CHAPTER 1

THERMAL DIFFUSION AND RADIATION EFFECTS ON UNSTEADY MHD FREE COVECTION HEAT AND MASS TRANSFER FLOW PAST A LINEARLY ACCELERATED VERTICAL PLATE WITH VARIABLE TEMPERATURE AND MASS DIFFUSION

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CHAPTER – 1

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1.1: INTRODUCTION:

The study of magneto hydro-dynamics with mass and heat transfer in the presence of radiation and diffusión has attracted the attention of a large number of scholars due to diverse applications. In Astrophysics and Geophysics, it is applied to study the Stellar and Solar structures, Radio propagation through the ionosphere, etc. In engineering we find its applications like in MHD pumps, MHD bearings, etc. The phenomenon of mass transfer is also very common in theory of stellar structure and observable effects are detectable on the solar surface. In free convection flow the study of effects of magnetic field play a major role in liquid metals, electrolytes and ionized gases. In power engineering, the thermal physics of hydro magnetic problems with mass transfer have enormous applications. Radiative flows are encountered in many industrial and environmental processes, e.g. heating and cooling chambers, fossil fuel combustion energy processes, evaporation from large open water reservoirs, astrophysical flows, solar power technology and space vehicle re-entry.

MHD effects on impulsively started vertical infinite plate with variable temperature in the presence of transverse magnetic field were studied by Soundalgekar et al.[1]. The effects of transversely applied magnetic field, on the flow of an electrically conducting fluid past an impulsively started infinite isothermal vertical plate were also studied by Soundalgekar et al.[2]. The dimensionless governing equations were solved using Laplace transform technique. Kumari and Nath [3] studied the development of the asymmetric flow of a viscous electrically conducting fluid in the forward stagnation point region of a two-dimensional body and over a stretching surface was set into impulsive motion from the rest. The governing equations were solved using finite difference scheme. The radiative free convection flow of an optically thick gray-gas past semi-infinite vertical plate was studied by Soundalgekar and Takhar[4]. Hossain and Takhar[5] have considered Radiation effects on mixed convection along an isothermal vertical plate. In all above studies, the stationary vertical plate was considered. Raptis and Perdikis[6] studied the effects of thermal-radiation and free convection flow past a moving vertical plate. The governing equations were solved analytically. Das et al.[7] have considered Radiation effects on flow past an impulsively started infinite isothermal vertical plate. The governing equations were solved by the Laplace transform technique.
Muthucumarswamy and Janakirama [8] have studied MHD and radiation effects on moving isothermal vertical plate with variable mass diffusion.

Alam and Sattar[9] have analyzed the thermal-diffusion effect on MHD free convection and mass transfer flow. Jha and Singh [10] have studied the importance of the effects of thermal-diffusion(mass diffusion due to temperature gradient). Alam et al.[11] studied the thermal-diffusion effect on unsteady MHD free convection and mass transfer flow past an impulsively started vertical porous plate. Alam et al.[12] studied combined free convection and mass transfer flow past a vertical plate with heat generation and thermal-diffusion through porous medium. Rajesh et al.[13] and Kumar et al.[14] studied thermal diffusion and radiation effects on MHD flow past a vertical plate with variable temperature and mass diffusion. Saxena and Dubey [15] studied unsteady MHD heat and mass transfer free convection flow of a polar fluid past a vertical moving porous plate in a porous medium with heat generation and thermal diffusion, and the governing equations were solved using perturbation technique. Again, Saxena and Dubey [16] investigated heat and mass transfer effects on MHD free convection flow of a visco-elastic fluid embedded in a porous medium with variable permeability in the presence of radiation and heat source in a slip flow regime. Mass transfer effects on MHD viscous flow past an impulsively started infinite vertical plate with constant mass flux studied by Saravana et. Al.[17]. Rathod and Asha[18] examined magnetic field effects on two-dimensional viscous incompressible Newtonian fluid with the help of numerical technique. Chauhan and Kumar [19] considered Newtonian second grade fluid on unsteady flow in a channel partially filled by porous medium. Very recently, Kumar et al.[20] investigated thermal diffusion and radiation effects on unsteady MHD flow through porous medium with variable temperature and mass diffusion in the presence of heat source or sink. The dimensionless governing equations were solved by using Laplace transform technique.

