International Journal For Advanced Research In Science & Technology
A peer reviewed international journal www.ijarst.in
ISSN: 2457-0362

Analysis of convection and mass transfer past moving surfaces of incompressible fluids under uniform magnetic fields with heat absorption

P. Satyanarayana Reddy
Assistant professor, Department of Mathematics BJR Government Degree College, Narayanaguda, Hyderabad

Abstract:
A theoretical analysis of unsteady free convective heat and mass transer flow past moving surface of an electrically conducting and viscous incompressible fluid under the influence of a uniform magnetic field with heat absroption is presented. The governing partial differential equations are reduced to a system of nonlinear ordinary differential equations and solved analytically using perturbation technique. The numerical results are presented graphically for different values of the parameters entering into the problem.
Keywords: Unsteady; heat and mass transer; uniform magnetic field; heat absroption.

1. INTRODUCTION:

As a consequence of non-homogeneous fields of volumetric forces such as Coriolis, MHD, gravitational, centrifugal, etc., natural or free convection occurs. Many researchers have examined this occurrence. Some of the many real-world contexts in which free or natural convection flow is useful include: cooling electronic equipment; geothermal systems; processing materials; designs related to thermal insulation; energy system security; atmospheric fluxes; air conditioning systems; etc. There is a vast array of practical uses for heat transfer mechanisms involving the motion of materials through fluids. Both temperature differences and concentration fluctuations contribute to the speed of some Earth flows. Buoyancy is particularly important in atmospheric research because differences in air and ground temperatures may lead to complicated flow patterns. The many industrial, scientific, and engineering processes that make use of free convection have piqued the attention of many theoretical models as well as experimental and practical components of studying the coupled transport of heat and mass. Newtonian and non-Newtonian fluids with elliptical, rectangular, cube, triangle, and circular geometries and a variety of boundary conditions have been addressed in the literature using computational, theoretical, and experimental methods. The flow of an electrically conducting fluid may be controlled by applying an external magnetic field. You may also adjust the pace of transmission. Many fields of study and technology have practical uses in industry, such as nuclear cooling reactors, plasma research, crystal growth, petroleum extraction, boundary layer control in aerodynamics, and many more. So, the study of the most broad settings of MHD, including the impact of an external magnetic field on electrically conduction fluid, has recently attracted fresh interest from academics.

From an engineering and industrial perspective, there are several practical applications of researching the Soret and Dufour effects along MHD flows when heat mass transfer happens simultaneously in moving fluids. These effects have received substantial attention from writers, and they include Hall accelerators and MHD power generators, among others. Kao et al. [1] investigated the reaction of a free convective flow to a flat plate with a temperature discontinuity on the wall and the solution heat transfer. For the evenly accelerated and impulsive motion of the plate, Rapits et al. [2] investigated the effect of a static moving magnetic field in an electrically conducting fluid. Research by Tokis et al. [3] examined the effects of a fluid-fixed, uniformly-moving magnetic field. After fully developed MHD free convective flow, Prasad et al. [4] examined the impacts of temperature transport characteristics, taking viscous and Ohmic dissipation into account. Using a lid-driven half annulus closure packed with Fe3O4-water Nanofluid, Sheikholeslami et al. [5] studied the forced convective heat transfer outcomes of a non-uniform magnetic field. Presumably, the fluid's magnetization varies linearly with the magnitude of both the temperature and the magnetic field. The numerical investigation of heat transfer and hydrodynamic properties in mixed convective nanofluid flows with sinusoidal walls subjected to a magnetic field was carried out by Rashidi et al. [6]. Using the spectrum relaxation approach, Shateyi et al. [7] investigated the natural convective heat mass transfer flow in a multi-harmonic heterogeneous (MHD) system subjected to thermal radiation and chemical reactions over a permeable moving vertical plate including a convective boundary state. Researchers Khadijah et al. [8] used ramping boundary flow, which is based on time-dependent magnetohydrodynamics, to examine normal convective viscous fluid in an annulus. Improved natural convective heat transmission is the goal of this investigation, which employs zigzag-shaped ribs placed on vertical, isothermal, heated surfaces. In their theoretical study, Ilias et al. [9] examined the nanofluid flow of an unstablely oriented MHD boundary layer heat transfer over an inclined plate on the inner edge. Unstable fourth-grade MHD fluid flow employing a Homotopy perturbation system under magnetic field and suction/injection action was investigated by Fenuga et al. [10] along with the mathematical model and its solution. In their study on the unsteady MHD flow, Prasad et al. [11] calculated the effects of heat radiation and absorption on a Kuvshinski fluid model including a chemical reaction in an aligned magnetic field. Effect of an aligned magnetic field on an upper convicted Maxwell fluid flowing over an inclined stretching sheet was studied by Bilal et al. [12].

In free convection, the only thing that happens is the movement of the fluid due to buoyancy, which is a way to transfer heat. The relevance of natural convections to engineering and the natural world has motivated several researchers to devote the last two decades to studying these phenomena. Ahmed [13] investigated the influence of radiation and Soret effects on transient magnetohydrodynamic free convection from an infinite vertical plate that was begun impulsively. The effects of thermal radiation on magnetohydrodynamic (MHD) flow, which include heat and mass transport of a micropolar fluid between two vertical walls, were studied by Patel [14]. Chemical processes were investigated by Reddy et al. [15] as they pertain to magnetohydrodynamic natural flow in a porous media via an exponentially stretched sheet, taking into account the existence of heat source/sink and viscous dissipation. Magnetohydrodynamic free convective flow in a channel filled with nanofluids was studied by Jha et al. [16] in relation to heat sources and sinks. Matta et al. [17] observed magnetohydrodynamic free convection flow around a semi-infinite moving vertical porous plate with a heat sink and chemical reaction, and they examined the impact of viscous dissipation on this flow. The effect of the Arrhenius activation energy on magnetohydrodynamic micropolar nanofluid flow via a porous stretched sheet was studied by Borah et al. [18], taking into account the viscous dissipation and the heat source. Akhtar et al. [19] investigated the effects of radiation and heat dissipation on magnetohydrodynamic convective flow with a heat sink.

