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AN ANALYTICAL STUDY OF CHEMICALLY RADIATIVE PERMEABLE MAGNETIZED VERTICAL PLATE

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Abstract:
Novel research here is an exact analysis of radiation, chemical reaction and rotation effects on unsteady MHD flow past an accelerated isothermal plate with variable mass diffusion has been presented. The non-dimensional governing equations are solved using Laplace transform method. The velocity, temperature and concentration of the fluid in the boundary layer for various physical parameters like, radiation parameter, chemical reaction parameter, rotation parameter, Prandtl number, Schmidt number and time have been analyzed. The solutions are in relations of exponential and complementary error function. This study is useful in controlling of molten iron flow in the steel industry, liquid metal cooling in nuclear reactors and meteorology.

Keywords: MHD, radiation, chemical reaction.

1. INTRODUCTION:

Fluid dynamics plays a significant role in the transmission of heat and mass during chemical reactions. Notable acclaim was bestowed upon it as a result of its exceptional qualities and practical technical uses. Aerodynamic extrusion of plastic sheets, refrigeration, electronic equipment, nuclear reactors, chemical catalytic reactors, electronic devices, gas turbines, and human transpiration are a few noteworthy uses. In references [1-3], the impact of the Arrhenius activation energy under various physical circumstances was covered. As molecules can only reach the top of the activation energy barrier to complete the reaction, they discovered that the activation energy of a chemical reaction is strongly connected to its rate. The impact of chemical reactions on free convective flow and mass transfer over a stretched surface was previously studied by Seddeek et al. [4]. They found that the boundary layer flow's velocity, temperature, and concentration all drop when the chemical parameters are increased. The impact of thermal diffusion, which encompasses the use of magnetic fields and suction/injection, on the distribution of heat and mass on a moving vertical plate during chemical reactions was studied by Olanrewaju et al. [5]. Through chemical reactions, mass transfers, and MHD flows, Shahzed et al. [6] studied the effects of Casson fluid on porous media.

Whenever the convective heat transfer coefficient is low, thermal radiation plays a significant role in the transmission of heat from surfaces. Sunlight, open-hearth fireplaces, blood circulation, and control heating systems that combine light and heat among its few and notable uses. Since this is happening, beams of energy are being transferred from the thing that is the source. According to Sheikholeslami et al. [7], the impact of heat radiation on the MHD nanofluid flow between two horizontally moving plates has been investigated. Prior research by Li et al. [8] examined the impact of radiation and MHD on momentum and heat transmission inside a vertical cylindrical annulus. When the scattering albedo hits one, they saw a significant shift in the predicted temperature profile. Research by Alsagri et al. [9] shown that a reduction in the velocity field for nanoparticles is produced by an increase in magnetic radiations. Considering a constant heat source at the wall and fully formed blood

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flow via the capillaries, Sinha et al. have offered the heat transmission properties [10]. According to their findings, this Joule-heating parameter may be used to regulate blood temperature. References [11–14] provide a small number of significant papers pertaining to this physical feature.
An abundance of technical issues and natural phenomena may be studied using MHD. In geophysics, MHD features are encountered in the magnetic field interactions of conducting fluids; in engineering, the principle is used in the design of heat exchangers, pumps, and flow meters; in spacecraft propulsion, thermal protection, braking, control, and reentry; in the creation of new power generation systems, etc. Because the air becomes sufficiently ionized at high enough flight speeds to cause dissociation, and because the appropriate application of a magnetic field may regulate the motion of this ionized air, MHD research is critically significant in aerodynamics. Studying MHD is equally important for the medical field. The accurate solution for unstead magneto hydrodynamic free convection flow with constant heat flux is obtained by Sachetiet al. [15]. In his work, Ali J. Chamkha [16] examined the transmission of heat and mass through a semi-infinite vertical permeable moving plate that was subject to heat absorption, when the flow was unsteady and MHD convective. At 4°C, Takhar and Ram [17] have also calculated the water's heat transport by porous convection without the need of MHD.

