Radiation Absorption Impact On Chemically Reactive and Heat Absorbing Fluid Flow With Heat and Mass Transfer Past a Semi-Infinite Vertical Permeable Moving Plate in Non-Homogeneous Porous Medium in Conducting Field

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ABSRTACT:
This investigation is focused radiation absorption impact on chemically reactive and heat absorbing fluid flow with heat and mass transfer past a semi-infinite vertical permeable moving plate in non-homogeneous porous medium in the presence of a uniform transverse magnetic field. The plate is assumed to be moving with a constant velocity in the direction of fluid flow while the free stream velocity is assumed to follow the exponentially increasing small perturbation law. The governing equations of this problem are solved using perturbation technique and the solutions for velocity, temperature, concentration are derived. With the aid of these the expressions for skin friction coefficient, Nusselt number and Sherwood number are obtained. The effects of various thermo physical parameters such as Soret number, radiation absorption parameter, Schmidt number, magnetic parameter, chemical reaction parameter, modified Grashof number, thermal Grashof number, Soret number, radiation parameter, Prandlt number and heat absorption parameter over the velocity, temperature, concentration, skin friction coefficient, Nusselt number and Sherwood number are discussed through graphs and tables.

Keywords: *Thermal radiation, Thermal diffusion, Chemical reaction, Heat source, Magneto hydrodynamic (MHD), porous medium.*

I. INTRODUCTION

The study of heat and mass transfer to chemical reacting MHD free convection flow with radiation effects on a vertical plate has received a growing interest during the last decades. Accurate knowledge of the overall convection heat transfer has vital importance in several fields such as thermal insulation, drying of porous solid materials, heat exchanges, stream pipes, water heaters, refrigerators, electrical conductors , industrial, geophysical and astrophysical applications. Kim [1] investigated unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction. Raju et al. [2] discussed unsteady MHD free convection oscillatory Couette flow through a porous medium with periodic wall. Mythreye et al. [3] considered chemical reaction on unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption. Raptis et al. [4] evaluated magneto hydrodynamics free convection flow and mass transfer through a porous medium bounded by an infinite vertical porous plate with constant heat flux. Singh et al. [5] discussed heat transfer effects on flow of viscous fluid through non- homogeneous porous medium. Kim [6] evaluated unsteady convection flow of micro polar fluids past a vertical porous plate embedded in a porous medium. Raju et al. [7] investigated unsteady MHD thermal diffusive, radiative and free convective flow past a vertical porous plate through non-homogeneous porous medium. Seshaiah et al. [8] considered induced magnetic field effects on free convective flow of radiative, dissipative fluid past a porous plate with temperature gradient heat source. El-Hakiem [9] discussed Joule heating effects on MHD free convection flow of a micro polar fluid. Sharmaand et al. [10] investigated thermal convection in micro polar fluids in porous medium. Golse et al. [11] evaluated radiative transfer equations and rossel and approximation in gray matter. Ravikumar et al. [12] considered combined effects of heat absorption and MHD on convective Rivlin-Ericksen flow past a semi-infinite vertical porous plate. Kapoor et al. [13] discussed analytical study of MHD natural convective flow of incompressible fluid flow from a vertical flat plate in porous medium. Singh

[14] investigated heat source and radiation effects on magneto-convection flow of a visco-elasic fluid past a stretching sheet analysis with kummer's function. Khan et al. [15] discussed on accelerated flows of a visco-elastic fluid with the fractional burgers. Mohamad [16] evaluated double-diffusive convection-radiation interaction on unsteady MHD flow over a vertical moving porous plate with heat generation and soret effect. Combarnous et al. [17] investigated hydro-thermal convection in saturated porous media. Das et al. [18] considered mass transfer effects on MHD flow and heat transfer past a vertical porous plate through a porous medium under oscillatory suction and heat source. Mishra et al. [19] evaluated mass and heat transfer effect on MHD flow of a visco-elastic fluid through porous medium with oscillatory suction and heat source. Ravikumar et al. [20] discussed combined effects of heat absorption and MHD on Convective Rivlin-Ericksen flow past a semi-infinite vertical porous plate with variable temperature and suction.

