Sciences, Vol. 13 (22), pp. 8863-8872
16. D Chenna Kesavaiah and R S Jahagirdar (2018): MHD Free Convective Flow through Porous Medium under the Effects of Radiation and Chemical reaction, Journal of Applied Science and Computations, Vol. 5 (10), pp. 1125-1140
17. Rajaiah M, Sudhakaraiah A, Venkatalakshmi P and Sivaiah M. Unsteady MHD free convective fluid flow past a vertical porous plate with Ohmic heating In the presence of suction or injection, International Journal of Mathematics and Computer Research, 2014; 2 (5): 428-453
18. D Chenna Kesavaiah, T Ramakrishna Goud, Nookala Venu, Y V Seshagiri Rao (2017): Analytical study on induced magnetic field with radiating fluid over a porous vertical plate with heat generation, Journal of Mathematical Control Science and Applications, Vol. 3 (2), pp. 113-126
19. Haranth Y and Sudhakaraiah A. Viscosity and Soret effects on unsteady hydromagnetic gas flow along an inclined plane, International Journal of Science and Research, 2015; 4 (2): 2650-2654
20. D Chenna Kesavaiah, T. Ramakrishna Goud, Nookala Venu, Y V Seshagiri Rao (2021): MHD effect on convective flow of dusty viscous fluid with fraction in a porous medium and heat generation, Journal of Mathematical Control Science and Applications, Vol. 7 (2), pp. 393-404
21. Haranth Y and Sudhakaraiah A. Viscosity and Soret effects on unsteady hydromagnetic gas flow along an inclined plane, International Journal of Science and Research, 2015; 4 (2): 2650-2654
22. D Chenna Kesavaiah and B Venkateswarlu (2020): Chemical reaction and radiation absorption effects on convective flows past a porous vertical wavy channel with travelling thermal waves, International Journal of Fluid Mechanics Research, Vol. 47 (2), pp. 153-169
23. K. Ramesh Babu, D. Chenna Kesavaiah, B. Devika, Dr. Nookala Venu (2022): Radiation effect on MHD free convective heat absorbing Newtonian fluid with variable temperature, NeuroQuantology, Vol. 20 (20), pp. 1591-1599
24. G. Bal Reddy, D. Chenna Kesavaiah, G. Bhaskar Reddy, Dr. Nookala Venu (2022): A note on heat transfer of MHD Jeffrey fluid over a stretching vertical surface through porous plate, NEUROQUANTOLOGY, Vol. 20 (15), pp. 3472-3486
25. D Chenna Kesavaiah, G. Bhaskar Reddy, Anindhya Kiran, Dr. Nookala Venu (2022): MHD effect on boundary layer flow of an unsteady incompressible micropolar fluid over a stretching surface, NEUROQUANTOLOGY, Vol. 20 (8), pp. 9442-9452
26. Rajaiah M, Sudhakaraih A, Varma S V K, and Venkatalakshmi P. Chemical and Soret effect on MHD free convective flow past an accelerated vertical plate in presence of inclined magnetic field through porous medium. i-manager’s Journal on Mathematics, 2015; 4(1): 32-39
27. D Chenna Kesavaiah, P. Govinda Chowdary, G. Rami Reddy, Dr. Nookala Venu (2022): Radiation, radiation absorption, chemical reaction and hall effects on unsteady flow past an isothermal vertical plate in a rotating fluid with variable mass diffusion with heat source, NEUROQUANTOLOGY, Vol. 20 (11), pp. 800-815
28. Srinathuni Lavanya, D Chenna Kesavaiah (2014): Radiation and Soret Effects to MHD Flow in Vertical Surface with Chemical reaction and Heat generation through a Porous Medium, International Journal of Computational Engineering Research, Vol. 04 (7), pp. 62-73