In this research, an exact analysis of radiation, chemical reaction and rotation effects on unsteady MHD flow past an accelerated isothermal inclined plate with variable mass diffusion has been presented. The non-dimensional governing equations are solved using Laplace transform method. The velocity, temperature and concentration of the fluid in the boundary layer for various physical parameters like, radiation parameter, chemical reaction parameter, rotation parameter, Prandtl number, Schmidt number and time have been analyzed.

2. MATHEMATICAL FORMULATION:

Take into account the case of an incompressible fluid's erratic flow past an isothermal inclined infinite plate that is evenly accelerated as both the fluid and the plate spin like a rigid body with a uniform angular velocity Ω about z^* axis.

Considered assumptions:

1. The fluid's concentration and temperature at a distance from the plate are assumed to be T_∞^* & C_∞^*.
2. At time $t^* > 0$, the plate starts moving with a velocity $u = u_0 t^*$ in its own plane and temperature from the plate increases to T_w and the concentration level near the plate is made to raise linearly with time.
3. Since the plate occupying the plane $z^* = 0$ is of infinite extent, all the physical quantities depend only on z^* and t^*.

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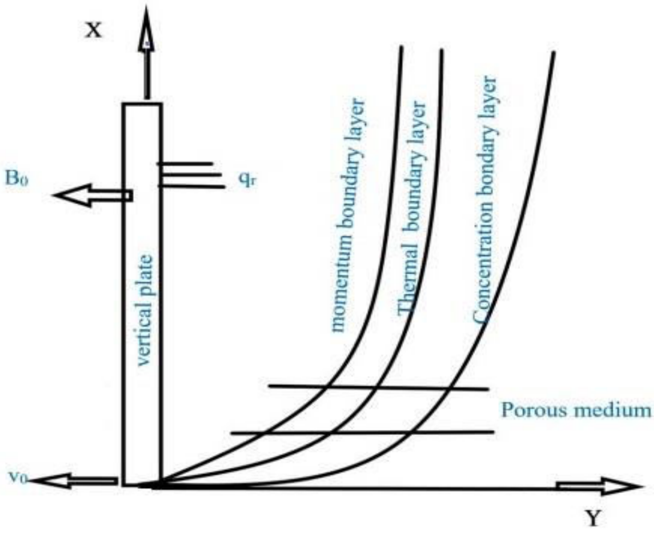

Fig.1: Flow Model

The unsteady MHD flow governed by under the usual Boussinesq's approximation is as follows:

$$\frac{\partial u^*}{\partial t^*} - 2\Omega^* v^* = g\beta(T^* - T^*_\infty) + g\beta^*(C^* - C^*_\infty) + \upsilon\frac{\partial^2 u^*}{\partial z^2} - \frac{\sigma B_0^2 u^*}{\rho} - \frac{\upsilon}{k}u^* \quad (1)$$

$$\frac{\partial v^*}{\partial t} + 2\Omega^* u^* = \upsilon\frac{\partial^2 v^*}{\partial z^2} - \frac{\sigma B_0^2 u^*}{\rho} - \frac{\upsilon}{k}v^* \quad (2)$$

$$\rho C_p \frac{\partial T^*}{\partial t^*} = K\frac{\partial^2 T^*}{\partial z^2} - \frac{\partial q_r}{\partial z} \quad (3)$$

$$\frac{\partial C^*}{\partial t^*} = D\frac{\partial^2 C^*}{\partial z^2} - Kr^*(C^* - C^*_\infty) \quad (4)$$

With the boundary conditions

$$t^* \le 0: \quad u^* = 0, \quad v^* = 0, \quad T^* = T^*_\infty, \quad C^* = C^*_\infty \quad \forall z$$

$$t^* > 0: \begin{array}{l} u^* = u_0 t^*, \quad v^* = 0, \quad T^* = T^*_w, \quad C^* = C^*_\infty + (C^*_w - C^*_\infty) \quad \forall t^* \, at \quad z = 0 \\ u^* \to 0, \quad v^* \to 0, \quad T^* \to T^*_\infty, \quad C^* \to C^*_\infty \quad as \quad z \to \infty \end{array} \quad (5)$$