II. MATHEMATICAL FORMULATION

Consider unsteady two-dimensional flow of a laminar, incompressible, viscous, electrically conducting, chemically reactive, radiative and heat absorbing fluid past a semi-infinite vertical permeable moving plate embedded in a non-uniform porous medium and subjected to a uniform transverse magnetic field in the presence of thermal and concentration buoyancy effects. The governing equations for this investigation are based on the balances of mass, linear momentum, energy and concentration species. Taking into consideration the assumptions made above, these equations can be written in Cartesian frame of reference, as follows

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

$$\frac{\partial u^1}{\partial t^1} + v\frac{\partial u^1}{\partial y^1} = -\frac{1}{\rho}\frac{\partial p^1}{\partial x^1} + \upsilon\frac{\partial^2 u^1}{\partial y^{1^2}} + g\beta_T(T - T_\infty) + g\beta_C(C - C_\infty) - \frac{\sigma B_0^2 u^1}{\rho} - \frac{\upsilon u^1}{K_0\left(1 + A\varepsilon e^{n^1 t^1}\right)} \tag{2}$$

$$\frac{\partial T}{\partial t^1} + v^1\frac{\partial T}{\partial y^1} = \alpha\frac{\partial^2 T^1}{\partial y^{1^2}} - \frac{Q_0}{\rho C_p}(T - T_\infty) - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y^1} + \frac{Q_1}{\rho C_p}(C - C_\infty) \tag{3}$$

$$\frac{\partial C}{\partial t^1} + v^1\frac{\partial C}{\partial y^1} = D\frac{\partial^2 C}{\partial y^{1^2}} - K(C - C_\infty) \tag{4}$$

Where x^1, y^1, and t^1 are the dimensional distances along and perpendicular to the plate and dimensional time respectively. U^1 and υ^1 are the components of dimensional velocities along $x^1$and y^1directions, respectively, ρ is the fluid density, υ is the kinematic viscosity, Cp is the specific heat at constant pressure, σ is the fluid electrical conductivity, B_0 is the magnetic induction, K^1 is the permeability of the porous medium, T is the dimensional temperature, Q_0 is the dimensional heat absorption coefficient, c is the dimensional concentration, α is the fluid thermal diffusivity, D is the mass diffusivity, g is the gravitational acceleration, and β_T and β_C are the thermal and concentration expansion coefficients respectively. The magnetic and viscous dissipations are neglected in this study. Under these assumptions, the appropriate boundary conditions for the velocity, temperature and concentration fields are

$$u^1 = u_P^1,\ \ T = T_w,\ \ C = C_w \quad at\ y^1 = 0 \tag{5}$$

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

Where u_p^1, C_w and T_w are the wall dimensional velocity, concentration and temperature, respectively. U_∞^1, C_∞ an T_∞ are the free stream dimensional velocity, concentration and temperature, respectively. U_0 and n^1 are constants. It is clear from Eq. (1) that the suction velocity at the plate surface is a function of time only.

Assuming that it takes the following exponential form:

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

Where A is a real positive constant, ε and ε A are small less than unity, and V0 is a scale of suction velocity which has non-zero positive constant. Outside the boundary layer, Eq. (2) gives

$$-\frac{1}{\rho}\frac{\partial p^1}{\partial x^1}=\frac{dU_\infty}{\partial t^1}+\frac{\sigma B_0^2 U_\infty^1}{\rho}+\frac{\upsilon U_\infty^1}{K_0(1+A\varepsilon e^{n^1t^1})} \tag{8}$$

Where $V_0 > 0$ and ε« 1 are positive constants.

Introducing the non-dimensional quantities.

$$y=\frac{V_0 y^1}{\upsilon},\quad t=\frac{V_0^2 t^1}{\upsilon},\quad u=\frac{u^1}{U_0},\quad \theta=\frac{T-T_\infty}{T_w-T_\infty}, U_\infty=\frac{U_\infty^{\,1}}{U_0},\quad U_p=\frac{u_p^1}{U_0}, n=\frac{\upsilon n^1}{V_0^2},$$
$$C=\frac{C-C_\infty}{C_w-C_\infty},\quad K=\frac{K_0V_0^2(1+A\varepsilon e^{n^1t^1})}{\upsilon^2},\quad Q=\frac{v}{\rho C_p V_0^2}(Q_0+4I^1),\ ,\ \Pr=\frac{\upsilon}{\alpha},\ Sc=\frac{\upsilon}{D}, M=\frac{\sigma B_0^2\upsilon}{\rho V_0^2},$$
$$Gc=\frac{\upsilon g\beta_C(C_w-C_\infty)}{U_0V_0^2},\ Gr=\frac{\upsilon g\beta_T(T_w-T_\infty)}{U_0V_0^2},\ Kr=\frac{Kv}{V_0^2},\ N=M+\frac{1}{K},\ Ra=\frac{Q_1\upsilon}{\rho C_p V_0^2}\frac{(T_w-T_\infty)}{(C_w-C_\infty)} \tag{9}$$