This chapter deals with the effects of thermal-diffusion and radiation on unsteady MHD flow past an impulsively started linearly accelerated infinite vertical plate with variable temperature and also with variable mass diffusion in the presence of heat source or sink and transverse applied magnetic field. The dimensionless governing equations involved in the analysis are solved using Laplace transform technique. The solutions are expressed in terms of exponential and complementary error functions.

1.2: NOMENCLATURE:

- \( a' \) Absorption coefficient
- \( a \) Accelerated parameter
- \( B_0 \) External magnetic field
\( C \) Species concentration
\( C_w \) Concentration of the plate
\( C_x \) Concentration of the fluid far away from the plate
\( C \) Dimensionless concentration
\( C_p \) Specific heat at constant pressure
\( D \) Chemical molecular diffusivity
\( D_i \) Coefficient of thermal diffusivity
\( g \) Acceleration due to gravity
\( G_r \) Thermal Grashof number
\( G_m \) Mass Grashof number
\( M \) Magnetic field parameter
\( Nu \) Nusselt number
\( Pr \) Prandtl number
\( q \) Radiative heat flux in the y-direction
\( R \) Radiative parameter
\( Sc \) Schmidt number
\( So \) Soret number
\( Sh \) Sherwood number
\( T' \) Temperature of the fluid near the plate
\( T_w \) Temperature of the plate
\( T_x \) Temperature of the fluid far away from the plate
\( t' \) Time
\( t \) Dimensionless time
Velocity of the fluid in the \( x' \) - direction

Velocity of the plate

Dimensionless velocity

Co-ordinate axis normal to the plate

Dimensionless co-ordinate axis normal to the plate

Greek symbols:

\( \kappa \)  
Thermal conductivity of the fluid

\( \alpha \)  
Thermal diffusivity

\( \beta \)  
Volumetric coefficient of thermal expansion

\( \beta^* \)  
Volumetric coefficient of expansion with concentration

\( \mu \)  
Dynamic viscosity

\( \nu \)  
Coefficient of viscosity

\( \rho \)  
Density of the fluid

\( \sigma \)  
Electric conductivity

\( \theta \)  
Dimensionless temperature

\( \text{erf} \)  
Error function

\( \text{erfc} \)  
Complementary error function

Subscripts:

\( \omega \)  
Conditions on the wall

\( \infty \)  
Free stream conditions

1.3: MATHEMATICAL FORMULATION:

In this chapter, we consider Thermal-diffusion and radiation effects on unsteady MHD flow of a viscous incompressible, electrically conducting, radiating fluid past an impulsively started linearly accelerated infinite vertical
plate with variable temperature and mass diffusion in the presence of heat source/sink under the influence of applied transverse magnetic field. The plate is taken along \( x' \)-axis in vertically upward direction and \( y' \)-axis is taken normal to the plate. Initially, it is assumed that the plate and fluid are at the same temperature \( T_0' \) and concentration level \( C_0' \) in stationary condition for all the points. At time \( t' > 0 \), the plate is linearly accelerated with a velocity \( u = u_0 t' \) in the vertical upward direction against to the gravitational field. And at the same time the plate temperature is raised linearly with time \( t \) and also the mass is diffused from the plate to the fluid is linearly with time. A transverse magnetic field of uniform strength \( B_0 \) is assumed to be applied normal to the plate. The viscous dissipation and induced magnetic field are assumed to be negligible. The fluid considered here is gray, absorbing/emitting radiation but a non-scattering medium.

![Physical configuration and coordinate system](image)

The following assumptions are made in obtaining the governing equations.

i. A transverse magnetic field of uniform strength \( B_0 \) is assumed to be applied normal to the plate.

ii. The viscous and joule's dissipation are neglected in the energy equations.
The induced magnetic field is assumed to be negligible as the magnetic Reynolds number of the flow is taken to be very small.

The fluid considered here is gray, absorbing/emitting radiation but a non-scattering medium.

Initially it is assumed that the plate and fluid are at the same temperature \( T' \) and concentration level \( C' \) in stationary condition for all the points.