This research work presents a theoretical analysis of unsteady free convective heat and mass transer flow past moving surface of an electrically conducting and viscous incompressible fluid under the influence of a uniform magnetic field with heat absroption. The governing partial differential equations are reduced to a system of nonlinear ordinary differential equations and solved analytically using perturbation technique. The numerical results are presented graphically for different values of the parameters entering into the problem.

2. MATHEMATICAL FORMULATION:

Our focus is on the unsteady two-dimensional flow of a laminar, incompressible, viscous, electrically conducting, and heat-absorbing fluid as it passes through a uniform porous medium embedded in a semi-infinite inclined moving surface with an acute angle to the vertical. This flow is subjected to a uniform transverse magnetic field and is accompanied by thermal and concentration buoyancy effects. We suppose that the flow is along the x-axis, which follows the semi-infinitely slanted sliding plate, and the y-axis, which is perpendicular to it. A uniformly strong magnetic field B0 is applied perpendicular to the flow direction.

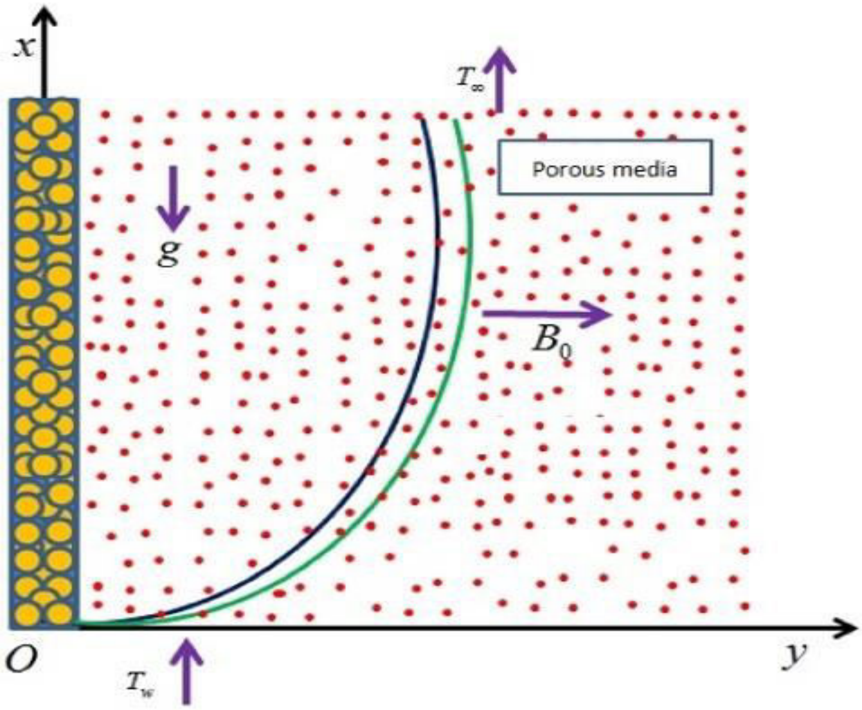

Fig.1: Flow geometry

Our presumptions are as follows:

1. The magnetic Reynolds number and transverse applied magnetic field are negligible.
2. There is almost no hall effect and generated magnetic field.
3. A constant velocity is maintained by the permeable inclined plate as it advances in the direction of fluid flow.

4. A minor perturbation law that increases exponentially is followed by the free stream velocity.
5. The suction velocity, wall concentration, and temperature all change exponentially with time.

The following cartesian formulation of the governing equations is possible in light of the assumptions given above:
:

$$\frac{\partial \upsilon^*}{\partial y^*}=0 \tag{1}$$

$$\frac{\partial u^*}{\partial t^*}+\upsilon^*\frac{\partial u^*}{\partial y^*}=-\frac{1}{\rho}\frac{\partial p^*}{\partial x^*}+\nu\frac{\partial^2 u^*}{\partial y^2}+g\beta_T(T-T_\infty)+g\beta_c(c-c_\infty)-\nu\frac{u^*}{K^*}-\frac{\sigma}{\rho}B_0^2u^* \tag{2}$$

$$\frac{\partial T}{\partial t^*}+\upsilon^*\frac{\partial T}{\partial y^*}=\alpha\frac{\partial^2 T}{\partial y^{*2}}-\frac{Q_0}{\rho c_p}(T-T_\infty) \tag{3}$$

$$\frac{\partial c}{\partial t^*}+\upsilon^*\frac{\partial c}{\partial y^*}=D\frac{\partial^2 c}{\partial y^{*2}} \tag{4}$$