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

$$\frac{\partial u}{\partial t}-(1+A\varepsilon e^{nt})\frac{\partial u}{\partial y}=\frac{dU_\infty}{dt}+\frac{\partial^2 u}{\partial y^2}+G_r\theta+G_C C+N(U_\infty-u) \tag{10}$$

$$\frac{\partial\theta}{\partial t}-(1+A\varepsilon e^{nt})\frac{\partial\theta}{\partial y}=\frac{1}{\Pr}\frac{\partial^2\theta}{\partial y^2}-Q\theta+Ra \tag{11}$$

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

$Gc=\frac{\upsilon g\beta_C(C_w-C_\infty)}{U_0V_0^2}$, (Modified Grashof number)

$Gr=\frac{\upsilon g\beta_T(T_w-T_\infty)}{U_0V_0^2}$, (Grashof number)

$M=\frac{\sigma B_0^2\upsilon}{\rho V_0^2}$, (Magnetic parameter)

$K=\frac{K_0V_0^2(1+A\varepsilon e^{n^1t^1})}{\upsilon^2}$, (Porosity parameter)

$P_r=\frac{K}{\rho c_p V_0^2}=\frac{\upsilon}{\alpha}$, (Prandtl number)

$Q=\frac{v}{\rho C_p V_0^2}(Q_0+4I^1)$, (Heat source parameter)

$Kr=\frac{Kv}{V_0^2}$, (Chemical reaction parameter)

$Sc=\frac{v}{D}$, (Schmidt number)

$Ra=\frac{Q_1\upsilon}{\rho C_p V_0^2}\frac{(T_w-T_\infty)}{(C_w-C_\infty)}$, (Radiation absorption parameter)

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

$$u = U_P,\ \theta = 1,\ C = 1 \quad at \quad y = 0 \tag{13}$$

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

III. SOLUTION OF THE PROBLEM

Eqs. (10)– (12) represent a set of partial deferential equations that cannot be solved in closed form. However, it can be reduced to a set of ordinary deferential equations in dimensionless form that can be solved analytically. This can be done by representing the velocity, temperature and concentration as

$$u = u_0(y) + \varepsilon e^{nt} u_1(y) + o(\varepsilon^2) + ... \tag{15}$$

$$\theta = \theta_0(y) + \varepsilon e^{nt} \theta_1(y) + o(\varepsilon^2) + ... \tag{16}$$

$$C = C_0(y) + \varepsilon e^{nt} C_1(y) + o(\varepsilon^2) + ... \tag{17}$$

Substituting Eqs. (15)–(17) into 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, C_0) and (u_1, θ_1, C_1)

$$u_0^{11} + u_0^1 - Nu_0 = -N - Gr\theta_0 - GcC_0 \tag{18}$$

$$u_1^{11} + u_1^1 - (N+n)u_1 = -(N+n) - Gr\theta_1 - GcC_1 - Au_0^1 \tag{19}$$

$$\theta_0^{11} + \Pr\theta_0^1 - \Pr Q\theta_0 = -RaP_rC_0 \tag{20}$$

$$\theta_1^{11} + \Pr\theta_1^1 - \Pr(Q+n)\theta_1 = -A\Pr\theta_0^1 - Ra\Pr C_1 \tag{21}$$

$$C_0^{11} + ScC_0^1 - ScKrC_0 = 0 \tag{22}$$

$$C_1^{11} + ScC_1^1 - Sc(Kr+n)C_1 = -ScAC_0^1 \tag{23}$$

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

$$u_0 = Up,\ u_1 = 0,\ \theta_0 = 1,\ \theta_1 = 0,\ C_0 = 1,\ C_1 = 0 \quad at \ \ y = 0 \tag{24}$$

$$u_0 = 1,\ u_1 = 1,\ \ \theta_0 \to 0,\ \ \theta_1 \to 0,\ \ C_0 \to 0,\ \ C_1 \to 0 \ at \ \ y \to 0 \tag{25}$$