Under the above assumptions and by the usual Boussinesq's approximation, the unsteady flow is governed by the following equations:

\[
\frac{\partial u'}{\partial t'} = \beta(T' - T'_x) + \beta' (C' - C'_x) + \nu \frac{\partial^2 u'}{\partial y'^2} - \frac{\alpha \beta u'}{\rho} 
\]  

(1)

\[
\frac{\partial T'}{\partial t'} = \kappa \frac{\partial^2 T'}{\partial y'^2} - \frac{\partial q'}{\partial y'} + Q(T' - T') 
\]  

(2)

\[
\frac{\partial C'}{\partial t'} = D \frac{\partial^2 C'}{\partial y'^2} + D \left( \frac{\partial^2 T'}{\partial y'^2} \right) 
\]  

(3)

With the following initial and boundary conditions

\( t' < 0 : u' = 0, \quad T' = T'_x, \quad C' = C'_x, \quad \text{for all } y' \)

\( t' > 0 : u' = u_0 t', \quad T' = T'_x + (T'_x - T'_w) At', \quad C' = C'_x + (C'_x - C'_w) At' \quad \text{at} \quad y' = 0 \)

\( u' = 0, \quad T' \rightarrow T'_x, \quad C' \rightarrow C'_x \quad \text{as} \quad y' \rightarrow \infty \)  

(4)

Where, \( A = \frac{u_0^2}{v} \).

The local radiant for the case of an optically thin gray gas is expressed by

\[
\frac{\partial q'}{\partial y'} = -4A' \alpha (T'_x - T^4) 
\]  

(5)

It is assumed that the temperature differences within the flow are sufficiently small and that \( T^4 \) may be expressed as a linear function of the temperature. This is obtained by expanding \( T^4 \) in a Taylor series about \( T'_x \) and neglecting the higher order terms, we get

\[
T^4 \equiv 4T'_x^2 T' - 3T'_x^4 
\]  

(6)
From equations (5) and (6), equation (2) reduces to

\[ \rho C_p \frac{\partial T'}{\partial t'} = \kappa \frac{\partial^2 T'}{\partial y'^2} + 16 \alpha^* \sigma T'^3 \left( T_e' - T' \right) \]  

(7)

On introducing the following non-dimensional quantities:

\[ u = \frac{u'}{u_0}, \quad t = \frac{t'u_0^2}{v}, \quad y = \frac{y' u_0}{v}, \quad \theta = \frac{T' - T_e'}{T_e' - T_e'^3} \]

\[ C = \frac{C_e' - C'}{C_e' - C_e'^3}, \quad P_r = \frac{\mu C_e'}{\kappa}, \quad S_o = \frac{D_o (T_e' - T_e'^3)}{v (C_e' - C_e'^3)} \]

\[ G = \frac{R \beta_i (T_e' - T_e'^3)}{u_0^2}, \quad G_m = \frac{R \beta_i (C_e' - C_e'^3)}{u_0^2}, \quad S_i = \frac{v}{D}, \quad M = \frac{\alpha B_i v}{\rho u_0^2} \]

\[ R = \frac{16 \alpha^* v^3 \sigma T_e'^3}{k u_0^2}, \quad H = \frac{Q v^3}{k u_0^2} \]

(8)

We get the following governing equations which are dimensionless

\[ \frac{\partial u}{\partial t} = G; \theta + G_m C + \frac{\partial^2 u}{\partial y'^2} - Mu, \]

(9)

\[ \frac{\partial \theta}{\partial t} = \frac{1}{Pr} \frac{\partial^2 \theta}{\partial y'^2} \left( R + H \right) \theta, \]

(10)

\[ \frac{\partial C}{\partial t} = \frac{1}{Sc} \frac{\partial^2 C}{\partial y'^2} + S_i \frac{\partial^2 \theta}{\partial y'^2} \]

(11)

The initial and boundary conditions in dimensionless form are as follows:

\[ t' \leq 0: \quad u = 0, \quad \theta = 0, \quad C = 0 \text{ for all } y, \]

\[ t > 0: \quad u = t, \quad \theta = t, \quad C = t \quad \text{ at } \quad y = 0, \]

\[ u \to 0, \quad \theta \to 0, \quad c \to 0 \quad \text{ as } \quad y \to \infty. \]

(12)

1.4: METHOD OF SOLUTION:

The dimensionless governing equations from (9) to (11), subject to the boundary conditions (12) are solved by usual Laplace transform technique and the solutions are expressed in terms of exponential and complementary error functions.
The Laplace transform of the equations (9) to (11) and the boundary conditions (12) are given by

\[
\frac{\partial^2 \bar{\theta}}{\partial y^2} - (S + sP_c) \bar{\theta} = 0
\]