This investigation looks just at the magnetic and viscous dissipations. The temperature and concentration buoyancy effects are denoted by the third and fourth components on the right side of the momentum equation (2), for example. Furthermore, the heat absorption effect is represented by the final part of the energy equation (3). It is appropriate to use the following boundary conditions on the fields of velocity, temperature, and concentration:

$$u^*=u_p^*,T=T_w+\varepsilon(T_w-T_\infty)e^{n^*t^*},c=c_w+\varepsilon(c_w-c_\infty)e^{n^*t^*}\ at\quad y^*=0 \tag{5}$$

$$u^*\to U_\infty^*=U_0(1+\varepsilon e^{n^*t^*}),T\ \to\ T_\infty,\quad c\to\ c_\infty\ as\quad y^*\to\ \infty \tag{6}$$

The suction velocity at the plate surface is clearly a function of time alone, as shown by Eq. (1). Accordingly, we think it has the following exponential shape.:

$$\upsilon^*=-V_0(1+\varepsilon Ae^{n^*t^*}) \tag{7}$$

where A is a real positive constant, ε and εA are small less than unity, and $V_0$is a scale suction velocity which has non-zero positive constant. Outside the boundary layer, Eq (2) gives

$$-\frac{1}{\rho}=\frac{\partial U_\infty^*}{\partial t^*}+\frac{\upsilon}{K^*}U_\infty^*+\frac{\sigma}{\rho}B_0^2U_\infty^* \tag{8}$$

It is convenient to employ the following dimensionless variables:

International Journal For Advanced Research In Science & Technology
A peer reviewed international journal www.ijarst.in
ISSN: 2457-0362

$$u=\frac{u^*}{U_0},\quad \upsilon=\frac{\upsilon^*}{V_0},\quad y=\frac{V_0 y^*}{\upsilon},\quad U_\infty=\frac{U_\infty^*}{U_0},\quad U_p=\frac{u_p^*}{U_0},\quad t=\frac{t^* V_0^2}{\upsilon},$$
$$\theta=\frac{T-T_\infty}{T_w-T_\infty},\quad C=\frac{c-c_\infty}{c_w-c_\infty},\quad n=\frac{n^*\upsilon}{V_0^2},\quad K=\frac{K^* V_0^2}{\upsilon^2},\quad \Pr=\frac{\upsilon\rho c_p}{k}=\frac{\upsilon}{\alpha},\tag{9}$$
$$Sc=\frac{\upsilon}{D},\quad M=\frac{\sigma\upsilon B_0^2}{\rho V_0^2},\quad Gr=\frac{\upsilon\beta_T g(T_w-T_\infty)}{U_0 V_0^2},\quad Gm=\frac{\upsilon\beta_c g(C_w-C_\infty)}{U_0 V_0^2},$$
$$S=\frac{\upsilon Q_0}{\rho c_p V_0^2}$$

In view of Eqs. (7)-(9), Eqs.(2)-(4) reduce to the following dimensionless form:

$$\frac{\partial u}{\partial t}-(1+\varepsilon Ae^{nt})\frac{\partial u}{\partial y}=\frac{\partial U_\infty}{\partial t}+\frac{\partial^2 u}{\partial y^2}+Gr\theta+GmC+N(U_\infty-u)\tag{10}$$

$$\frac{\partial \theta}{\partial t}-(1+\varepsilon Ae^{nt})\frac{\partial \theta}{\partial y}=\frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2}-S\theta\tag{11}$$

$$\frac{\partial C}{\partial t}-(1+\varepsilon Ae^{nt})\frac{\partial C}{\partial y}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}\tag{12}$$

Where $N=(M+\frac{1}{K})$,

The dimensionless form of the boundary conditions (5) and (6) become

$$u=U_p,\quad \theta=1+\varepsilon e^{nt},\quad C=1+\varepsilon e^{nt}\quad at\quad y=0\tag{13}$$

$$u\to U_\infty,\quad \theta\to 0,\quad C\to 0\quad as\quad y\to\infty\tag{14}$$

3.3. SOLUTION OF THE PROBLEM:

There is no closed form solution to the system of partial differential equations represented by Eqs. (10)–(12). But it simplifies to a system of analytically solvable ordinary differential equations in a dimensionless form. Three variables—velocity, temperature, and concentration—can be represented in this way:

$$\begin{aligned} u&=u_0(y)+\varepsilon e^{nt}u_1(y)+O(\varepsilon^2)+\cdots\\ \theta&=\theta_0(y)+\varepsilon e^{nt}\theta_1(y)+O(\varepsilon^2)+\cdots\\ C&=h_0(y)+\varepsilon e^{nt}h_1(y)+O(\varepsilon^2)+\cdots \end{aligned}\tag{15}$$

Substituting Eq. (1) in to Eqs. (10) – (12), equating the harmonic and non-harmonic terms, and neglecting the higher-order terms of $O(\varepsilon^2)$, one obtains the following pairs of equations for (u_0,θ_0,h_0) and (u_1,θ_1,h_1).

$$u_0''+u_0'-Nu_0=-Gr_1\theta_0-Gm_1C_0-N\tag{16}$$

$$u_1''+u_1'-(N+n)u_1=-Au_0'-n-N-Gr_1\theta_1-Gm_1C_1\tag{17}$$

$$\theta_0''+\Pr\theta_0'-S\Pr\theta_0=0\tag{18}$$

$$\theta_1'' + \Pr\theta_1' - (n+S)\Pr\theta_1 = -\Pr A\theta_0' \tag{19}$$

$$h_0'' + Sch_0' = 0 \tag{20}$$

$$h_1'' + Sch_1' - Scnh_1 = -ScAh_0' \tag{21}$$

Where a prime denotes ordinary differentiation with respect to y. The corresponding boundary conditions can be written as

$$\begin{gathered} u_0 = U_p,\quad u_1 = 0,\quad \theta_0 = 1,\quad \theta_1 = 1,\quad h_0 = 1,\quad h_1 = 1 \qquad at \quad y = 0 \\ u_0 = 1,\quad u_1 = 1,\quad \theta_0 \to 0,\quad \theta_1 \to 0,\quad h_0 \to 0,\quad h_1 \to 0 \quad as \quad y \to \infty \end{gathered} \tag{22}$$