Without going into detail, the solutions of Eqs. (18)– (23) Subject to Eqs. (24) and (25) can be shown to be

$$u_0(y) = K_8 e^{-m_1 y} + K_9 e^{-m_5 y} + K_{10} e^{-m_9 y} + 1 \tag{26}$$

$$u_1(y) = K_{11} e^{-m_1 y} + K_{12} e^{-m_3 y} + K_{13} e^{-m_5 y} + K_{14} e^{-m_7 y} + K_{15} e^{-m_9 y} + K_{16} e^{-m_{11} y} + 1 \tag{27}$$

$$\theta_0(y) = K_2 e^{-m_1 y} + K_3 e^{-m_5 y} \tag{28}$$

$$\theta_1(y) = K_4 e^{-m_1 y} + K_5 e^{-m_3 y} + K_6 e^{-m_5 y} + K_6 e^{-m_7 y} \tag{29}$$

$$C_0(y) = e^{-m_1 y} \tag{30}$$

$$C_1(y) = K_1 e^{-m_1 y} + K_1 e^{-m_3 y} \tag{31}$$

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

$$u(y) = K_8 e^{-m_1 y} + K_9 e^{-m_5 y} + K_{10} e^{-m_9 y} + 1 + \varepsilon e^{nt}(K_{11} e^{-m_1 y} + K_{12} e^{-m_3 y} + K_{13} e^{-m_5 y} + K_{14} e^{-m_7 y} + K_{15} e^{-m_9 y} + K_{16} e^{-m_{11} y} + 1) \tag{32}$$

$$\theta(y) = K_2 e^{-m_1 y} + K_3 e^{-m_5 y} + \varepsilon e^{nt}(K_4 e^{-m_1 y} + K_5 e^{-m_3 y} + K_6 e^{-m_5 y} + K_6 e^{-m_7 y}) \tag{33}$$

$$C(y) = e^{-m_1 y} + \varepsilon e^{nt}(K_1 e^{-m_1 y} + K_1 e^{-m_3 y}) \tag{34}$$

The skin-friction coefficient, the Nusselt number and the Sherwood number are important physical parameters for this type of boundary-layer flow. These parameters can be defined and determined as follows:

$$Sk = \frac{\tau_w^1}{\rho U_0 V_0} = \left(\frac{\partial u}{\partial y}\right)_{y=0} = -m_1 k_8 - m_5 k_9 - m_9 k_{10} + \varepsilon e^{nt}(-m_1 k_{11} - m_3 k_{12} - m_5 k_{13} + -m_7 k_{14} - m_9 k_{15} - m_{11} k_{16}) \tag{35}$$

$$Nu = \frac{x\left(\frac{\partial \theta}{\partial y^1}\right) y^1 = 0}{T_w - T_\infty} = Nu \operatorname{Re}_x^{-1} = \left(\frac{\partial \theta}{\partial y}\right)_{y=0} = -m_1 K_2 - -m_5 K_3 + \varepsilon e^{nt}(-m_1 k_4 - m_3 k_5 - m_5 k_6 - m_7 k_7) \tag{36}$$

$$Sh = \frac{x(\frac{\partial C}{\partial y^1})y^1 = 0}{C_w - C_\infty} = Sh\,\mathrm{Re}_x^{-1} = \left(\frac{\partial C}{\partial y}\right)_{y=0} = -m_1 + \varepsilon e^{nt}(-m_1 k_1 - m_3 k_1) \tag{37}$$

IV. RESULTS AND DISCUSSIONS

Numerical evaluation of the analytical results reported in the previous section was performed and a representative set of results is reported graphically in Figs. 1–9. These results are obtained to illustrate the influence of the chemical reaction parameter Kr, the Schmidt number Sc, the heat absorption coefficient Q, the magnetic field parameter M on the velocity, temperature and the concentration profiles, while the values of the physical parameters are fixed at real constants, A = 0.01, Up = 1, Gr=5, Gc=5, M=1,Sc=0.62, Ra=1, Kr=0.1,N = 1, the frequency of oscillations n =1, scale of free stream velocity Q = 5, Prandtl number Pr = 0.72 and t = 0.1. Figs. 1, 2 and 3 display results for the velocity increases when the parameters Gr,Gc and K increases. Also, we observe from Fig 2 the magnitude of the stream wise velocity decreases due to the parameters M increases. Figs. 5 and 6 display the effects of the Schmidt number Sc and Chemical reaction on the concentration profiles, respectively. As the Schmidt number (Sc) and Chemical reaction increases, the concentration decreases. This causes the concentration buoyancy effects to decrease yielding a reduction in the fluid velocity. The reductions in the velocity, temperature and concentration profiles are accompanied by simultaneous reductions in the momentum and concentration boundary layers thickness. Figs. 7 and 9 illustrate the influence of the heat absorption coefficient and Prandtl number on the temperature profiles, respectively. The presence of heat absorption effects has the tendency to reduce the fluid temperature. This causes the thermal buoyancy effects to decrease resulting in a net reduction in the fluid velocity. The fig 7 shows that the temperature distribution decreases as heat absorption increases. It is also observed that both the hydrodynamic (velocity) and the thermal (temperature) boundary layers decrease as the heat absorption effects increase. But in the case of radiation parameter increases then temperature also increases.