29. Rajaiah M and Sudhakaraiah A. Unsteady MHD free convection flow past an accelerated vertical plate with chemical reaction and Ohmic heating, International Journal of Science and Research, 2015; 4 (2): 1503-1510
30. Srinathuni Lavanya, D Chenna Kesavaiah and A Sudhakaraiah (2014): Radiation, heat and mass transfer effects on magnetohydrodynamic unsteady free convective Walter's memory flow past a vertical plate with chemical reaction through a porous medium, International Journal of Physics and Mathematical Sciences, Vol. 4 (3), pp. 57-70
31. D. Chenna Kesavaiah, K. Ramakrishna Reddy, Ch. Shashi Kumar, M. Karuna Prasad (2022): Influence of joule heating and mass transfer effects on MHD mixed convection flow of chemically reacting fluid on a vertical surface, NeuroQuantology, Vol. 20 (20), pp. 786-803
32. Ch. Shashi Kumar, K. Ramesh Babu, M. Naresh, D. Chenna Kesavaiah, Dr. Nookala Venu (2023): Chemical reaction and Hall effects on unsteady flow past an isothermal vertical plate in a rotating fluid with variable mass diffusion, Eur. Chem. Bull. Vol. 12 (8), pp. 4991-5010
33. Anita Tuljappa, D. Chenna Kesavaiah, M. Karuna Prasad, Dr. V. Bharath Kumar (2023): Radiation absorption and chemical reaction effects on MHD free convection flow heat and mass transfer past an accelerated vertical plate, Eur. Chem. Bull. Vol. 12(1), pp. 618-632
34. D Ch Kesavaiah, P V Satyanarayana, J Gireesh Kumar and S Venkataramana (2012): Radiation and mass transfer effects on moving vertical plate with variable temperature and viscous Dissipation, International Journal of Mathematical Archive, Vol. 3 (8), pp. 3028-3035
35. G Rami Reddy , D Chenna Kesavaiah , Venkata Ramana Musala and G Bkaskara Reddy (2021): Hall Effect on MHD Flow of a Visco-Elastic Fluid through Porous Medium Over an Infinite Vertical Porous Plate with Heat Source, Indian Journal of Natural Sciences, Vol. 12 (68), pp. 34975-34987
36. D. Chenna Kesavaiah, Ch. Shashi Kumar, M. Chitra, Vuppala Lakshmi Narayana (2024): Viscous dissipation effect on steady free convective hydromagnetic heat transfer flow of a reactive viscous fluid in a bounded domain, African Journal of Biological Sciences, Vol. 6(Si4), pp. 4287-4295
37. Rajaiah M and Sudhakaraiah A. Radiation and Soret effect on Unsteady MHD flow past a parabolic started vertical plate in the presence of chemical reaction with magnetic dissipation through a porous medium, International Journal of Science and Research, 2015; 4 (2): 1608-1613
38. Cowling TG. Magnetohydrodynamics. New York: Interscience Publishers; 1957
39. Cramer KR, Pai SI. Magnetofluid dynamics for engineers and applied physicists. New York: McGraw Hill Book Company; 1973