Solutions of equations canbe shown to be:

$$u_0 = C_2 e^{-m_2 y} + C_3 e^{-Scy} + C_4 e^{-m_4 y} + 1 \tag{23}$$

$$u_1 = C_5 e^{-Scy} + C_6 e^{-m_1 y} + C_7 e^{-m_2 y} + C_8 e^{-m_3 y} + C_9 e^{-m_4 y} + C_{10} e^{-m_5 y} + 1 \tag{24}$$

$$\theta_0 = e^{-m_2 y} \tag{25}$$

$$\theta_1 = (1 - C_1)e^{-m_3 y} + C_1 e^{-m_2 y} \tag{26}$$

$$h_0 = e^{-Scy} \tag{27}$$

$$h_1 = e^{-m_1 y} + \frac{ASc}{n}\left(e^{-m_1 y} - e^{-Scy}\right) \tag{28}$$

In view of the above solutions, the velocity, temperature and concentration distributions in the boundary layer becomes

$$\begin{aligned} u(y,t) = (C_2 e^{-m_2 y} + C_3 e^{-Scy} + C_4 e^{-m_4 y} + 1) + \\ \varepsilon e^{nt}(C_5 e^{-Scy} + C_6 e^{-m_1 y} + C_7 e^{-m_2 y} + C_8 e^{-m_3 y} + C_9 e^{-m_4 y} + C_{10} e^{-m_5 y} + 1) \end{aligned} \tag{29}$$

$$\theta(y,t) = e^{-m_2 y} + \varepsilon e^{nt}\left((1 - C_1)e^{-m_3 y} + C_1 e^{-m_2 y}\right) \tag{30}$$

$$C(y,t) = e^{-Scy} + \varepsilon e^{nt}\left(e^{-m_1 y} + \frac{ASc}{n}\left(e^{-m_1 y} - e^{-Scy}\right)\right) \tag{21}$$

The skin-friction coefficient, the Nusselt number and the sherwood number are important physical parameters for this type of boundary-layer flow.

Skin-friction coefficient:

From velocity field, now, we study the skin-friction coefficient which is given in non-dimensional form as follows:

$$\begin{aligned} \tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} &= -m_2 C_2 - ScC_3 - m_4 C_4 \\ &+ \varepsilon e^{nt}(-ScC_5 - m_1 C_6 - m_2 C_7 - m_3 C_8 - m_4 C_9 - m_5 C_{10}) \end{aligned} \tag{22}$$

International Journal For Advanced Research In Science & Technology
A peer reviewed international journal
www.ijarst.in
ISSN: 2457-0362

Nusselt number:

From temperature field, now, we study the Nusselt number which is given in non-dimensional form as follows:

$$Nu = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} = -m_2 + \varepsilon e^{nt}(-m_2 C_1 - m_3 + m_3 C_1) \tag{23}$$

Sherwood number:

From concentration field, now we study Sherwood number which is given in non-dimensional form as follows:

$$Sh = \left(\frac{\partial C}{\partial y}\right)_{y=0} = -Sc + \varepsilon e^{nt}\left(-m_1 + \frac{ASc}{n}\left(-m_1 + Sc\right)\right) \tag{24}$$

4. RESULTS AND DISCUSSION:

The analytical findings mentioned earlier were subjected to numerical examination, and Figures 2–10 display a sample set of results. As an example of how the heat absorption coefficient S, the thermal Grashof number Gr, the solutal Grashof number Gm, the Prandtl number, the magnetic field parameter M, the permeability parameter k, and the Schmidt number Sc all play a role, these data are taken. Water vapor is assumed to have a Schmidt number Sc of 0.60. A cooling issue is indicated by the use of physical variables Gr = 2 and Gm = 1 throughout the computations. Figure 2 shows how the momentum boundary-layer thickness changes as the intensity of the magnetic field increases. It is now known that a magnetic field may reduce the velocity of a fluid by acting as a drag force that resists the flow of the fluid, thereby dampening the velocity field. Both the velocity and temperature profiles are affected by the heat absorption coefficient S, as seen in Figures 3 and 4, respectively. In a physical sense, the fluid's temperature tends to drop when heat absorption (thermal sink) effects are present. As a consequence, the fluid's velocity is reduced since the thermal buoyancy effects are lessened. Both the velocity and temperature distributions in figures 3 and 4 fall as S rises, clearly indicating these behaviors. The hydrodynamic boundary layer, which measures velocity, and the thermal boundary layer, which measures temperature, both diminish with increasing heat absorption effects. Figures 5 and 6 demonstrate the impact of the Prandtl number Pr on the velocity profile and the temperature profile, respectively. Both the fluid's velocity and temperature decrease as the Prandtl number increases. For one thing, a thermal boundary layer with a lower Pr value is more uniformly heated than one with a higher Pr value. When the thermal conductivity increases and the Prandtl number decreases, this effect takes place. Consequently, with smaller Prandtl numbers, heat may dissipate from a heated surface more rapidly than with larger ones. In Figure 7, we can see how the thermal Grashof number affects the velocity. In the boundary layer, the thermal Grashof number indicates how much of an influence thermal buoyant force has in comparison to the viscous hydrodynamic force. It is not surprising that the increased thermal buoyancy force causes the velocity to rise. The peak velocities also rise sharply close to the porous plate as Gr rises, before gradually falling to the free stream velocity. For different values of the solutal Grashof number Gm, Figure 8 shows typical boundary layer velocity patterns. The species buoyancy force to viscous hydrodynamic force ratio is defined by the solutal Grashof number Gm.

