HALL CURRENT, ROTATION AND CHEMICAL REACTION EFFECTS ON MHD FREE CONVECTION FLOW PAST AN ACCELERATED VERTICAL PLATE THROUGH A POROUS MEDIUM

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ABSTRACT

An investigation of unsteady hydromagnetic free convection flow of a viscous, incompressible and electrically conducting fluid past an infinite vertical embedded in a porous medium taking into an account of the Hall current is carried out. 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 governing partial differential equations are solved by perturbation method. 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*

INTRODUCTION

Theoretical/experimental investigation of hydrodynamic free convection flow from a solid body with different geometries embedded in a porous medium has received considerable attention during the past decades due to its varied and wide applications in several areas of science and technology such as geothermal reservoirs, thermal insulators, chemical catalytic reactors, grain storage, food processing, energy efficient drying of porous solids, heat exchanger devices, nuclear waste repositories, enhanced recovery of oil and gas, underground energy transport, etc. The most basic problem of natural convection in porous media is the boundary layer flow along a heated vertical flat plate embedded in a fluid – saturated porous medium which was investigated by comprehensive reviews of thermal convection in porous media are well presented in the form of books and monograms by Rami Reddy et. al. [3] expressed on Hall effect on MHD flow of a Visco-Elastic fluid through porous medium Over an infinite vertical porous plate with heat source, Nield and Bejan [4] studied convection in porous media, Ingham and Pop [5] has been considered transport phenomena in porous media, Vafai [6] wrote a book on Handbook of porous media, Pop and Ingham [7] expressed on convective heat transfer:

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mathematical and computational modelling of viscous fluids and porous media, Bhavana and Chenna Kesavaiah [8] explained perturbation solution for thermal diffusion and chemical reaction effects on MHD flow in vertical surface with heat generation.

An ionized fluid with low density is subjected to a strong magnetic field then the electrical conductivity normal to the magnetic field is lowered owing to free spiralling of electrons and ions about the magnetic lines of force prior to collision and a current is thereby generated which is mutually perpendicular to electric and magnetic fields. This current is known as Hall current. It plays an important role in determining flow features of the fluid flow problems because it induces secondary flow in the flow – field. In view of above some or the researchers are studied Ingham et. al. [9] expressed emerging technologies and techniques in porous media, Bejan et. al. [10] motivated study on porous and complex flow structures in modern technologies, Sherman and Sutton [11] Engineering Magnetohydrodynamics, Fife [12] demonstrated on Hybrid-PIC Modelling and electrostatic probe survey of Hall thrusters, Shang et. al. [13] communicated on mechanisms of plasma actuators for hypersonic flow control, Chenna Kesavaiah [14] shows radiative MHD Walter's Liquid-B flow past a semi-infinite vertical plate in the presence of viscous dissipation with a heat source, Kholshchevnikova [15] revealed influence of the Hall effect on the characteristics of a MHD generator with two pairs of electrodes, Michaeli [16] shows hall effect in superconducting films, Mallikarjuna Reddy et. al. [17] explained on radiation and diffusion thermo effects of viscoelastic fluid past a porous surface in the presence of magnetic field and chemical reaction with heat source.

In wholly the foregoing surveys, the Hall consequences are being disregarded. The attention of persistent fascinating terrain comprises the electro-magnetic forces together with Hall consequences might not be overlooked. As a matter of fact, Hall constraint is the proportion flanked by the cyclotron-electron periodicity and the atom-electron collision prevalence. The Hall property is noteworthy while the magnetic scope is drugged or whilst the impingement incidence is near to the ground. Besides the ions along with electron-emissive encompass dissimilar accumulations by reason of which thyself motions dispute. Customarily the electrons have superior dispersion velocity than with the intention of ions and as a primary proximity; dispersion speed of the electrons establishes the flow of charge compactness. While the electromagnetically forces are discernible, the dispersal velocity of the ions development is insignificant. As long as we believe the dispersal velocity of ions over and above such of electrons after that ions slip must not be overlooked. Hall possessions come across immense solicitations specifically when reviewed in conjunction with heat transport for instance refrigerator convolutes, MHD vulcanization accelerators, electrical charge manufacturers, etc. In view of the above applications Davidson [18] explained magnetohydrodynamics in materials processing, Hardianto et. al. [19] expressed computational study of diagonal channel