(13)

\[
\frac{\partial^2 \bar{\varepsilon}}{\partial y^2} - sS_te\bar{\varepsilon} = -s_0S_te(S + sP_c) \bar{\theta}
\]

(14)

\[
\frac{\partial^2 \bar{u}}{\partial y^2} - (s + M) \bar{u} = -G_e \bar{\theta} - G_e \bar{\varepsilon}
\]

(15)

\[
t > 0: \bar{u} = \frac{1}{s^2}, \bar{\theta} = \frac{1}{s}, \bar{\varepsilon} = \frac{1}{s^2} \text{ at } y = 0
\]

(16)

\[
t > 0: \bar{u} = 0, \bar{\theta} = 0, \bar{\varepsilon} = 0 \text{ as } y \to \infty
\]

Where \( s \) is the Laplace transformation parameter

\[
\bar{c}(y,s) = L[c(y,t)] = \int_0^\infty e^{-st}c(y,t)dt
\]

\[
\bar{\theta}(y,s) = L[\theta(y,t)] = \int_0^\infty e^{-st}\theta(y,t)dt
\]

\[
\bar{u}(y,s) = L[u(y,t)] = \int_0^\infty e^{-st}u(y,t)dt
\]

Solving the equations (13) to (15) with the help of equations (16), we get

\[
\bar{\theta}(y,s) = \frac{e^{-\sqrt{b\gamma} s}}{s^2}
\]

(17)

\[
\bar{c}(y,s) = \left[ \frac{(1+b)}{s^2} + \frac{(d-b)}{c}s + \frac{(d-b)}{c}s + \frac{1}{s+c} \right] e^{-\sqrt{b\gamma} s}
\]

(18)
\[ \bar{u}(y,s) = \left[ \frac{1}{s^2} \left( A_1 + A_2 \right) + A_3 \frac{A_4 + A_5}{s + c} + A_6 \frac{A_7 + A_8}{s - n} \right] e^{-\sqrt{s_c} M} + \left[ \frac{A_7 + A_8}{s + c} + A_3 \frac{A_4 + A_5}{s - n} \right] e^{-\sqrt{s_c} M} \]

Taking inverse Laplace transform on equations (17) to (19) we get the general solution of the problem for the temperature \( \theta(y,t) \), species concentration \( c(y,t) \) and the velocity \( u(y,t) \) for \( t > 0 \) in non-dimensional form as

\[ \theta(y,t) = \left[ \frac{t + y^2}{2} \exp\left( -\frac{y \sqrt{s_c}}{4} \right) \right] \exp\left( \frac{y \sqrt{Pr}}{2 t} + \sqrt{s_c} \right) + \]

\[ \left[ \frac{t + y^2}{2} \exp\left( -\frac{y \sqrt{s_c}}{4} \right) \right] \exp\left( \frac{y \sqrt{Pr}}{2 t} - \sqrt{s_c} \right) \]

\[ C(y,t) = (1 + b) \left[ \frac{t + y^2}{2} \right] \exp\left( -\frac{y \sqrt{s_c}}{4} \right) - \frac{d - b}{c} \exp\left( -\frac{y \sqrt{s_c}}{4} \right) \]

\[ + \left[ \frac{t + y^2}{2} \right] \exp\left( -\frac{y \sqrt{s_c}}{4} \right) \exp\left( \frac{y \sqrt{Sc}}{2 t} + \sqrt{ct} \right) + \exp\left( -\frac{y \sqrt{s_c}}{4} \right) \exp\left( \frac{y \sqrt{Sc}}{2 t} - \sqrt{ct} \right) \]

\[ - \frac{1}{2} \left( \frac{d - b}{c} \right) \exp(-ct) \left[ \exp\left( y \sqrt{s_c} \right) \exp\left( \frac{y \sqrt{Pr}}{2 t} + \sqrt{s_c} \right) \right] + \exp\left( -y \sqrt{s_c} \right) \exp\left( \frac{y \sqrt{Pr}}{2 t} - \sqrt{s_c} \right) \]

\[ - \frac{1}{2} \left( \frac{d - b}{c} \right) \exp(-ct) \left[ \exp\left( y \sqrt{s_c} \right) \exp\left( \frac{y \sqrt{Pr}}{2 t} + \sqrt{s_c} \right) \right] + \exp\left( -y \sqrt{s_c} \right) \exp\left( \frac{y \sqrt{Pr}}{2 t} - \sqrt{s_c} \right) \]