Species buoyancy forces rise, which is to be anticipated, leading to higher fluid velocities and more noticeable peaks. In the region around the plate, the velocity distribution reaches a peak and then drops down to the free stream value. Figure 9 shows the velocity profile and Figure 10 shows the concentration profile how the Schmidt number Sc affects them. The concentration falls with increasing Schmidt number. This slows the fluid down since the concentration buoyancy effects are less. At the same time as the velocity and concentration profiles are becoming smaller, the boundary layers around them are getting smaller as well. Figures 9 and 10 make these actions very obvious. Figure 11 shows the effects of k on velocity profiles, and its behavior is amplified.

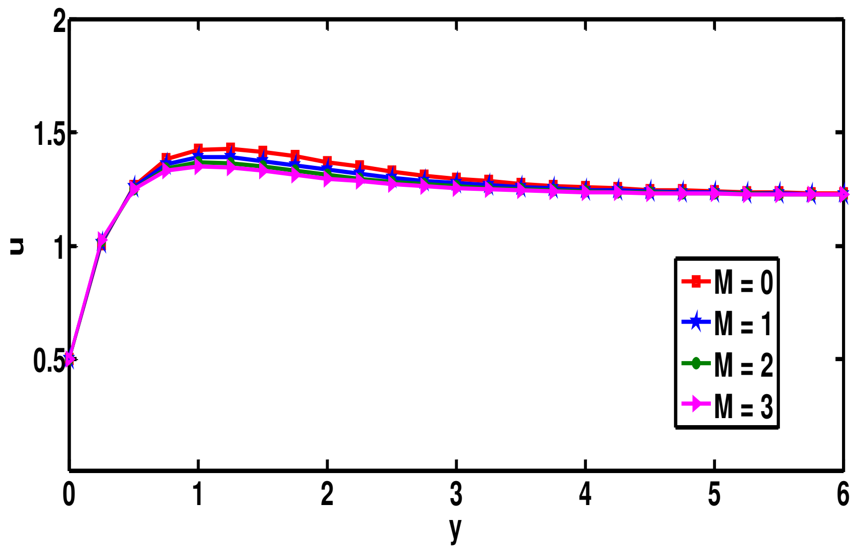

Figure 2: Parameter M impact on u profiles

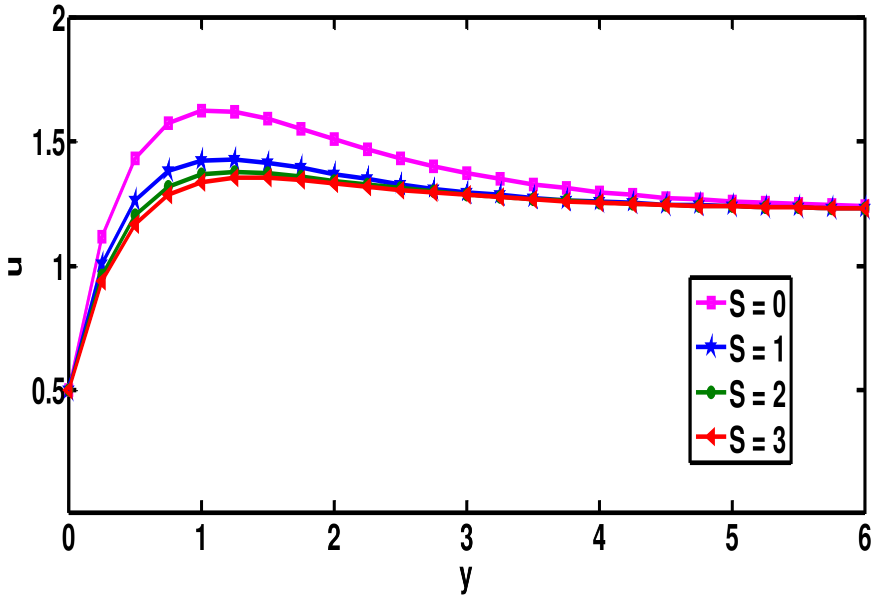

Figure 3: Parameter S impact on u profiles

International Journal For Advanced Research In Science & Technology
A peer reviewed international journal
www.ijarst.in
ISSN: 2457-0362