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magnetohydrodynamic power generation, Mathon et. al. [20] has been studied electro-chemical processes controlled by high magnetic fields: application to MHD sea water propulsion, Chenna Kesavaiah et. al. [21] motivated study on forced convective heat flow of a liquid for different depths of the channel with a constant heat source, Van Wie [22] revealed on future technologies – application of plasma devices for vehicle systems, Morley et. al. [23] has been considered thermo fluid magnetohydrodynamic issues for liquid breeders, Veera Krishna et. al. [24] shows on hall effects on unsteady magnetohydrodynamic flow of a Nanofluid past an Oscillatory vertical rotating flat plate embedded in porous media, Obulesu [25] expressed MHD heat and mass transfer steady flow of a convective fluid through a porous plate in the presence of multiple parameters, Srinathuni Lavanya and Chenna Kesavaiah [26] explained on heat transfer to MHD free convection flow of a viscoelastic dusty gas through a porous medium with chemical reaction, V Nagaraju et. al. [27] has been discussed radiation effects on MHD convective heat and mass transfer flow past a semi-infinite vertical moving porous plate in the presence of chemical reaction, V Nagaraju et. al. [28] investigated MHD Viscoelastic Fluid flow Past an Infinite Vertical Plate in the Presence of Radiation and Chemical Reaction. The same related investigations are studied by various authors from [29] to [35]

The objective of the present investigation is to study unsteady hydromagnetic free convection flow of an electrically conducting, viscous and incompressible fluid past a vertical plate embedded in a porous medium taking into account the effects of Hall current when the fluid flow is generated to impulsive movement of the vertical plate. According to the best of authors knowledge this problem has not yet received attention of researcher through it is significantly important in science and engineering.

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 law [1] 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.

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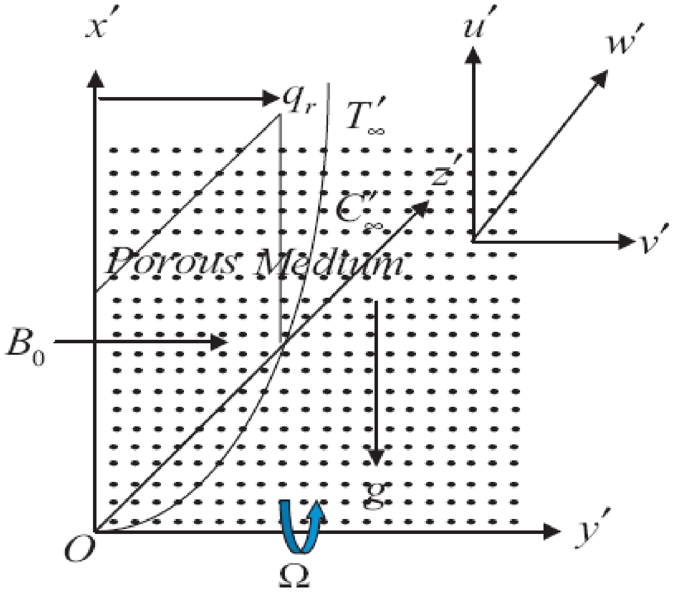

Figure (1): Geometry of the problem

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 [2]. 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.

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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 and chemical reaction effect into account, are given by

Conservation of momentum

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

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

Conservation of energy

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

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

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

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

The following dimensionless variables and parameters of the problem are

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

where $Gr, Gm, M, K_1, \Pr, Sc, K^2$ 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

$$\frac{\partial u}{\partial t}+2K^2w=\frac{\partial^2 u}{\partial y^2}-\frac{M^2}{1+m^2}\left(u+mw\right)+Gr\,\theta+Gm\,\phi-\frac{u}{K_1} \tag{7}$$

$$\frac{\partial w}{\partial t}+2K^2u=\frac{\partial^2 w}{\partial y^2}+\frac{M^2}{\left(1+m^2\right)}\left(mu-w\right)-\frac{w}{K_1} \tag{8}$$

$$\frac{\partial \theta}{\partial t}=\frac{1}{\Pr}\frac{\partial^2\theta}{\partial y^2} \tag{9}$$

$$\frac{\partial \phi}{\partial t}=\frac{1}{Sc}\frac{\partial^2\phi}{\partial y^2}-Kr\,\phi \tag{10}$$

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

$$\begin{aligned} &u=w=0, \theta=0, \phi=0 && \text{for all } y \text{ and } t\le 0\\ &u=t, w=0, \theta=1, \phi=1 && \text{at } y=0 \text{ and } t>0\\ &u\to 0,\; w\to 0,\; \theta\to 0_\infty,\; \phi\to 0 \;\; as\;\; y\to\infty && \text{for } t>0 \end{aligned} \tag{11}$$

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

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

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

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$$
\begin{aligned}
&F=0,\theta=0,\phi=0 && \text{for all } y \text{ and } t\le 0\\
&F=t,\theta=1,\phi=1 && \text{at } y=0 \text{ and } t>0\\
&F\to 0,\ \theta\to 0_\infty,\ \phi\to 0 && as\ y\to\infty \text{ for } t>0
\end{aligned} \tag{13}
$$

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

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

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

$$F_0'' - i\omega\alpha F_0 = -Gr\theta_0 - Gm\phi_0 \tag{15}$$

$$\theta_0'' - i\omega \Pr \theta_0 = 0 \tag{16}$$

$$\phi_0'' - i\omega KrSc\,\phi_0 = 0 \tag{17}$$

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

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

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:

$$F(y,t)=\left(L_1+L_2\,e^{-\sqrt{KrSc}\,y}+L_3\,e^{-\sqrt{\alpha^2\omega^2}\,y}\right)e^{i\omega t}$$