The non-dimensional quantities are

$$U = \frac{u^*}{(\upsilon u_0)^{1/3}}, \quad V = \frac{v^*}{(\upsilon u_0)^{1/3}}, \quad t = \left(\frac{t^* u_0^2}{\upsilon}\right)^{1/3}, \quad Z = z\left(\frac{u_0}{\upsilon^2}\right)^{1/3}, \quad \theta = \frac{T^* - T^*_\infty}{T^*_w - T^*_\infty},$$

$$\Pr = \frac{\mu C_p}{K}, \quad C = \frac{C^* - C^*_\infty}{C^*_w - C^*_\infty}, \quad Gr = \frac{g\beta(T^*_w - T^*_\infty)}{u_0}, \quad Gm = \frac{g\beta^*(C^*_w - C^*_\infty)}{u_0},$$

$$Sc = \frac{\upsilon}{D}, \quad Kr = Kr^*\left(\frac{\upsilon}{u_0^2}\right)^{1/3}, A = \left(\frac{u_0^2}{\upsilon}\right)^{1/3}, \quad \Omega = \Omega^*\left(\frac{u_0^2}{\upsilon}\right)^{1/3}, \quad K_p = K\left(\frac{u_0}{\upsilon^2}\right)^{2/3}, \quad (6)$$

$$R = \frac{16a^*\sigma\upsilon^{4/3}T^3_\infty}{Ku_0^{2/3}}, \quad M = \frac{\sigma B_0^2 \upsilon^{1/3}}{\rho u_0^{2/3}}$$

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On introducing the above non dimensional quantities (6) in equations (1) to (4), lead to

$$\frac{\partial U}{\partial t}-2\Omega V=Gr\theta+GmC+\frac{\partial^2 U}{\partial z^2}-MU-\frac{U}{K_P} \quad (7)$$

$$\frac{\partial V}{\partial t}+2\Omega U=\frac{\partial^2 V}{\partial z^2}-MV-\frac{V}{K_P} \quad (8)$$

$$\frac{\partial \theta}{\partial t}=\frac{1}{\Pr}\frac{\partial^2 \theta}{\partial z^2}-\frac{R}{\Pr}\theta \quad (9)$$

$$\frac{\partial C}{\partial t}=\frac{1}{Sc}\frac{\partial^2 C}{\partial z^2}-KrC \quad (10)$$

The corresponding boundary conditions are

$$t\le 0:\quad U=0,\quad V=0,\quad \theta=0,\quad C=0\quad \forall z$$

$$t>0:\quad \begin{array}{l} U=t,\quad V=0,\quad \theta=1,\quad C=t\quad at\quad z=0 \\ U\to 0,\quad V\to 0,\quad \theta\to 0,\quad C\to 0\quad as\quad z\to\infty \end{array} \quad (11)$$

The rotating free convection flow past an accelerated inclined plate is described by coupled partial differential equations (7) to (10) with prescribed boundary conditions (11). To solve the equations (7) and (8), we introduce a complex velocity $q=U+iV$, equations (7) and (8) can be combined into a single equation:

$$\frac{\partial q}{\partial t}=\frac{\partial^2 q}{\partial z^2}+Gr\,\theta+Gm\,C-M_1\,q \quad (12)$$

Where $m=2i\Omega,\quad M_1=M+\frac{1}{K}+m$

The initial and boundary conditions in the non-dimensional quantities are

$$\begin{array}{ll} & q=0,\quad \theta=0,\quad C=0\quad for\ all\ z\quad t\le 0 \\ t>0: & q=t,\quad \theta=1,\quad C=t\quad at\quad z=0 \\ & q\to 0,\quad \theta\to 0,\quad C\to 0\quad as\quad z\to\infty \end{array} \quad (13)$$