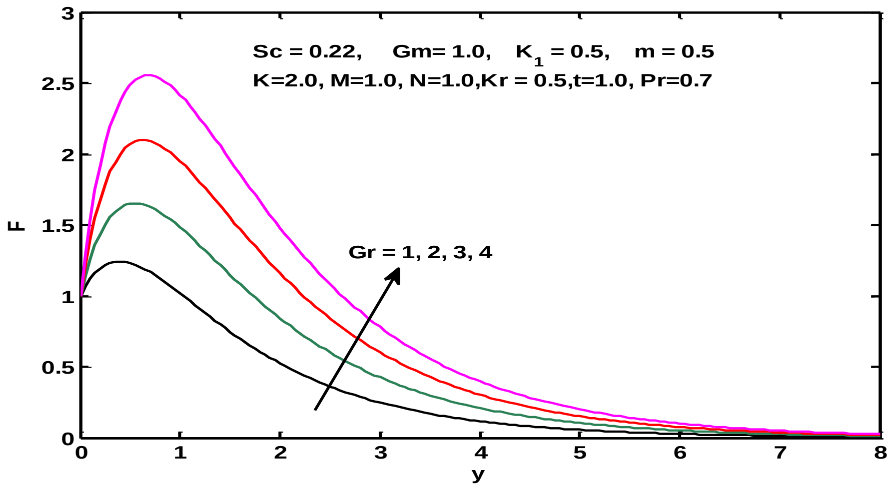

Figure (2): Variation of velocity profiles for Gr

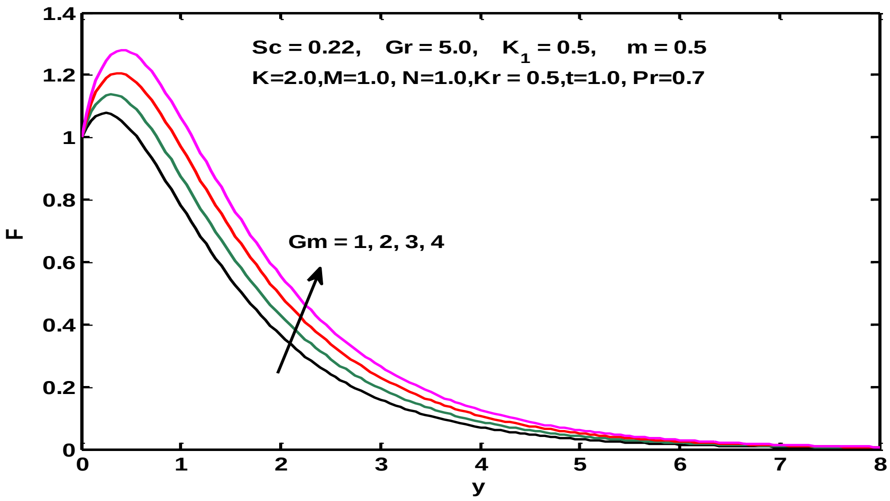

Figure (3): Variation of velocity profiles for Gm

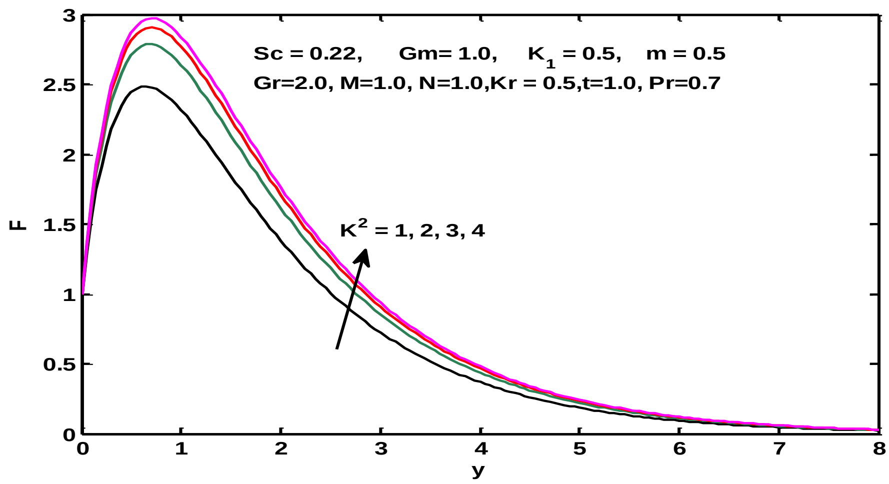

Figure (4): Variation of velocity profiles for K