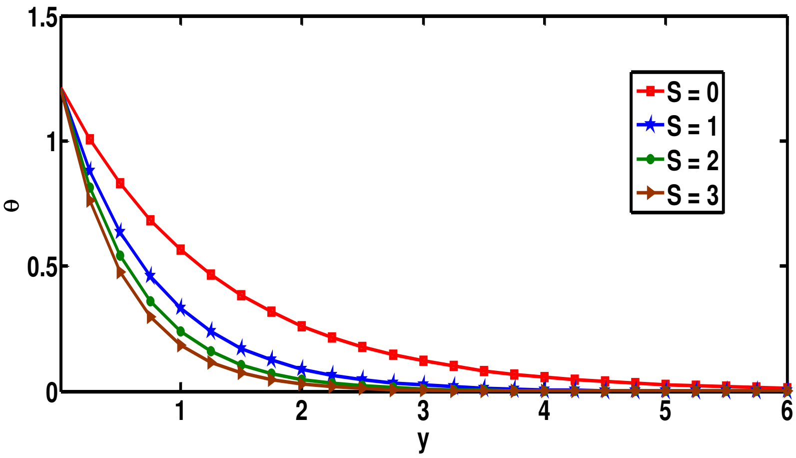

Figure 4: Parameter S impact on θ profiles

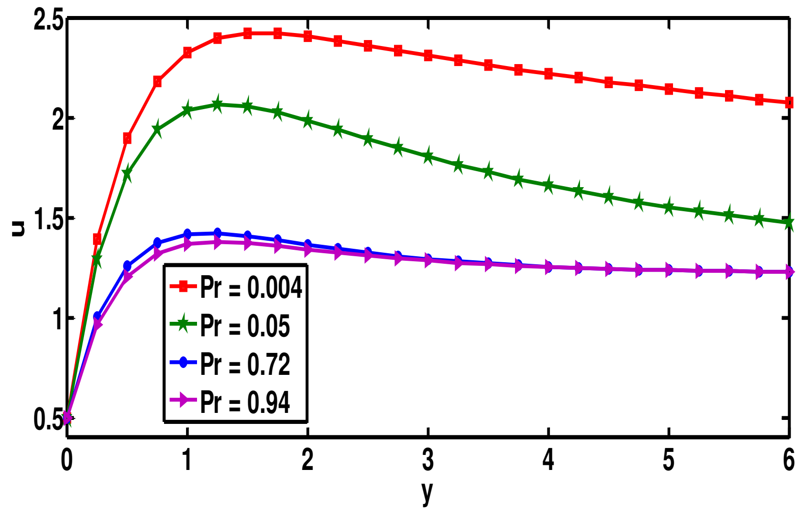

Figure 5: Parameter Pr impact on u profiles

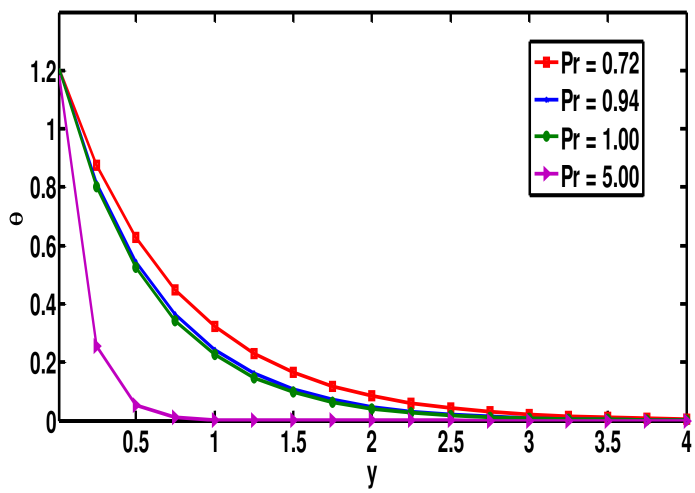

Figure 6: Parameter Pr impact on θ profiles

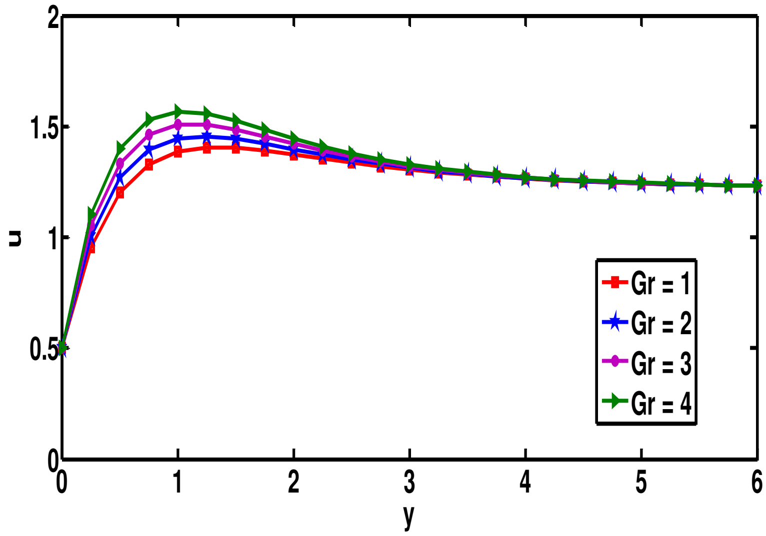

Figure 7: Parameter Gr impact on u profiles

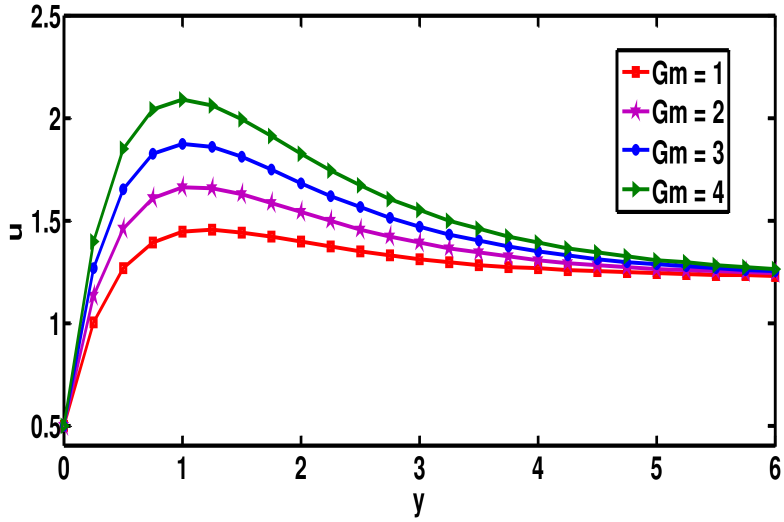

Figure 8: Parameter Gm impact on u profiles

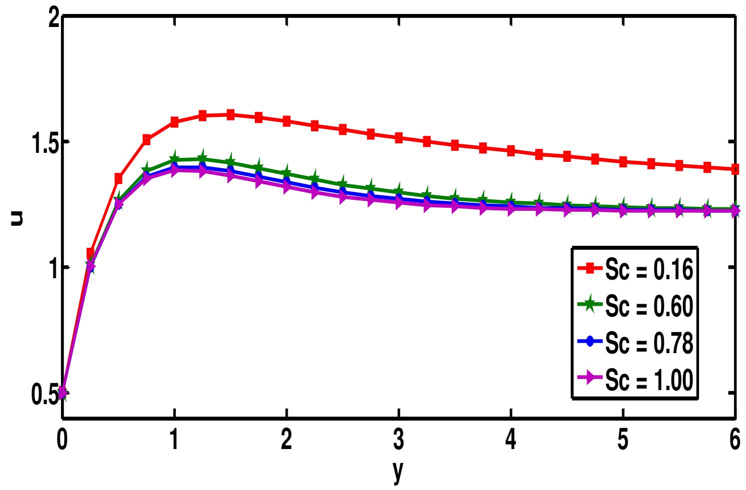

Figure 9: Parameter Sc impact on u profiles

IJARST
International Journal For Advanced Research In Science & Technology
A peer reviewed international journal
www.ijarst.in
ISSN: 2457-0362

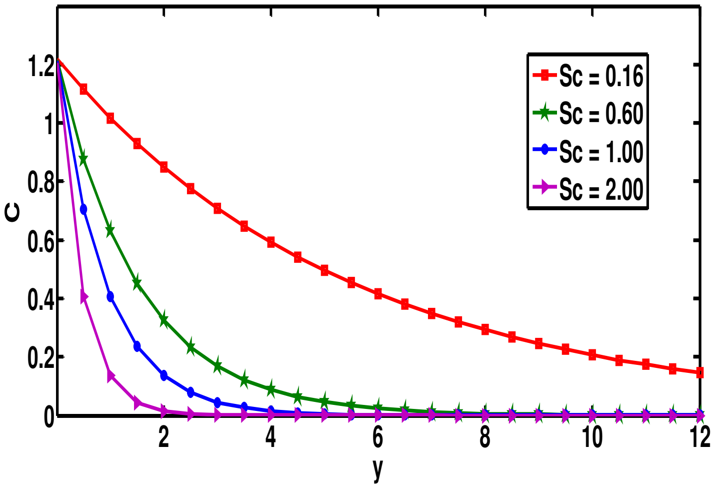

Figure 10: Parameter Sc impact on C profiles

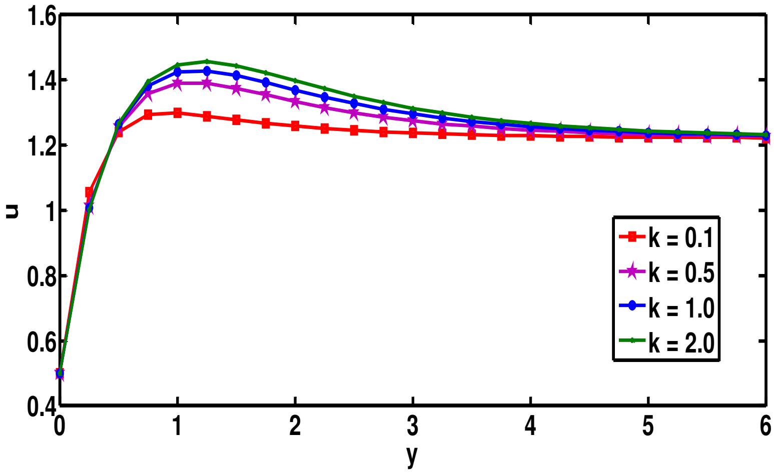

Figure 11: Parameter k impact on u profiles

5. CONCLUSIONS:

Unsteady mixed-mode heat-and-mass-transfer (MHCT) flows across a semi-infinite slanted permeable moving plate immersed in a porous material that absorbs heat were described by the governing equations. A transverse magnetic field was applied to the flow while the plate velocity was kept constant. The resultant linked partial equations are solved using a perturbation approach. The study's findings are as follows:

- A reduction in fluid velocity was seen when the concentration level was reduced as the Schmidt number was raised.
- The thermal boundary layer is reduced as the Prandtl number and heat absorption rise.
- Increasing the heat absorption coefficient, angle of inclination, magnetic parameter, and Prandtl number causes a drop in velocity, but increasing the porous parameter, thermal, and solutal Grashof numbers causes the opposite tendency.