3. SOLUTION OF THE PROBLEM:

The dimensionless governing equations (9), (10) and (12), subject to the initial and boundary conditions (13) are solved by the Laplace Transform technique and the solutions are obtained as follows:

$$\begin{aligned} C(z,t)=&\left(\frac{t}{2}-\frac{z\sqrt{Sc}}{4\sqrt{Kr}}\right)e^{-z\sqrt{Sc}\,\sqrt{Kr}}\,erfc\left(\frac{z\sqrt{Sc}}{2\sqrt{t}}-\sqrt{Kr\,t}\right) \\ &+\left(\frac{t}{2}+\frac{z\sqrt{Sc}}{4\sqrt{Kr}}\right)e^{z\sqrt{Sc}\,\sqrt{Kr}}\,erfc\left(\frac{z\sqrt{Sc}}{2\sqrt{t}}+\sqrt{Kr\,t}\right) \end{aligned} \quad (1)$$

$$\theta(z,t)=\frac{1}{2}\begin{pmatrix} e^{-z\sqrt{\Pr}\sqrt{\frac{R}{\Pr}}}erfc\left(\frac{z\sqrt{\Pr}}{2\sqrt{t}}-\sqrt{\frac{R}{\Pr}t}\right) \\ +e^{z\sqrt{\Pr}\sqrt{\frac{R}{\Pr}}}erfc\left(\frac{z\sqrt{\Pr}}{2\sqrt{t}}+\sqrt{\frac{R}{\Pr}t}\right) \end{pmatrix} \quad (2)$$

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$$q(z,t) = A_1 + \frac{Gr\cos\phi}{\Pr - 1}\left(-A_2 + A_3 + A_4 - A_5\right) + \frac{Gm\cos\phi}{Sc - 1}\left(-A_6 - A_7 + A_8 + A_9 + A_{10} - A_{11}\right) \quad (3)$$

4. RESULTS AND DISCUSSION:

To get a physical grasp of the issue, numerical computations are performed for several physical factors that depend on the flow and transport characteristics. Water vapor is represented by the value of the Schmidt number Sc, which is assumed to be 0.6. The Prandtl numbers, which stand for air and water, are set to 0.71 and 7, respectively. As the plate cools, we use the Grashof number Gr = 10, which is the correct value. Here are the default settings for the physical parameters: The parameters for the magnetic field, the mass Grashof number, the chemical reaction, the rotation, the permeability, and the time constant are as follows: M = 1, Gm = 5, Kr = 1, R = 1, t = 0.2. In all cases, unless otherwise stated, these values will correlate to the graphs. Figures 2–12 display the numerical values of the velocity, temperature, and concentration for various physical parameters such as the following: thermal Grashof number, mass Grashof number, radiation parameter, rotation parameter, magnetic parameter, angle of inclination, porosity parameter, and time. For varying Schmidt numbers, the impact of concentration profiles is seen in Figure 2. In the concentration field, the impact of concentration is crucial. All of the profiles have the characteristic that, as one moves away from the surface and into the free stream, the concentration monotonically drops until it reaches zero. The wall concentration is shown to decrease as the Schmidt number increases. For various values of t, the impact of the concentration profiles is shown in Figure 3. Looking at the data, we can see that the wall concentration drops as t values go smaller. The dimensionality-free concentration profiles of the chemical reaction parameter Kr are shown in Figure 4. Based on the data presented here, it seems that concentration decreases as Kr increases. Additionally, it is observed that the concentration boundary layer becomes thinner with increasing chemical reaction parameters. Equation (9) is used to get the air and water temperature profiles, which are shown in figure 5. In terms of the temperature field, the Prandtl number is a major factor. At air Pr = 0.71 and water Pr = 7.0, it is noted that the temperature increases as the Prandtl number decreases. So, it seems like air is better at transferring heat than water. The temperature profiles for various values of the radiation parameter R are shown in Figure 6. It is clear from this graph that as R grows, the temperature drops. The velocity profiles for various thermal and mass Grashof numbers are shown in figure 7. As both the thermal and mass Grashof numbers increase, we see a corresponding acceleration of the velocity. Figure 8 shows that the velocity profiles become flatter as the rotation value is bigger. In Figure 9, we can see how the velocity distribution is affected by the magnetic parameter. There is a resistance to the flow of fluids when a transverse magnetic field is present. The speed of an electrically conducting fluid is reduced by this force, which is called the Lorentz force. Figure 10 shows the velocity profile for various values of the radiation parameter R. The velocity is reduced when R is increased. Figure 11 shows the velocity field as a function of the chemical reaction parameter Kr. Figure 1 shows that for both heating and cooling the plate, the velocity drops as the chemical reaction parameter Kr increases. Various values of the porosity parameter K are shown in figure 12 at a period t = 0.2, and it is clear that an increase in K causes the fluid velocity to rise.