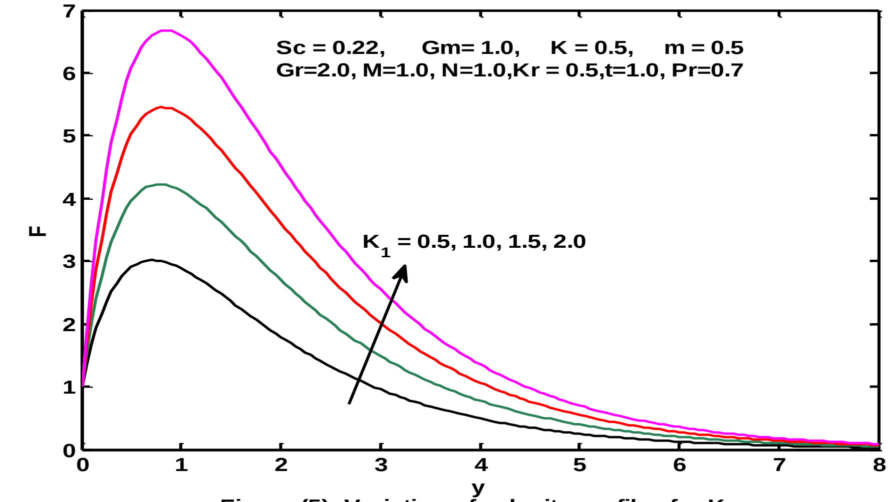

Figure (5): Variation of velocity profiles for K_1

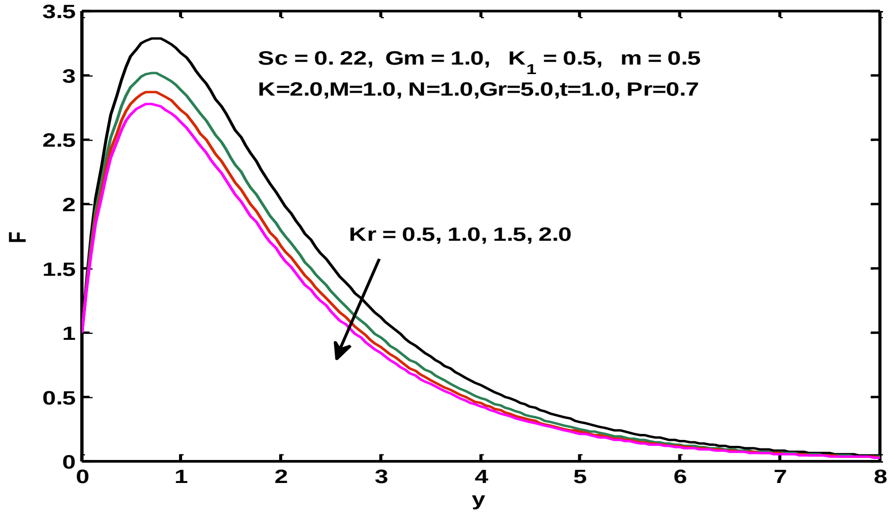

Figure (6): Variation of velocity profiles for Kr

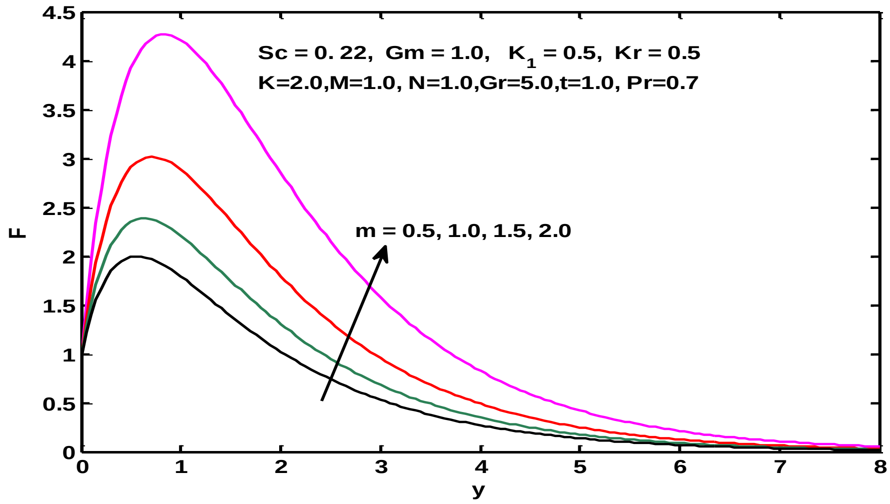

Figure (7): Variation of velocity profiles for m