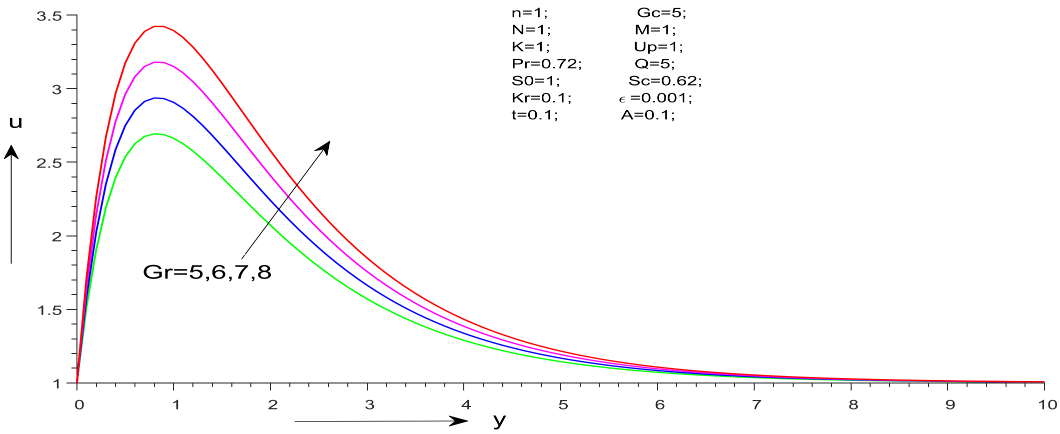

Fig 1:Effect of Grashof number on u.

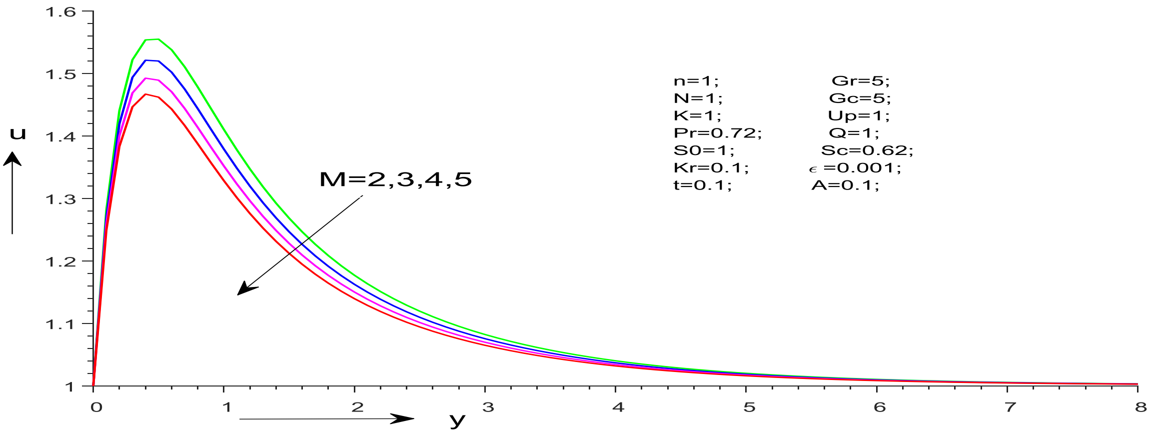

Fig 2:Effect of Magnetic parameter on u.