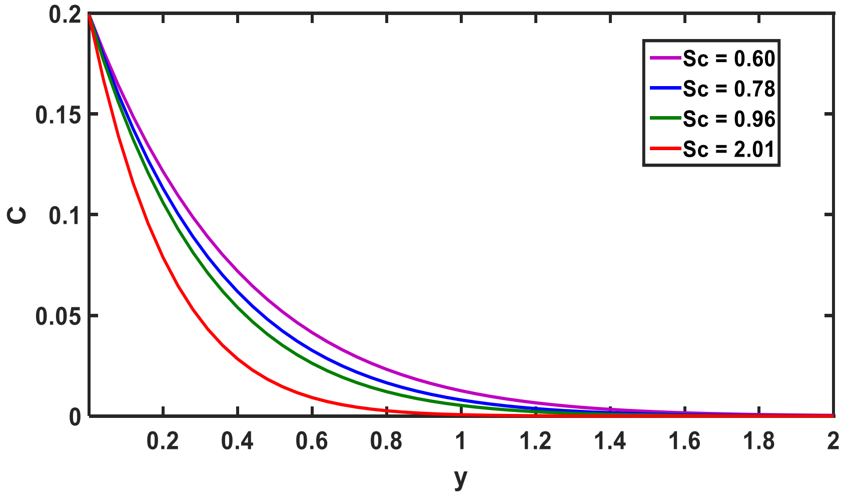

Figure 2: Concentration profiles for different Sc

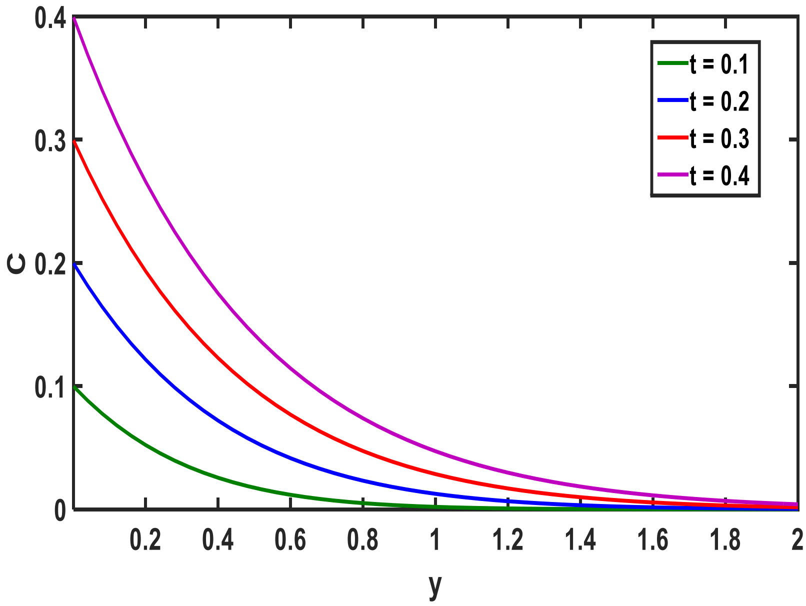

Figure 3: Concentration profiles for different values of t

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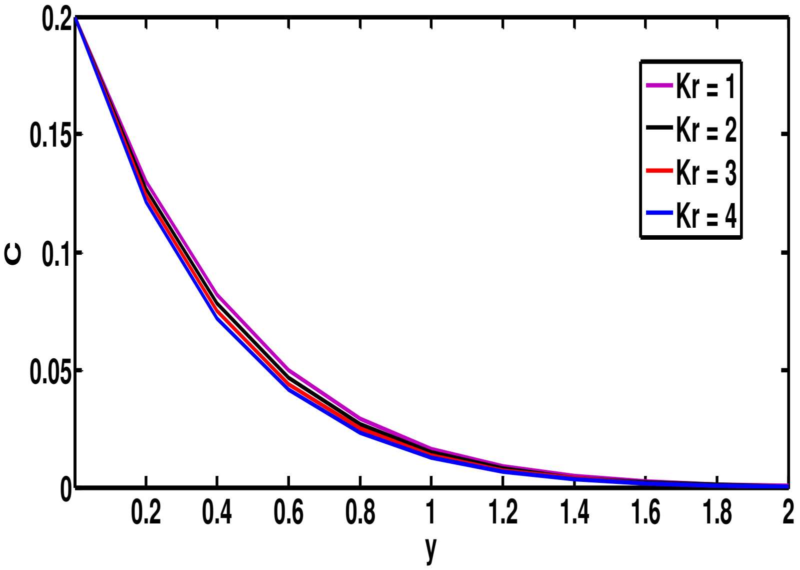