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

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

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

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

Table (1): Skin friction

Gr	Gm	Sc	K^2	K_1	Kr	m	ω	t	τ_x	τ_z
5	5	0.2	5	0.5	1	0.5	5	0.5	–0.9358	0.3456
10	5	0.2	5	0.5	1	0.5	5	0.5	0.5558	1.1428
15	5	0.2	5	0.5	1	0.5	5	0.5	0.9567	2.1568
20	5	0.2	5	0.5	1	0.5	5	0.5	1.2564	2.3659

Table (2): Sherwood number

Sc	ω	t	Kr	Sh
0.2	5	0.5	1.0	0.967
0.4	5	0.5	1.0	1.368
0.6	5	0.5	1.0	1.675
0.8	5	0.5	1.0	1.934

RESULTS AND DISCUSSION

In order to analyze the effect of the thermal buoyancy force, magnetic field, Hall current, permeability of the medium, thermal diffusivity and time on the flow-filed solution of the compact velocity $F(y,t)$ depicted graphically versus the boundary layer coordinate y in **figures (2) – (8)** for various values of $Gr, Gm, K^2, K_1, Kr, m, Sc$. It is revealed from the Figs 2 to 9 that the compact fluid velocity attain maximum value near the surface of the plate and then decrease properly on increasing the boundary layer coordinate y to approach the free stream value. **Figures (2) – (3)** demonstrate the effects of the Grashof number, thermal Grashof number on the compact fluid velocity respectively. It is noticed from the compact velocity increase on increasing values of Gr, Gm represents the relative strength of the thermal buoyancy force to the viscous force, increases on increasing the strength of the thermal buoyancy force. **Figure (4)** illustrates the influence of the radiation parameter on the compact velocity.. It is evident from this figure that, compact velocity increases on increasing K^2 in the region away from the plate. This implies that rotation retards fluid flow in the flow direction in the boundary layer region. This may be attributed to the fact that when the frictional layer at the moving plate is suddenly set into the motion then the Coriolis force acts as a constraint in the main fluid flow. **Figure (5)** displays the effects of Hall current on the compact velocity. It is evident from this figure the velocity increase on increasing hall current. This implies that Hall current tends to accelerate the fluid flow in the compact velocity direction throughout the boundary layer region. **Figure (6)** shows the effect of the chemical reaction parameter on the compact velocity. It is clear that an increase of chemical reaction parameter the velocity decreases. The effect of the magnetic field on the compact velocity shown in **figure (7)**, it is seen that an increase in magnetic field the compact velocity increases. Due to this reason permeability of the medium tends to accelerate fluid velocity flow direction throughout the boundary layer region. The influences of the Schmidt number Sc on the compact velocity profiles are plotted in **figure (8)** respectively. It is noticed that decreases in the compact velocity on increasing Schmidt number. 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 (velocity). **Figure (9)** shows the influence of a chemical reaction parameter 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. The influences of the Schmidt number on concentration profiles are plotted in **figure (10)** 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 (11)** shows the temperature profiles against on Prandtl number, it is observed that an increasing Prandtl number the results were decreases.

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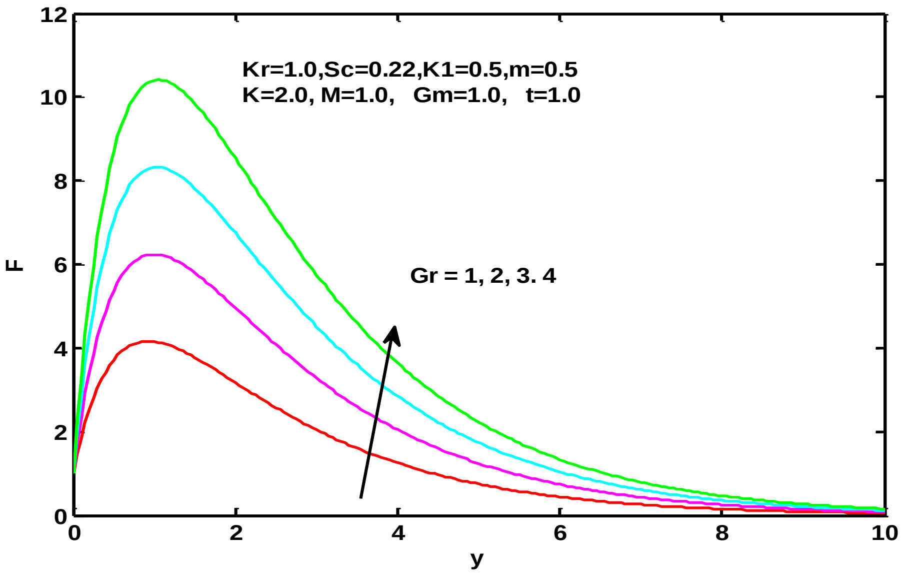