\[ - \frac{1}{2} \left( \frac{d - b}{c} \right) \exp(-ct) \left[ \exp\left( y \sqrt{s_c} \right) \exp\left( \frac{y \sqrt{Pr}}{2 t} + \sqrt{s_c} \right) \right] + \exp\left( -y \sqrt{s_c} \right) \exp\left( \frac{y \sqrt{Pr}}{2 t} - \sqrt{s_c} \right) \]
\[ u(y,t) = A_1 \left[ \frac{t}{2} + \frac{y \sqrt{\text{Pr}}}{4 \sqrt{S}} \right] \exp \left( \frac{y \sqrt{\text{Sc}}}{2 \sqrt{t}} - \sqrt{\frac{\text{Pr}}{S}} \right) \] 

\[ + A_2 \left[ \frac{t}{2} + \frac{y \sqrt{\text{Sc}}}{2 \sqrt{t}} \right] \exp\left( \frac{y \sqrt{\text{Sc}}}{2 \sqrt{t}} - \sqrt{\frac{\text{Pr}}{S}} \right) \] 

\[ + (1 - A_1 - A_2) \left[ \frac{t}{2} + \frac{y}{4 \sqrt{M}} \right] \exp(\sqrt{y \sqrt{M}}) \operatorname{erfc}\left( \frac{y \sqrt{\text{Sc}}}{2 \sqrt{t}} + \sqrt{\frac{\text{Pr}}{M}} \right) \] 

\[ + \exp\left( - y \sqrt{\text{Sc}} \right) \operatorname{erfc}\left( \frac{y \sqrt{\text{Sc}}}{2 \sqrt{t}} - \sqrt{\frac{\text{Pr}}{M}} \right) \] 

\[ + \frac{A_1}{2} \exp(-\sqrt{c}) \] 

\[ + \exp\left( - y \sqrt{\text{Sc}} \right) \operatorname{erfc}\left( \frac{y \sqrt{\text{Sc}}}{2 \sqrt{t}} - \sqrt{\text{c}} \right) \] 

\[ + \frac{A_4}{2} \exp(-\sqrt{(M-1)y}) \] 

\[ + \exp\left( - y \sqrt{\text{M-1}} \right) \operatorname{erfc}\left( \frac{y \sqrt{\text{M-1}}}{2 \sqrt{t}} - \sqrt{(M-1)y} \right) \] 

\[ + \frac{A_4}{2} \exp(-lt) \] 

\[ + \exp\left( - y \sqrt{\text{M-1}} \right) \operatorname{erfc}\left( \frac{y \sqrt{\text{M-1}}}{2 \sqrt{t}} - \sqrt{(M-1)y} \right) \]
1.5: NUSSELT NUMBER:

From temperature field, we now study Nusselt number (rate of change of heat transfer) which is given in non-dimensional form as,

\[
Nu = - \left[ \frac{\partial \theta}{\partial y} \right]_{y=0} \tag{23}
\]

From equations (20), we get Nusselt number as follows:
1.6: SHERWOOD NUMBER:

From concentration field, we now study Sherwood number (rate of change of mass transfer) which is given in non-dimensional form as,

\[ Sh = - \left[ \frac{\partial C}{\partial y} \right]_{y=0} \]  \hspace{1cm} (25)

From equations (21), we get Sherwood number as follows:

\[ Sh = 2(1 + b) \sqrt{\frac{Sc}{\pi}} + \left( d - b \right) \frac{Sc}{\pi t} \]

\[ - \left( d - b \right) \exp(-ct) \left[ \frac{Sc}{\pi t} \exp( ct ) \right] \]

\[ + \frac{Pr}{\pi} \exp( - \frac{St}{Pr} ) + \sqrt{S} \exp( \frac{St}{Pr} ) \]

\[ + \left( d - b \right) \frac{Pr}{\pi t} \exp( - \frac{St}{Pr} ) + \sqrt{S} \exp( \frac{St}{Pr} ) \]

\[ + \left( d - b \right) \frac{Pr}{\pi t} \exp( - \frac{St}{Pr} ) + \sqrt{S} \exp( \frac{St}{Pr} ) \]

\[ + \frac{Pr}{\pi} \exp( - \frac{St}{Pr} ) + \sqrt{S} \exp( \frac{St}{Pr} ) \]

\[ + \frac{Pr}{2\sqrt{R}} \exp( - \frac{St}{Pr} ) + \sqrt{S} \exp( \frac{St}{Pr} ) \]  \hspace{1cm} (26)