Figure 4: Concentration profiles for different values of Kr

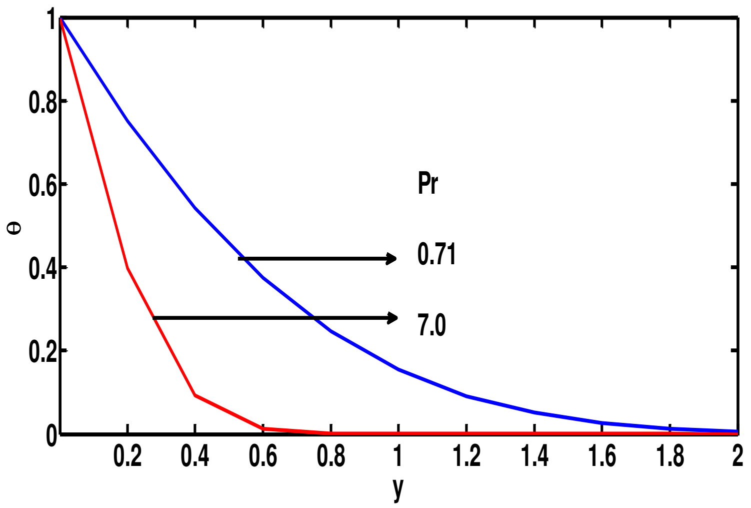

Figure 5: Temperature profiles for different Pr

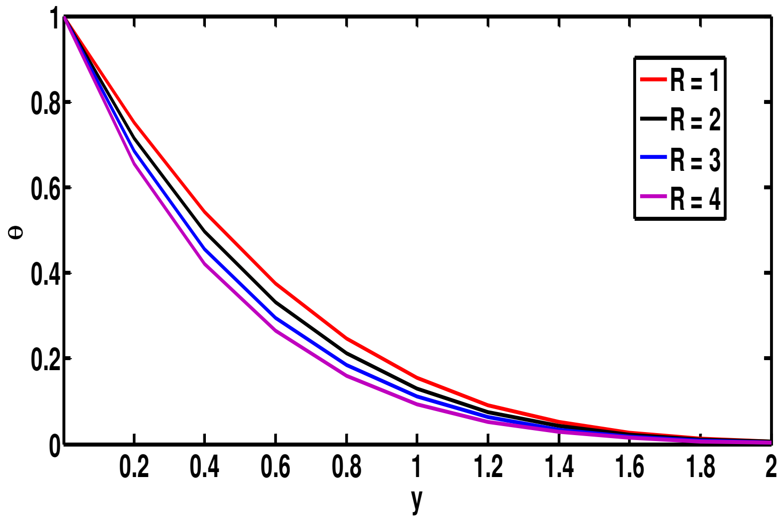

Figure 6: Temperature profiles for different R

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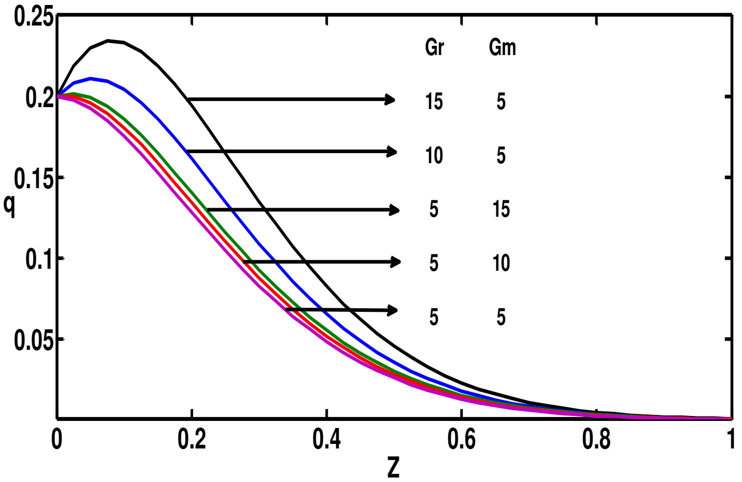