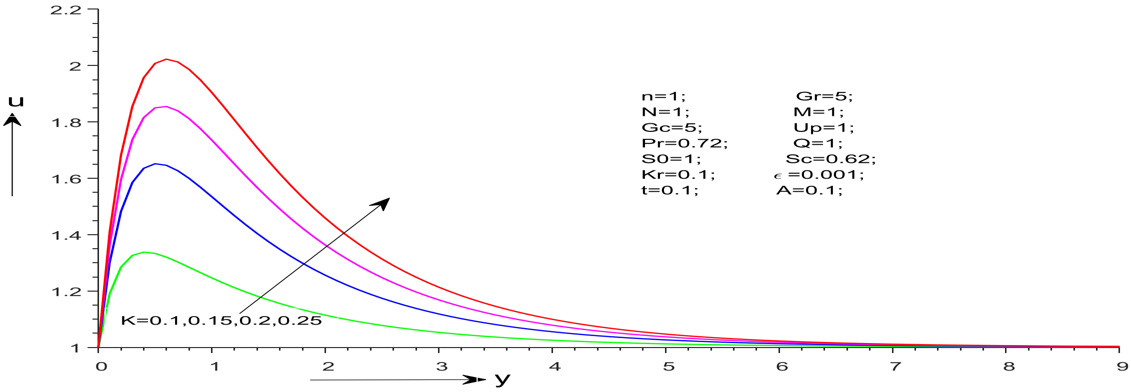

Fig 3 :Effect of porosity parameter on u.

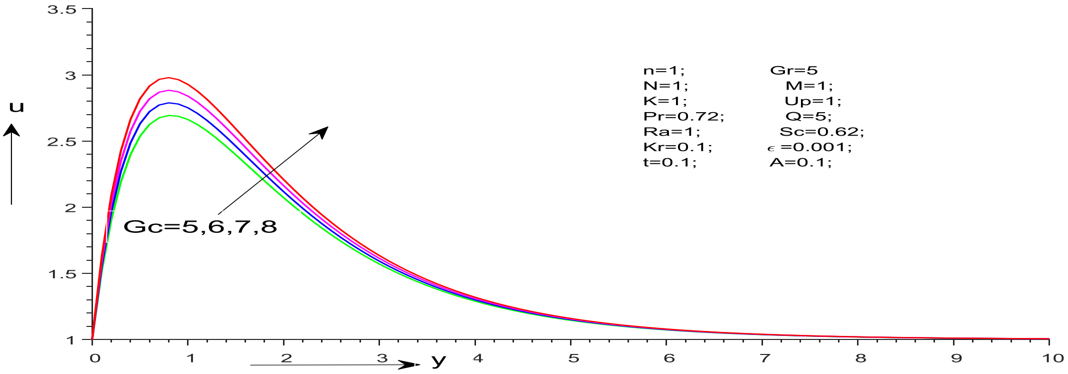

Fig 4: Effect of Modified Grashof number on velocity u.

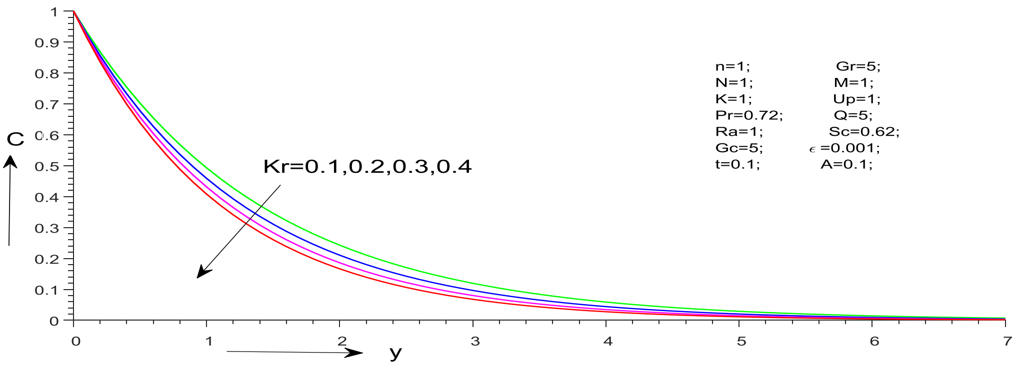

Fig 5:Effect of Chemical Reaction parameter on C.