1.7: RESULTS AND DISCUSSION:

In order to get the physical insight into the problem, we have plotted velocity, temperature, concentration, the rate of heat transfer and the rate of mass transfer for different values of the physical parameters like Radiation parameter(R), Magnetic parameter(M), Heat source parameter(H), Soret number(So), Schmidt number(Sc), Thermal Grashof number(Ge), Mass Grashof number(Gm), time (t) and Prandtl
number(Pr) through the figures (1) - (11) for the cases of heating (Gr < 0, Gm < 0) and cooling (Gr > 0, Gm > 0) of the plate at time t = 0.4. The heating and cooling take place by setting up free-convection current due to temperature and concentration gradient.

Figure (1) displays the influences of magnetic parameter(M) on the velocity field in cases of cooling and heating of the plate. It is found that the velocity decreases with an increase in magnetic parameter(M) in case of cooling of the plate, while it increases in the case of heating of the plate. Physically it meets the logic that the magnetic field exerts a retarding force on free convection flow. It is seen from figure (2) that the velocity increases with an increase in Soret number(So) in case of cooling of the plate but a reverse effect is identified in case of heating of the plate. From figures (3) and (4) it is observed that with an increase in radiation parameter(R) or Schmidt number(Sc), the velocity increases up to certain y value (distance from the plate) and decreases later for cooling of the plate, but a reverse effect is observed in case of heating of the plate. The velocity profiles for different values of time ( t) are shown in figure (5), it is seen that as time ( t) increases the velocity increases gradually in case of cooling of the plate and the trend is just reversed in case of heating of the plate.

The temperature of the flow field is mainly affected by the flow parameters, namely, Radiation parameter(R) and the heat source parameter(H) keeping Prandtl number(Pr) as constant. The effects of these parameters on temperature of the flow field are shown in figure (6). It is observed that as radiation parameter ( R) or heat source parameter (H) increases the temperature of the flow field decreases at all the points in flow region. Figure (7) shows the plot of temperature of the flow field against different values of Prandtl number (Pr) at time t = 0.2 & t =0.4 taking radiation parameter(R) as constant. It is observed that the temperature of the flow field decreases in magnitude as Pr increases. It is also observed that the temperature for air (Pr=0.71) is greater than that of water (Pr=7.0), this is due to the fact that thermal conductivity of the fluid decreases with increasing Prandtl number(Pr), results to decrease in thermal boundary layer.

The concentration distributions of the flow field are displayed through figures (8) - (10). It is affected by the flow parameters, namely Soret number(So), Schmidt number(Sc), radiation parameter(R) and Heat source parameter(H) respectively. From
these figures it is clear that the concentration increases with an increase in Soret number (So) and interestingly the concentration distribution is found to increase faster up to certain y value (distance from the plate) and decreases later as the Schmidt parameter (Sc) or Radiation parameter (R) or heat source parameter (H) become heavier.

Nusselt number (Nu) is presented in figure (11) against time t. From this figure the Nusselt number is observed to increase with an increase in radiation parameter (R) for both water (Pr=7.0) and air (Pr=0.71). It is also observed that Nusselt number for water is higher than that of air (Pr=0.71), the reason is that smaller values of Prandtl number (Pr) are equivalent to increasing the thermal conductivities and therefore heat is able to diffuse away from the plate more rapidly than higher values of Prandtl number (Pr), hence the rate of heat transfer is reduced. And finally, from figure (12), it is seen that sherwood number decreases with an increase in Schmidt number (Sc), Soret number (So) and radiation parameter (R).
Figure 1: Velocity profiles for different $M$ when $S_o=5$, $Sc=2.01$, $Pr=0.71$, $R=15$ and $t=0.4$

Figure 2: Velocity profiles for different $S_o$ when $M=3$, $Sc=2.01$, $Pr=0.71$, $R=10$, $H=5$ and $t=0.4$
Figure 3: Velocity profiles for different $R$ when $S_o=5$, 
$Sc=2.01$, $M=3$, $Pr=0.7$, $H=0$ and $t=0.4$

Figure 4: Velocity profiles for different $Sc$ when $So=5$, $M=3$
$Pr=0.71$, $R=10$, $H=5$ and $t=0.4$
Figure 5: Velocity profiles for different \( t \) when \( S = 5 \)

\[
Sc=2.01, \, M=3, \, Pr=0.71, \, R=10, \, H=5
\]

Figure 6: Temperature profiles for different values of \( R \) and \( H \)
Figure 7: Temperature profiles for different values of Pr.