Figure 7: Velocity profiles for different Gr and Gm

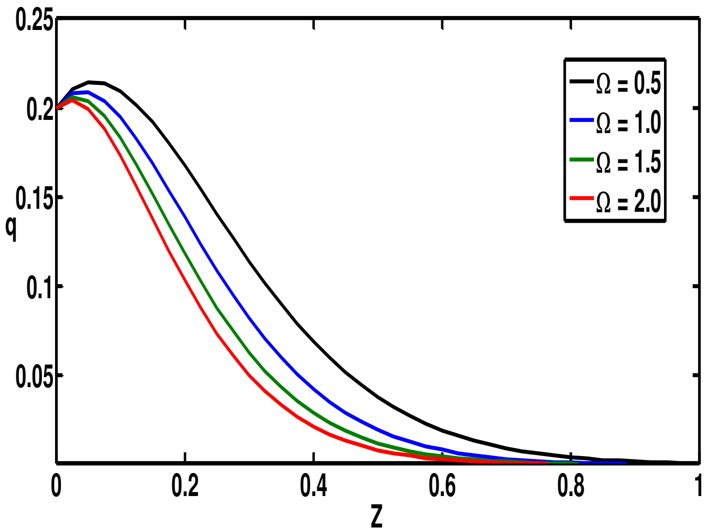

Figure 8: Velocity profiles for different Ω

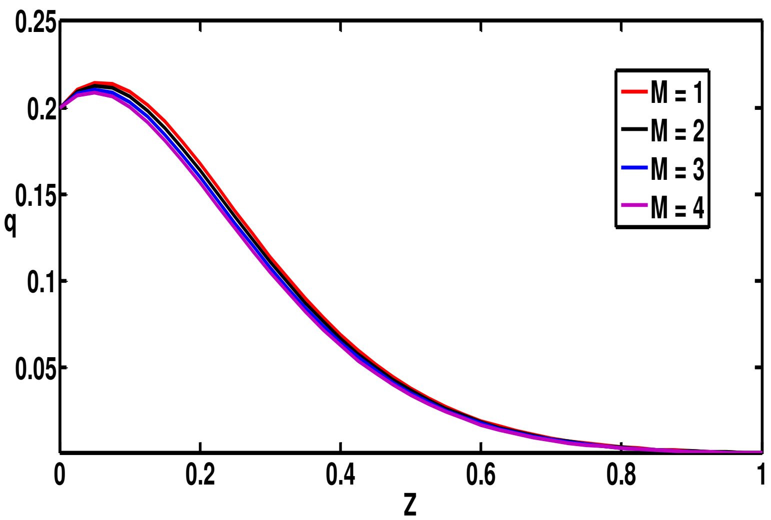

Figure 9: Velocity profiles for different M

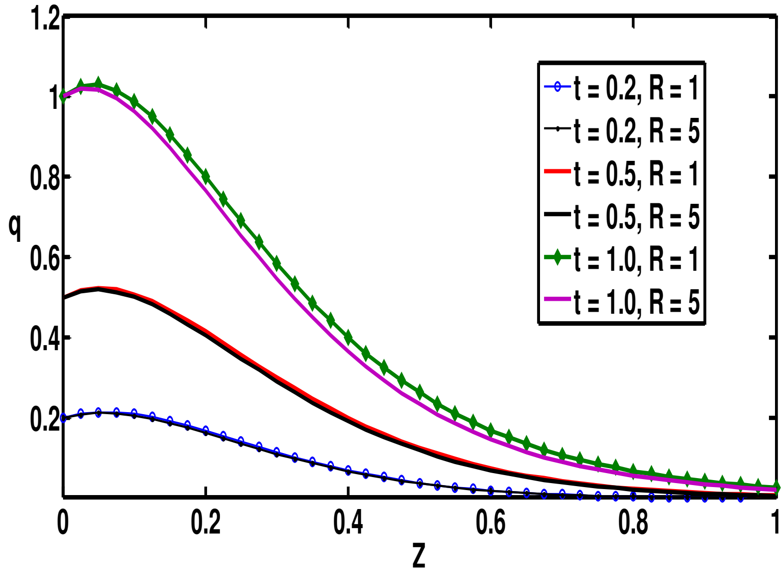

Figure 10: Velocity profiles for different R

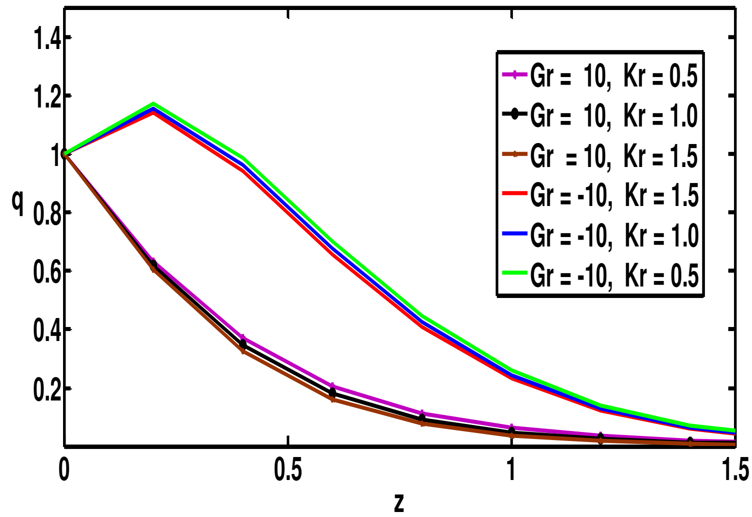

Figure 11: Velocity profiles for different Kr

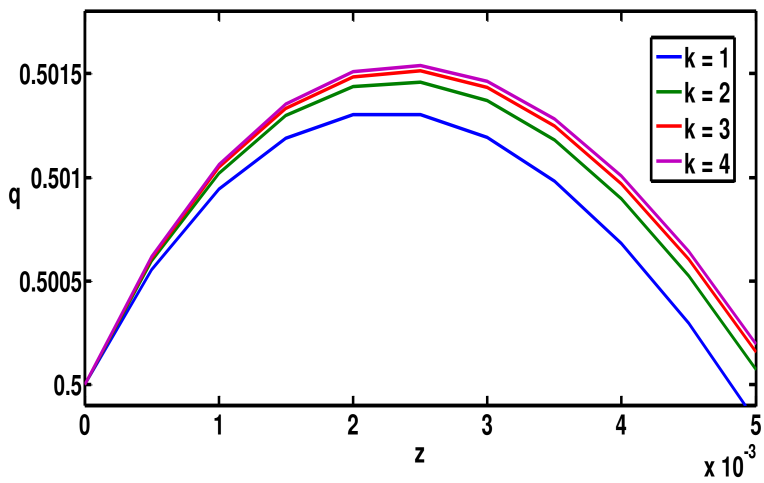

Figure 12: Velocity profiles for different k

5. CONCLUSIONS:

The impact of chemical reactions and heat radiation on unsteady multi-layer hydrodynamic flow (MHD) via an accelerated isothermal inclined plate with variable mass diffusion and a rotating fluid is investigated through a theoretical analysis. The Laplace transform method is used to provide exact solutions to problems. The study's findings are as follows:

- The concentration drops as the values of Sc and Kr rise. Regarding t, however, the pattern is inverted.
- A drop in temperature is caused by an increase in Pr and R.
- The values of Gr, Gm, M, R, and K have an inverse relationship with one another; as Ω rise, velocity decreases.

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