References:

1) Kao, T.-T. Laminar free convective heat transfer response along a vertical flat plate with step jump in surface temperature. Letters in Heat and Mass Transfer 1975, 2, 419-428, https://doi.org/10.1016/0094- 4548(75)90008-9.
2) Raptis, A.; Singh, A.K. MHD free convection flow past an accelerated vertical plate. International Communications in Heat and Mass Transfer 1983, 10, 313-321, http://dx.doi.org/10.1016/0735- 1933(83)90016-7.
3) Tokis, J.N. A class of exact solutions of the unsteady magnetohydrodynamic free-convection flows. Astrophysics and Space Science 1985, 112, 413-422, http://dx.doi.org/10.1007/bf00653524.
4) Prasad, k.V.; Vajravelu, K. MHD mixed convection heat transfer in a vertical channel with temperature-dependent transport properties. Journal of Applied Fluid Mechanics 2015, 8, 693-701, http://dx.doi.org/10.18869/acadpub.jafm.67.223.21562.
5) Sheikholeslami, M.; Rashidi, M.M.; Ganji, D.D. Effect of non-uniform magnetic field on forced convection heat transfer of Fe3O4–water nanofluid. Computer Methods in Applied Mechanics and Engineering 2015, 294, 299-312, http://dx.doi.org/10.1016/j.cma.2015.06.010.
6) Rashidi, M.M.; Nasiri, M.; Khezerloo, M.; Laraqi, N. Numerical investigation of magnetic field effect on mixed convection heat transfer of nanofluid in a channel with sinusoidal walls. J. Magn. Magn. Mater. 2016, 401, 159-168, http://dx.doi.org/10.1016/j.jmmm.2015.10.034.
7) Shateyi, S. Heat and mass transfer for natural convection MHD flow over a permeable moving vertical plate with convective boundary condition in the presence of viscous dissipation. AIP Conf. Proc. 2017, 1863, 560075, https://doi.org/10.5098/hmt.9.7.
8) Lawal, K.K.; Jibril, H.M. Impact of relative motion of a magnetic field on unsteady magnetohydrodynamic natural convection flow with a constant heat source/sink. Heat Transfer 2021, 50, 487-507, https://doi.org/10.1002/htj.21888.
9) Ilias, M.R.; Ismail, N.S.a.; Ab Raji, N.H.; Rawi, N.A.; Shafie, S. Unsteady aligned MHD boundary layer flow and heat transfer of a magnetic nanofluids past an inclined plate. International Journal of Mechanical Engineering and Robotics Research 2020, 9, https://doi.org/10.18178/ijmerr.9.2.197-206.
10) Fenuga, O.J.; Aroloye, S.J.; Salawu, S.O. Mathematical model and solution for an unsteady MHD fourth grade fluid flow over a vertical plate in a porous medium with magnetic field and suction/injection effects. Journal of Scientific Research 2020, 12, 485-498, https://doi.org/10.3329/jsr.v12i4.45551.
11) Rama Prasad, J.L.; Balamurugan, K.S.; Varma, S.V.K. Aligned magnetic field effect on unsteady MHD double diffusive free convection flow of Kuvshinski fluid past an inclined moving porous plate. In Proceedings of Advances in Fluid Dynamics, Singapore, 2021; 255-262, https://doi.org/10.1007/978-981-15- 4308-1.
12) Bilal, M.; Nazeer, M. Numerical analysis for the non-Newtonian flow over stratified stretching/shrinking inclined sheet with the aligned magnetic field and nonlinear convection. Archive of Applied Mechanics 2020, https://doi.org/10.1007/s00419-020-01798-w.

13) N. Ahmed, "Soret and Radiation Effects on Transient MHD Free Convection From an Impulsively Started Infinite Vertical Plate," ASME. J. Heat Transfer, 134(6), 062701 (2012). https://doi.org/10.1115/1.4005749
14) H.R. Patel, "Thermal radiation effects on MHD flow with heat and mass transfer of micropolar fluid between two vertical walls," International Journal of Ambient Energy, 42, 1281-1296 (2019). https://doi.org/10.1080/01430750.2019.1594371
15) N.N. Reddy, V.S. Rao, and B.R. Reddy, "Chemical reaction impact on MHD natural convection flow through porous medium past an exponentially stretching sheet in presence of Heat Source/Sink and viscous dissipation", Case Studies in Thermal Engineering, 25(3), 100879 (2021). https://doi.org/10.1016/j.csite.2021.100879
16) B.K. Jha, and G. Samaila, "Effect of heat source/sink on MHD free convection flow in a channel filled with nanofluid in the existence of induced magnetic field: an analytic approach," SN Appl. Sci. 2, 1321 (2020). https://doi.org/10.1007/s42452-020- 3139-8
17) S. Matta, B.S. Malga, G.R. Goud, L. Appidi, and P.P. Kumar, "Effects of viscous dissipation on MHD free convection flow past a semi-infinite moving vertical porous plate with heat sink and chemical reaction," Materials Today: Proceedings, (2023). https://doi.org/10.1016/j.matpr.2023.06.108
18) K. Borah, J. Konch, and S. Chakraborty, "Effect of Arrhenius Activation Energy in MHD Micropolar Nanofluid Flow Along a Porous Stretching Sheet with Viscous Dissipation and Heat Source", East European Journal of Physics, 4, 98-108 (2023). https://doi.org/10.26565/2312-4334-2023-4-10
19) S. Akhtar, K. Borah, and S. Chakraborty, "Effect of radiation and heat dissipation on MHD convective flow in presence of heat sink," East European Journal of Physics, 3, 471-478 (2023). https://doi.org/10.26565/2312-4334-2023-3-53