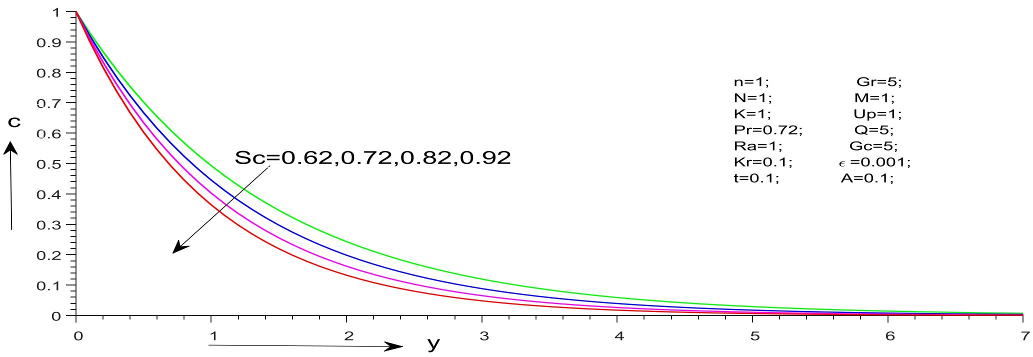

Fig 6: Effect of Schmidt number on C.

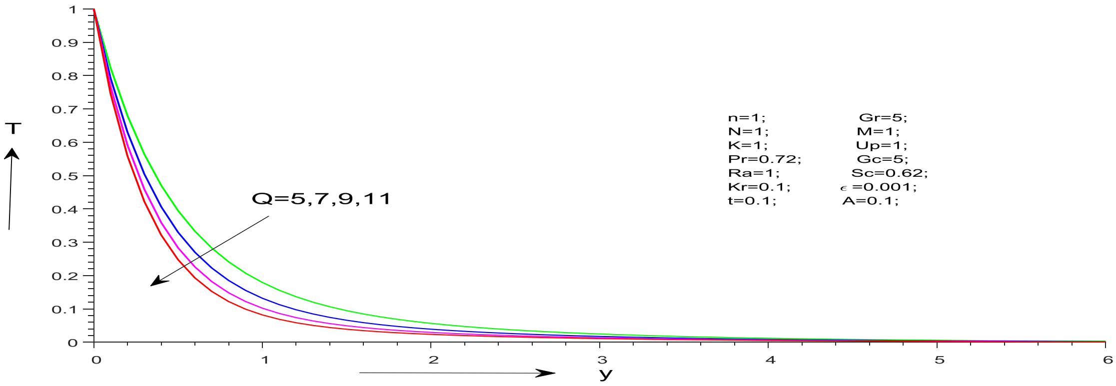

Fig 7:Effect of Heat source parameter on T.

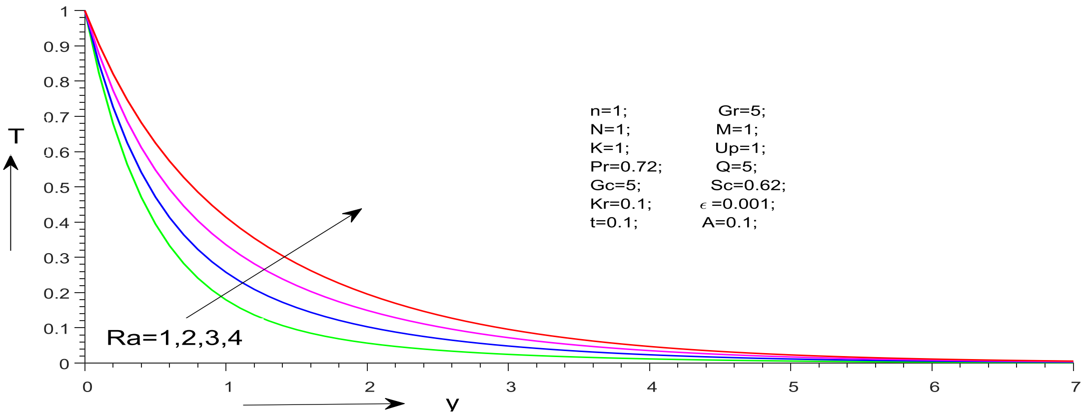

Fig 8:Effect of Radiation parameter on T.

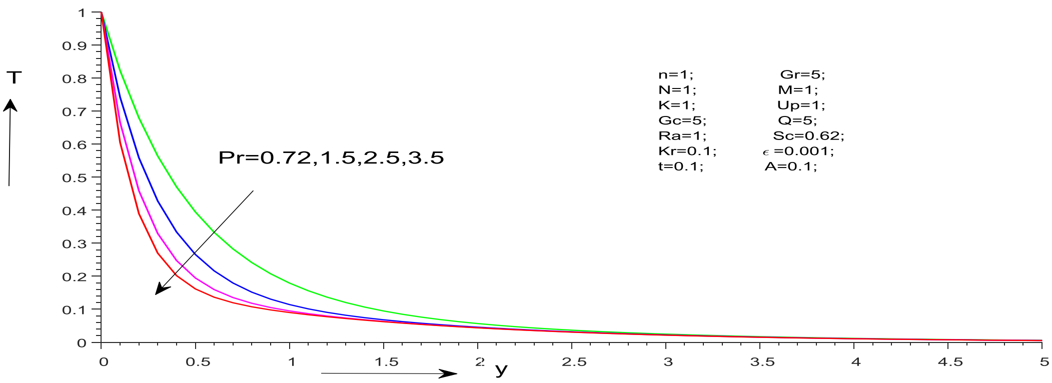

Fig 9: Effect of Prandtl number on T.