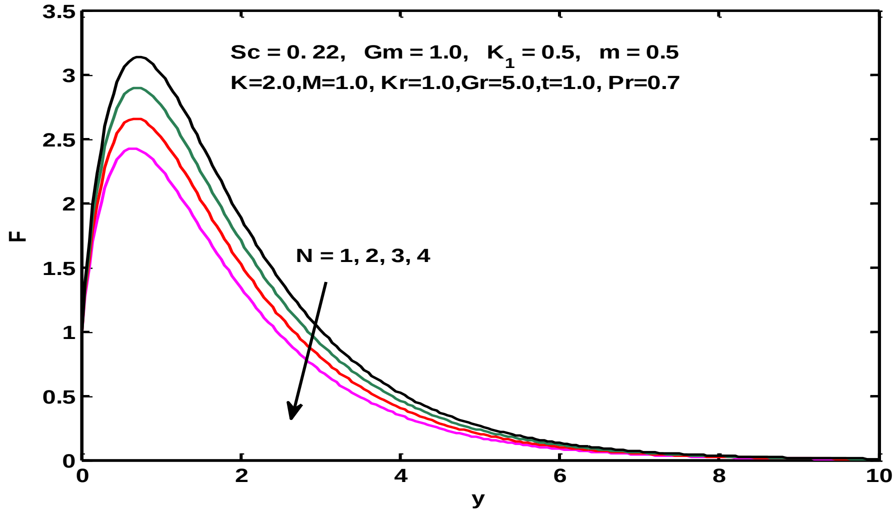

Figure (8): Variation of velocity profiles for N

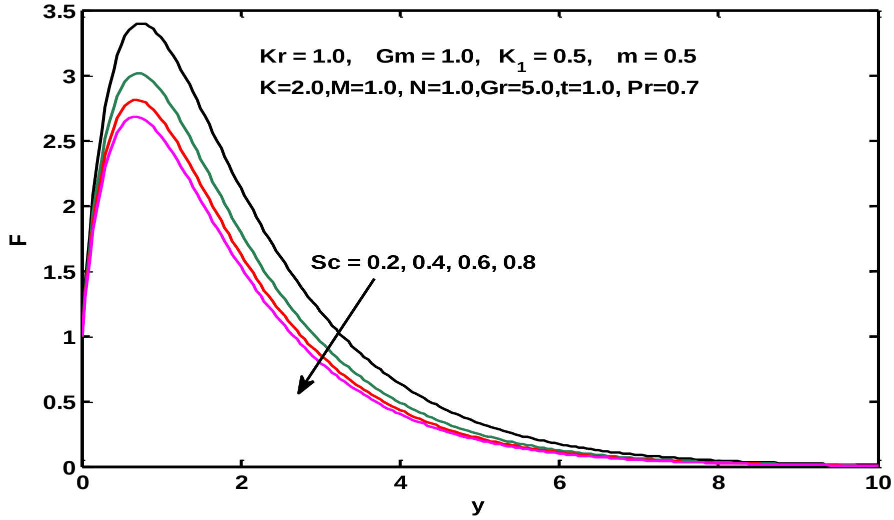

Figure (9): Variation of velocity profiles for Sc

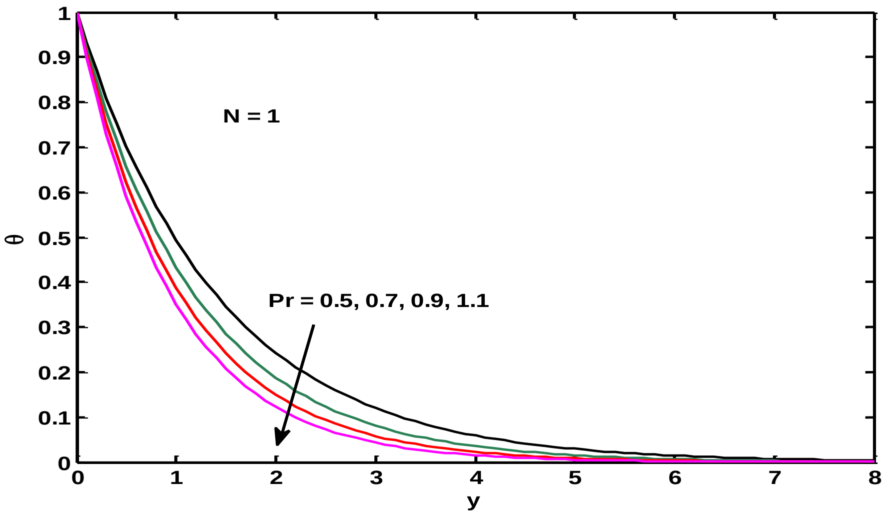

Figure (10): Variations of temperature profiles for Pr