Figure 8: Concentration profiles for different So with $R=4$, $H=1$, $Sc=2.01$ and $Pr=0.71$.
Figure 9: Concentration profiles for different Sc

With So=5, Pr=0.71, R=4 and H=1

Figure 10: Concentration profiles for different R and H

With So=5, Sc=2.01, H=1 and Pr=0.71
Figure 11: Nusselt number

Figure 12: Sherwood number for different Sc, So and R
1.9: CONCLUSIONS:

A theoretical analysis is performed to study the effects of thermal-diffusion and radiation on unsteady MHD flows of a viscous incompressible, electrically conducting fluid past an impulsively started linearly accelerated infinite vertical plate with variable temperature and mass diffusion in the presence of heat source/ sink under the influence of applied transverse magnetic field. The exact solutions of equations are obtained using the Laplace transform technique. The velocity, temperature, concentration, Skin-friction, the rate of heat transfer and the rate of mass transfer are studied through graphs in terms of different physical parameters like, Magnetic field parameter(M), Radiation parameter(R), Schmidt parameter(Sc), Soret number(So), Heat source parameter(H), Prandtl number(Pr), Thermal Grashof number(Gr), Mass Grashof number(Gm) and time (t).

It is found that the velocity decreases with an increasing in magnetic parameter(M) in case of cooling of the plate, while it increases in case of heating of the plate. Physically it meets the logic that the magnetic field exerts a retarding force on free convection flow. The velocity increases with an increase in Soret number(So) in case of cooling of the plate, but a reverse effect is identified in case of heating of the plate. It is noticed that with an increase in radiation parameter(R) or Schmidt number(Sc), the velocity increases up to certain value(distance from the plate) and decreases later for cooling of the plate, but a reverse effect is observed in case of heating of the plate. It is seen that as time (t) increases the velocity increases gradually in case of cooling of the plate and the trend is just reversed in case of heating of the plate. It is observed that as Radiation parameter(R) or Heat source parameter (H) increases the temperature of the flow field decreases at all the points in flow region. It is observed that the temperature of the flow field decreases in magnitude as Prandtl number(Pr) increases, for different values of Prandtl number(Pr) at time t = 0.2 & t =0.4 taking radiation parameter(R) as constant. The concentration increases with an increase in Soret number (So) and decreases later as the Schmidt parameter (Sc) or Radiation parameter(R) or heat source parameter(H) become heavier. The Nusselt number (Nu) is observed to increase with an increase in radiation parameter(R) for both water (Pr=7.0) and air (Pr=0.71). Sherwood number (Sh) decreases with an increase in Schmidt number (Sc) or Soret number (So) or radiation parameter(R).
1.10: REFERENCES:


1.11: APPENDIX:

\[ S = R + H, \quad b = S \cdot Sc, \quad c = \frac{S}{Pr - Sc}, \]

\[ d = \frac{b \cdot Pr}{S}, \quad l = \frac{S - M}{Sc - 1}, \quad n = \frac{M}{Sc - 1}, \]

\[ A_1 = \frac{bGm - Gr}{S - M}, \quad A_2 = \frac{(1 + b)Gm}{M}, \]

\[ A_3 = \frac{bGm (S - c Pr)}{cS (S - M + c - c Pr)} \]

\[ A_4 = \frac{bGm (S - c Pr)}{cS (S - M + c - c Pr)} \]

\[ A_5 = \frac{(Pr - 1)[SGr(S - M + c - c Pr) + Gmbc(M Pr - S)]}{S(S - M)^2 (S - M + c - c Pr)} \]

\[ A_6 = \frac{Gm(Sc - 1)[M (S + bc Pr) + cS(1 + b)(Sc - 1)]}{M^2 S(M - c + cSc)} \]

\[ A_7 = \frac{cS(Pr - 1)(Gr - bGm) + Gmb(S - M)(c Pr - S)}{cS(S - M)^2} \]

\[ A_8 = \frac{Gm[cS(Sc - 1) + M Pr bc - bS(M + c - cSc)]}{cM^2 S} \]