Table 1: Effect of various physical parameters on Skin friction, Nusselt number and Sherwood number

Gc	Gr	Pr	Q	Ra	Sc	Kr	Nusselt Number	Sherwood Number	Skin Friction
2	5	0.72	1	1	0.62	0.1	1.9753	0.7146	4.1996
3	5	0.72	1	1	0.62	0.1	1.9753	0.7146	4.6252
4	5	0.72	1	1	0.62	0.1	1.9753	0.7146	5.0508
5	5	0.72	1	1	0.62	0.1	1.9753	0.7146	5.4764
5	2	0.72	1	1	0.62	0.1	1.9753	0.7146	2.8846
5	3	0.72	1	1	0.62	0.1	1.9753	0.7146	3.6389
5	4	0.72	1	1	0.62	0.1	1.9753	0.7146	4.3933
5	5	1	1	1	0.62	0.1	2.3912	0.7146	5.4764
5	5	2	1	1	0.62	0.1	3.6555	0.7146	5.4764

5	5	3	1	1	0.62	0.1	4.7610	0.7146	5.4764
5	5	0.72	2	1	0.62	0.1	1.1631	0.7146	5.4764
5	5	0.72	3	1	0.62	0.1	1.4863	0.7146	5.4764
5	5	0.72	4	1	0.62	0.1	1.7492	0.7146	5.4764
5	5	0.72	1	2	0.62	0.1	1.6594	0.7146	5.4764
5	5	0.72	1	3	0.62	0.1	1.3435	0.7146	5.4764
5	5	0.72	1	4	0.62	0.1	1.0276	0.7146	5.4764
5	5	0.72	1	1	1	0.1	1.9753	1.0913	5.4764
5	5	0.72	1	1	2	0.1	1.9753	2.0943	5.4764
5	5	0.72	1	1	3	0.1	1.9753	3.0945	5.4764
5	5	0.72	1	1	0.62	0.2	1.9753	0.7790	5.4764
5	5	0.72	1	1	0.62	0.3	1.9753	0.8409	5.4764
5	5	0.72	1	1	0.62	0.4	1.9753	0.8964	5.4764

V. CONCLUSIONS

The resulting partial deferential equations were transformed into a set of ordinary deferential equations using two-term series and solved in closed-form. Numerical evaluations of the closed-form results were performed and some graphical results were obtained to illustrate the details of the flow and heat and mass transfer characteristics and their dependence on some of the physical parameters. Velocity increases as Gr,Gc and K are increases and Velocity increases in case of M increases. Temperature decreases as Pr and Q increases but in the case of Ra increases then temperature increases. The Concentration reduces with an increase in Sc and Kr. Skin friction increases with increases of Gr and Gc. Nusselt number increases as Pr and Q increases. Sherwood number increases with increases of Sc and Kr.

VI. NOMENCLATURE

B_0	Magnetic field of uniform strength
C	Non-dimensional Species concentration
C^l	Species concentration
D	Molecular diffusivity
G	Acceleration due to gravity
Gc	Modified Grashof number
Gr	Grashof number
K	Porosity parameter
K^1	Permeability of the medium
Kr	Chemical reaction parameter
M	Magnetic parameter
Nu	Nusselt number
P	Density of the fluid
Pr	Prandtl number
Q	Heat absorption parameter
Sc	Schmidt number
Sh	Sherwood number
Sk	Skin friction
So	Soret number
T	Non-dimensional temperature
T	Non dimensional time
t^l	time
U	Non-dimensional velocity
u^l	Velocity component along x-axis
V	Suction velocity
V_o	Constant suction velocity
Y	Non-dimensional distance along y-axis
Y	Kinematic coefficient of viscosity
y^l	Distance along y-axis
W	Electrical conductivity
Σ	Non-dimensional frequency of oscillation
Ω	A small positive constant

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