Figure (2): Compact velocity profiles for Gr

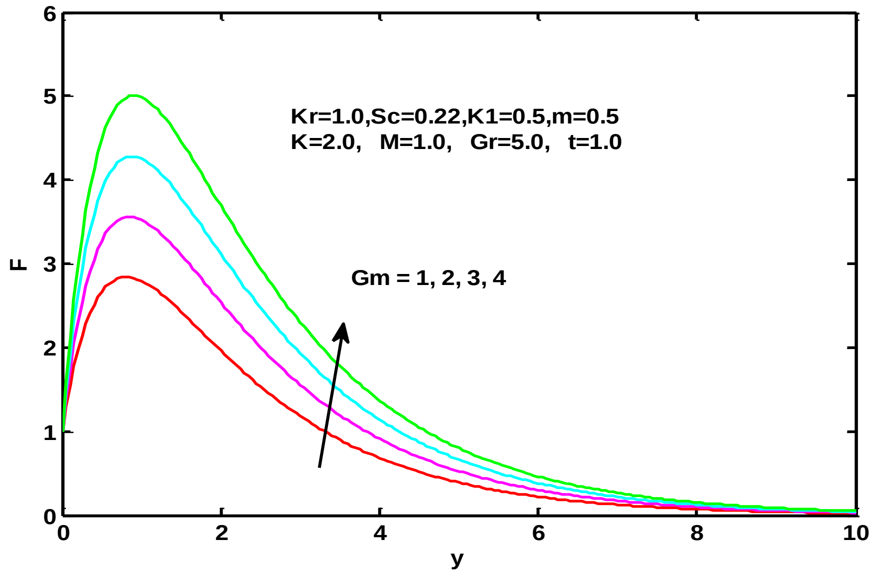

Figure (3): Compact velocity profiles for Gm

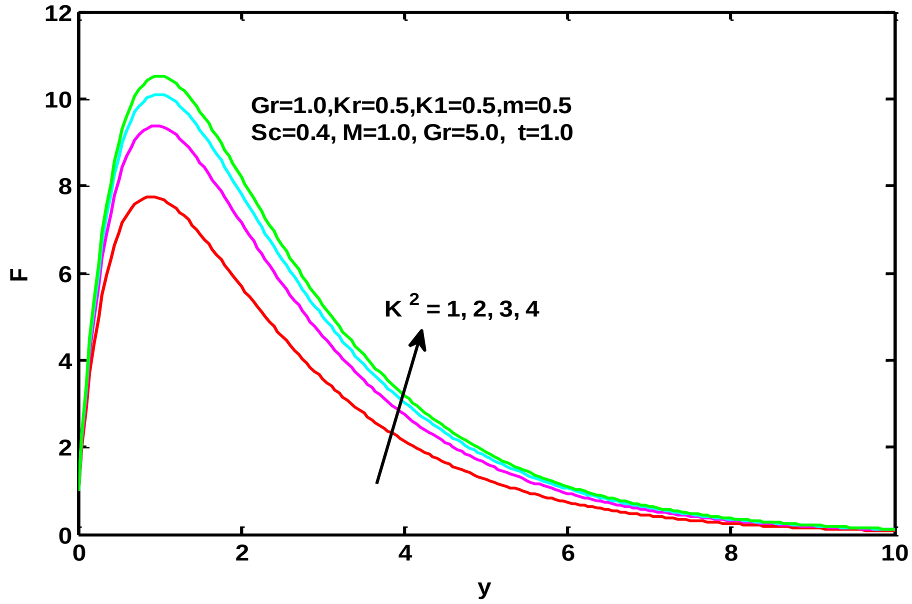

Figure (4): Compact velocity profiles for K^2

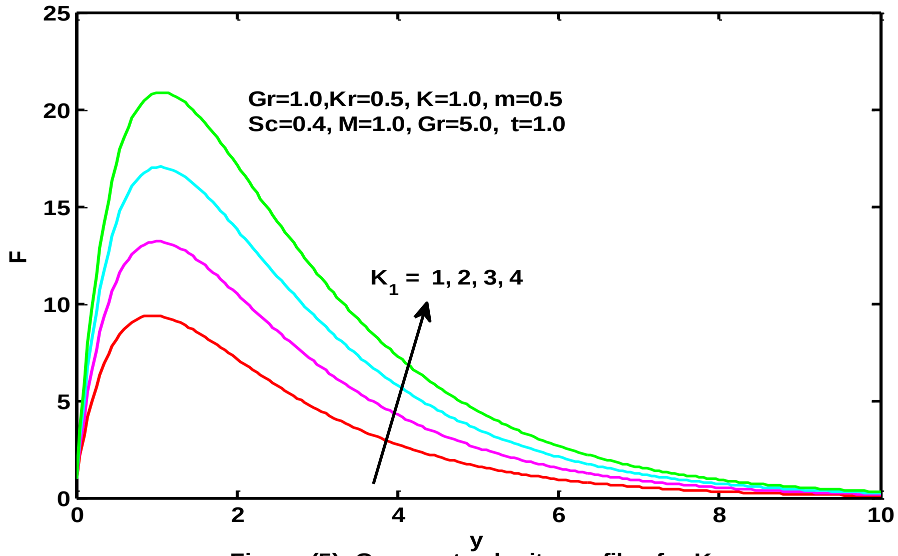

Figure (5): Compact velocity profiles for K_1

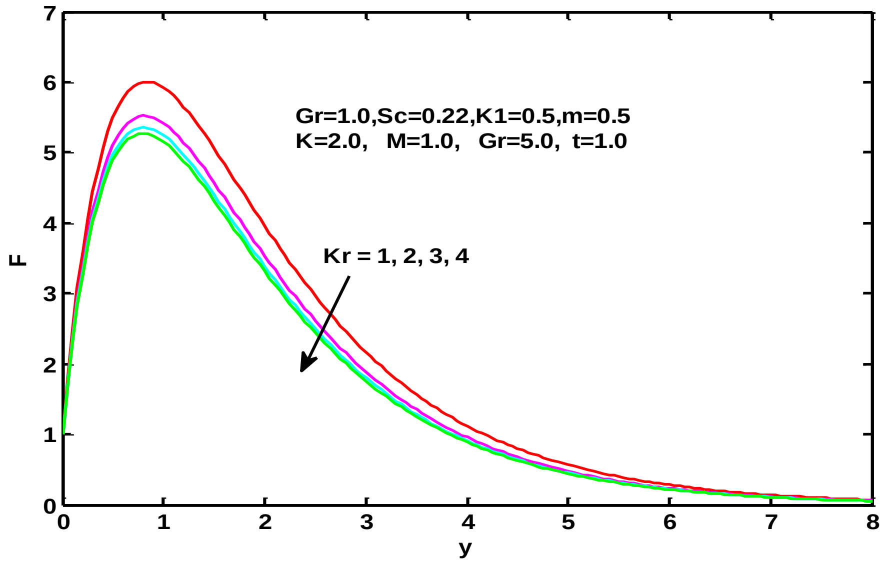

Figure (6): Compact velocity for Kr

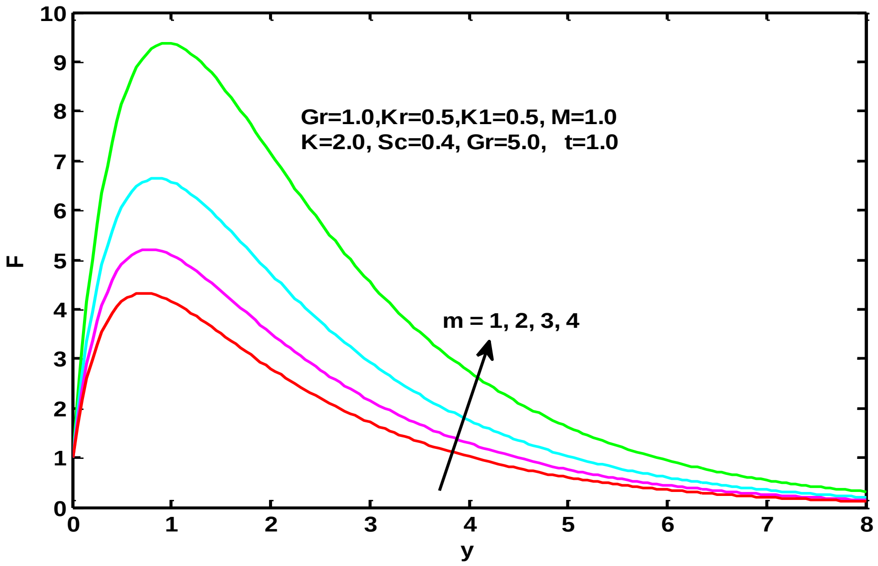

Figure (7): Compact velocity for m

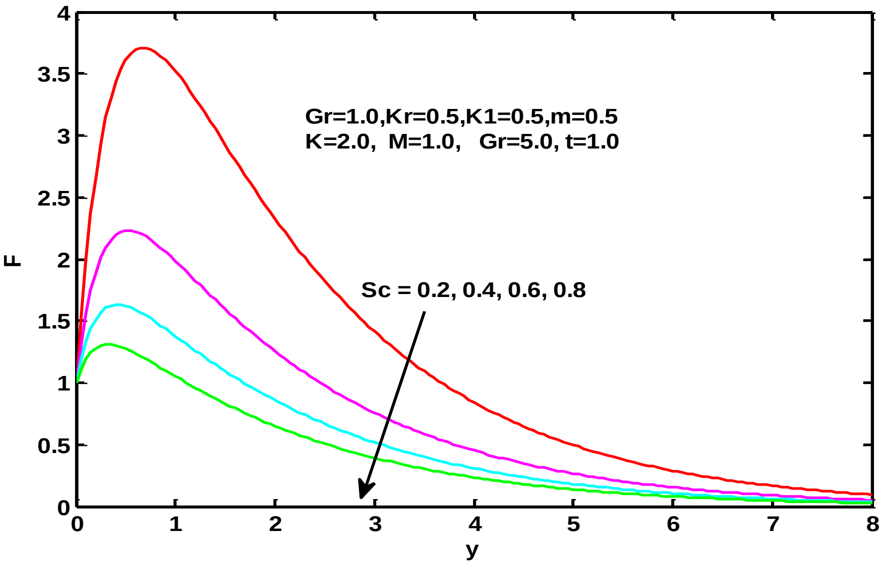

Figure (8): Compact velocity for Sc

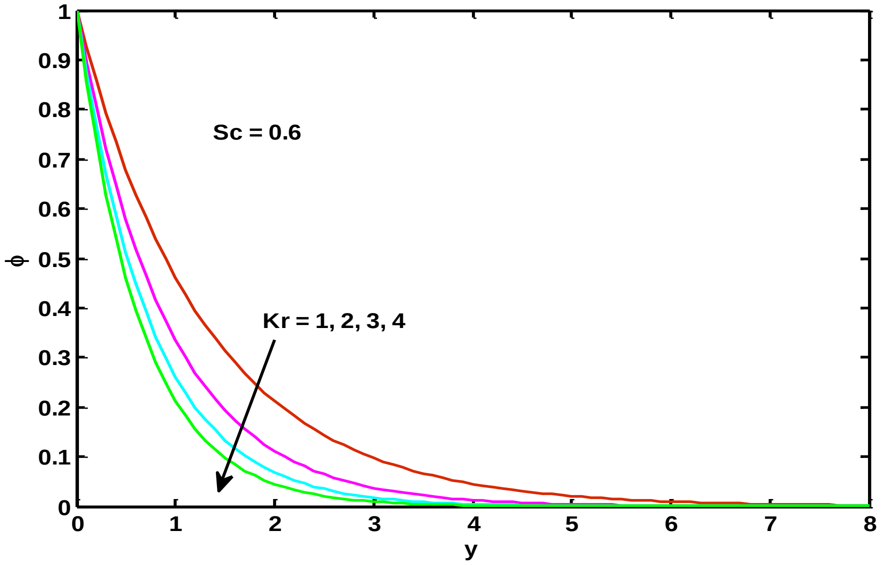

Figure (9): Concentration profiles for Kr

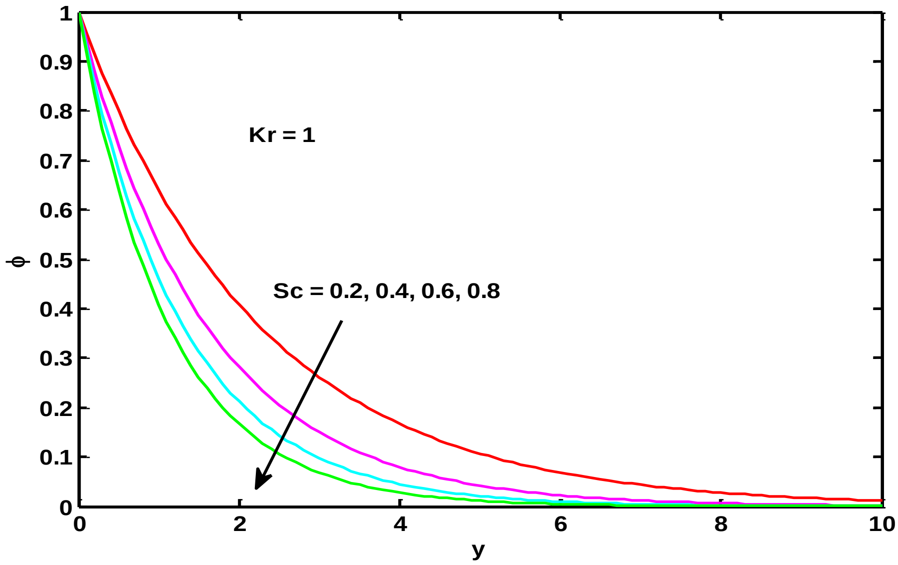

Figure (10): Concentration profiles for Sc

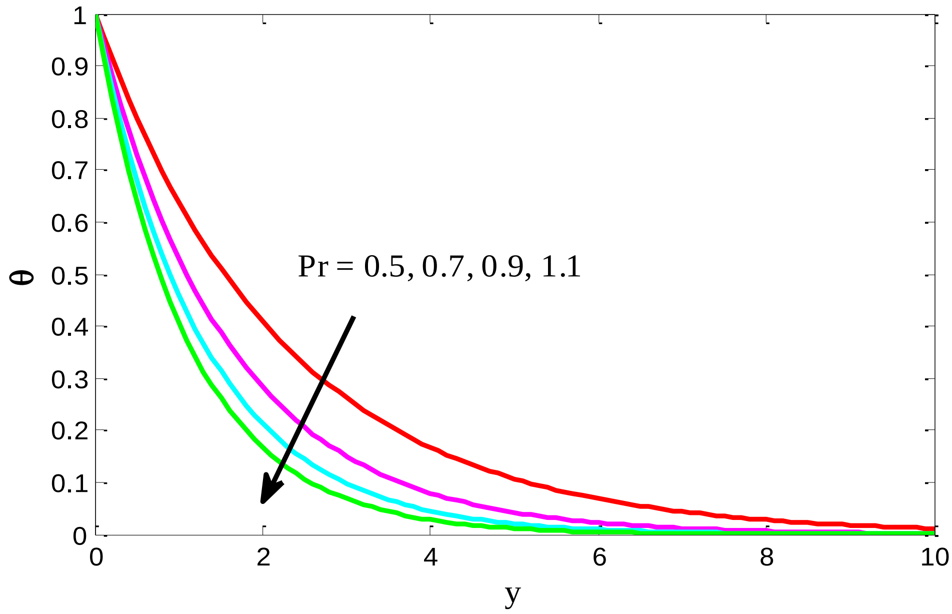