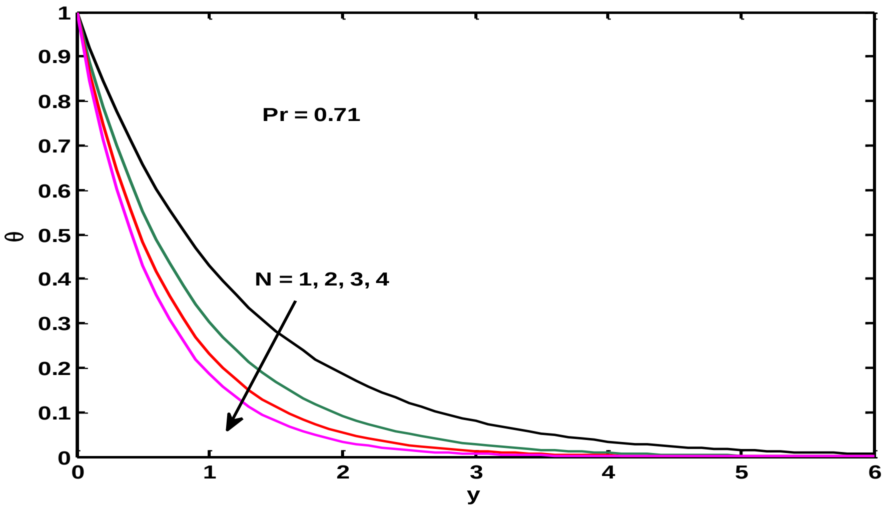

Figure (11): Variations of temperature profiles for N

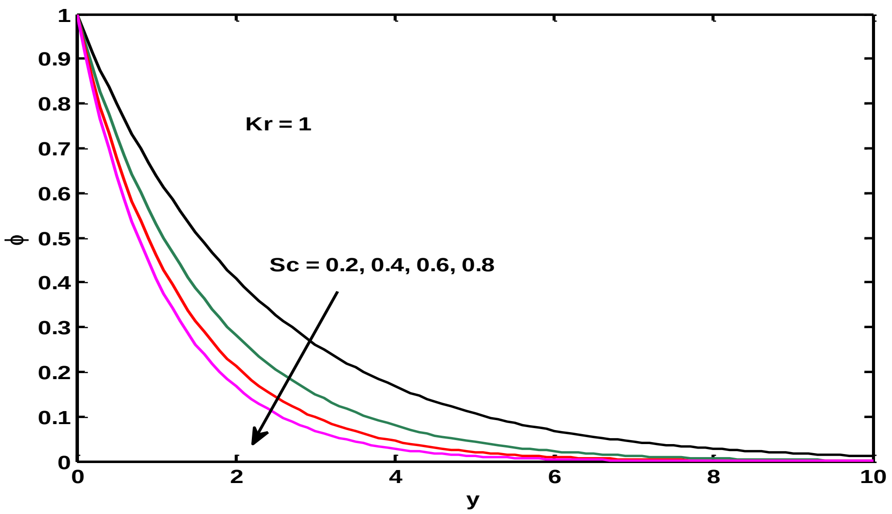

Figure (12): Variations of concentration profiles for Sc

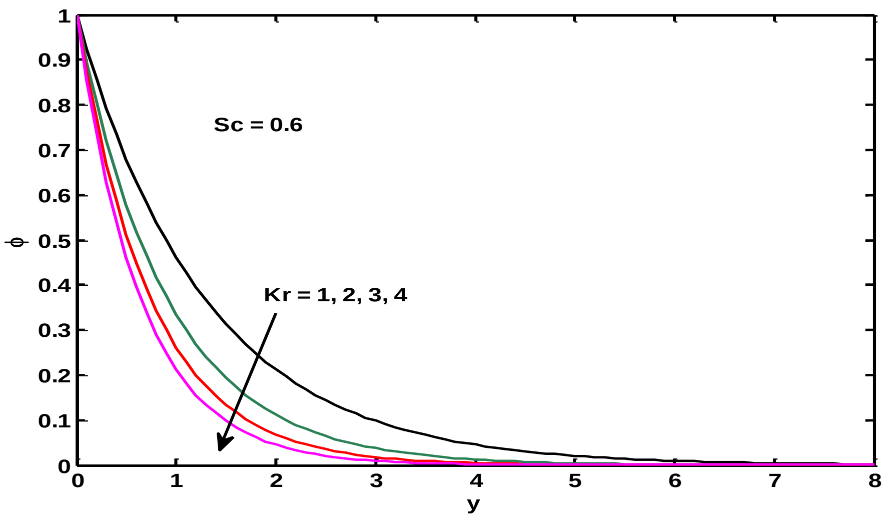

Figure (13): Variations of concentration profiles for Kr