Figure (11): Temperature profiles for Pr

APPENDIX

$$m_2 = -\sqrt{i\omega \Pr}, m_4 = -\sqrt{iKrSc}, L_1 = -\frac{Gr}{m_2^2 - i\omega\alpha}, L_2 = -\frac{Gc}{m_4^2 - i\omega\alpha}, L_3 = \left(t - A_1 - A_2\right)$$

REFERENCES

1. Cowling TG. Magnetohydrodynamics. New York: *Inter Science Publishers*; 1957.
2. Cramer KR, Pai SI. Magnetofluid dynamics for engineers and applied physicists. New York: *McGraw Hill Book Company*; 1973.

3. 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
4. Nield D.A. and Bejan A. (2006): Convection in Porous Media, Third Ed., *Springer*. New York:
5. Ingham D.B. and Pop I. (2005): Transport Phenomena in Porous Media. – vol. III, *Elsevier, Oxford*. U. K.
6. Vafai K. (2005): Handbook of Porous Media. – Second Ed., *Taylor & Francis*, New York.
7. Pop I. and Ingham D.B. (2001): Convective Heat Transfer: Mathematical and Computational Modelling of Viscous Fluids and Porous Media, *Pergamon. Oxford,* U. K.
8. M Bhavana and D Chenna Kesavaiah (2018): Perturbation solution for thermal diffusion and chemical reaction effects on MHD flow in vertical surface with heat generation, *International Journal of Future Revolution in Computer Science & Communication Engineering, Vol. 4 (1), pp. 215-220*
9. Ingham D.B., Bejan A., Mamut E. and Pop I. (2004): Emerging Technologies and Techniques in Porous Media, *Kluwer, Dordrecht,* Netherlands.
10. Bejan A., Dincer I., Lorente S., Miguel A.F. and Reis A.H. (2004): Porous and Complex Flow Structures in Modern Technologies, *Springer,* New York.
11. Sherman A. and Sutton G.W. (2006): Engineering Magnetohydrodynamics. – New York: *Dover Pub Inc.*
12. Fife J. (1998): Hybrid-PIC Modelling and electrostatic probe survey of Hall thrusters. – PhD Thesis, *Department of Aeronautics and Astronautics, MIT,* USA.
13. Shang J.S., Surzhikov S.T., Kimmel R., Gaitonde D., Menart J. and Hayes J. (2005): Mechanisms of plasma actuators for hypersonic flow control. – *Prog. Aerosp. Sci*., Vol.41, pp 642–668.
14. 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
15. Kholshchevnikova E.K. (1966): Influence of the Hall effect on the characteristics of a MHD generator with two pairs of electrodes. – *J. Appl. Mech. Tech. Phys.*, vol.7, No.4, pp.48–54.

16. Michaeli K., Tikhonov K. S. and Finkel'stein A.M. (2012): Hall effect in superconducting films, *Physical Review*, B 86 014515.
17. B Mallikarjuna Reddy, D Chenna Kesavaiah and G V Ramana Reddy (2019): radiation and diffusion thermo effects of viscoelastic fluid past a porous surface in the presence of magnetic field and chemical reaction with heat source, *Asian Journal of Applied Sciences,* Vol. 7 (5), pp. 597-607
18. Davidson P.A. (1999): Magnetohydrodynamics in materials processing.– *Annual Review Fluid Mech*. Vol.31, pp.273–300.
19. Hardianto T., Sakamoto N. and Harada N. (2008): Computational study of diagonal channel magnetohydrodynamic power generation, *Int. J. Energy Technol. Policy*, Vol.6, pp.96–111.
20. Mathon Ph., Nouri A., Alemany A., Chopart J.P., Sobolik V. and Baaziz D. (2009): Electro-chemical processes controlled by high magnetic fields: application to MHD sea water propulsion.– Magnetohydrodynamics, Vol.45, pp.281–288.
21. D Chenna Kesavaiah, G Shanya Psalms and G Srujana (2019): Forced convective heat flow of a liquid for different depths of the channel with a constant heat source, *Adalya Journal,* Vol. 8 (7), pp. 15-22
22. Van Wie D.M. (2005): Future Technologies – Application of Plasma Devices for Vehicle Systems. – The Johns Hopkins University, *Applied Physics Laboratory – Laurel, Maryland,* USA – NATO Document.
23. Morley N.B., Malang S. and Kirillov I. (2005): Thermo fluid Magnetohydrodynamic issues for liquid breeders, *Fusion Sci. Tech.*, Vol.47, pp.488–501.
24. M. Veera Krishna, N. Ameer Ahamad, and Ali J. Chamkha (2021): Hall effects on unsteady magnetohydrodynamic flow of a Nanofluid past an Oscillatory vertical rotating flat plate embedded in porous media, *Journal of Nanofluids* Vol. 10, pp. 259–269,
25. Obulesu Mopuri, Charankumar Ganteda, Bhagyashree Mahanta, Giulio Lorenzini (2020): MHD heat and mass transfer steady flow of a convective fluid through a porous plate in the presence of multiple parameters, *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, Vol. 89 (2), pp. 56-75
26. Srinathuni Lavanya and D Chenna Kesavaiah (2017): Heat transfer to MHD free convection flow of a viscoelastic dusty gas through a porous medium with chemical reaction, *International Journal of Pure and Applied Researches,* Vol. 3 (1), pp. 43 – 56.
27. V Nagaraju, K Hemalatha and V Srihari Babu. (2018): Radiation effects on MHD convective heat and mass transfer flow past a semi-infinite vertical moving porous plate

in the presence of chemical reaction, *International journal of engineering sciences and research technology*, 7(8), pp. 146-161.

28. V Nagaraju, K Hemalatha and V Srihari Babu. (2019): MHD Viscoelastic Fluid flow Past an Infinite Vertical Plate in the Presence of Radiation and Chemical Reaction, *International Journal of Applied Engineering Research*, Volume 14(5), pp. 1062-1069.
29. Omeshwar Reddy V, Neelima A and Thiagarajan S. (2019). "Finite difference solutions of MHD natural convective Rivlin-ericksen fluid flow past a vertically inclined porous plate in presence of thermal diffusion, diffusion thermo, heat and mass transfer effects." *International Journal of Applied Engineering Research*, 14(3): 703-716.
30. Nagaraju V, Srihari Babu V and Srilakshmi Ch. (2022). "Numerical investigation of radiation effects on MHD convective heat and mass transfer flow past a semi-infinite vertical moving porous plate in the presence of chemical reaction." *International Journal for Research in Applied Science &* Engineering *Technology,* Vol. 10 (1): 1595-1607. https://doi.org/10.22214/ijraset.2022.40105.
31. V Sri Hari Babu, Nagaraju Vellanki, G Rami Reddy, V. Omeswar Reddy. (*2021*). **"**Radiation and chemical reaction effects on mhd rotating fluid past a moving vertical plate**."** *Journal of Mathematical Control Science and Applications***,** 7(2*): 301-312.*
32. NAGARAJU VELLANKI, Y.V. SESHAGIRI RAO, G. RAMI REDDY, V SRI HARI BABU. (2021). "Radiation effect on unsteady free convection oscillatory couette flow through a porous medium with periodic wall temperature and heat generation." *Journal of Mathematical Control Science and Applications*, Vol 7(2):269-283.
33. OMESHWAR REDDY V, Y.V. SESHAGIRI RAO, K. VENUGOPAL REDDY, SHIVALEELA G *(2021). "*Radiation and mass transfer effects on unsteady hydro magnetic free convection flow through porous medium past a vertical plate with heat flux." *Journal of Mathematical Control Science and Applications, 7(2): 285-299.*
34. Omeshwar reddy V, V.Nagaraju, Y.V. Seshagiri Rao. (2020). "Thermo diffusion, heat and mass transfer analysis of MHD viscoelasticf luid flow towards a vertically inclined plate by perturbation technique." *Journal of Mathematical Control Science and Applications,* Vol 6(2):151-164.
35. Nagaraju V,V Sri Hari Babu, G. Rami Reddy, Lakshmi Appidi. (2021). "A perturbation analysis for effects on chemical reaction and thermal radiation on temperature and concentration on MHD free convection flow past a vertical porous plate in the presence of and heat source parameter." *Journal of Mathematical Control Science and Applications*, 7(2):253-267.