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RADIATION AND CHEMICAL REACTION EFFECTS OF HEAT AND MASS TRANSFER ON CONVECTIVE MHD SLIP FLOW WITH VARIABLE VISCOSITY IN POROUS MEDIA

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ABSTRACT

The study investigated radiation and chemical reaction effects of heat and mass transfer on convective Magnetohydrodynamics (MHD) slip flow in a porous medium over exponentially-stretching sheet in the presence of variable viscosity and heat generations. The governing boundary layer equations of the model were transformed to a system of ordinary coupled differential equations. The coupled system of equations were then solved numerically by a fourth order Runge-Kutta method along with shooting technique. A parametric study on the effect of variations in the fluid parameters on velocity, temperature and concentration were conducted and presented graphically. Also, the effects of radiation, magnetic field, thermal and solutal grashof parameters, pranddtl, schmidt and chemical reactions on heat and mass transfer as well as their effects on skin friction, Nusselt and Sherwood number on the fluid parameters were verified and discussed in detail. The findings include the numerical results of variation in Skin friction, Nusselt number and Sherwood number which explain the exponential velocity of the fluid flow, temperature of the energy as well as exponential concentration from which the chemical reaction effects were verified.

Keywords: MHD slip flow, Variable viscosity, Heat Source, Chemical Reaction, Porous Media

1.0 INTRODUCTION

Heat and mass transfers are important factors in boundary layer problems because of universality and usefulness in virtually every aspect of human endeavour. Research studies have extensively examined the combination of heat and mass transfer effects especially using radiation and chemical reaction with various parameters on MHD among othersto explain fluid flow concepts (Amoo and Idowu, 2017). Heat flow and transfer of fluid through porous media is equally necessary as a result, the effects over stretching or shrinking surface are important. Boundary layer flow over a moving continuous and linearly stretching surface is a significant type offlow which has considerable electrochemistry and polymer processing, practical applications in engineering, for example, materials manufactured by extrusion processes and heat treated material stravelling between a feed roll and a windup roll or on a conveyor belt possess the characteristics of amoving continuous surface (Devi, Neeraj, and Reddy, 2015, Amoo, Idowu and Amoo, 2017). To be more specific, it may be pointed out that many metallurgical processes involve the cooling of continuous strips or filaments by drawing them through a quiescent fluid and that in the process of drawing, these strips are sometimes stretched hence the usefulness of this study. It may be made of drawing, annealing and tinning of copper wires.

In all the cases, the properties of the final product depend to a great extent on the rate of cooling. By drawing such strips in an electrically conducting fluid subjected to a magnetic field, the rate of cooling can be controlled and a final product of desired characteristics can be achieved. Flow and heat transfer of a viscous fluid past a stretching

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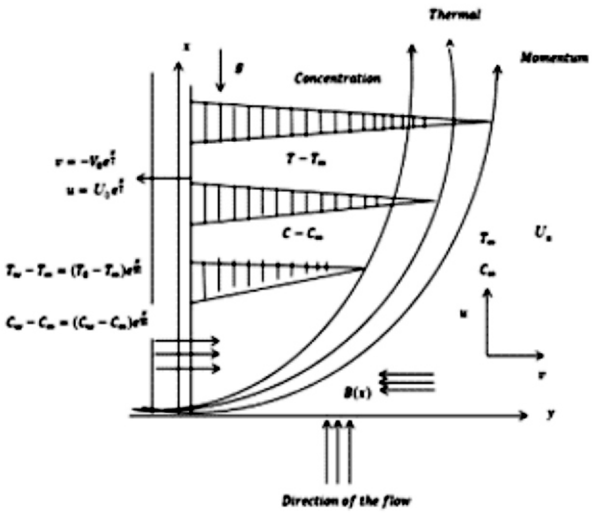
sheet is a significant problem with industrial heat transfer applications.

As a result, Sharman (2004) studied unsteady effect on MHD free convective and mass transfer flow through porous medium with constant suction and constant heating flux in rotating system, whereas in convective fluid, when the flow of mass is caused by a temperature difference, thermal diffusion effects cannot be neglected. Cortell (2006) presented effects of viscous dissipation and work-done by looking at the deformation on the MHD flow and heat transfer of visco-elastic fluid over stretching sheet. Hayat and Sajid (2007) studied analytical solution for axi-symmetric flow and heat transfer of a second grade fluid past a stretching sheet. In the same perspective, exact analytical solution for heat and mass transfer of MHD slip flow in nanofluids had been carried out by Turkyilmazoglu (2012). The slip effect on MHD boundary layer over exponentially stretching sheet was examined by Mukhopadhyay (2012) while Mukhopadhyay and Gorla (2008) presented the effects of partial slip on boundary layer flow past a permeable exponentially stretching sheet in the presence of thermal radiation, heat and mass transfer.Shekhar (2014) carried out analysis on the boundary layer phenomena of MHD flow and heat transfer over an exponentially stretching sheet embedded in a thermally stratified medium. The researcher neglected the chemical reaction and discovered that temperature gradient increases consistently with increase in stratification parameter. Also, Ibrahim and Suneetha (2015) presented the effects of heat generation and thermal radiation on steady MHD flow near a stagnation point on a stretching sheet in porous medium and presence of variable thermal conductivity and mass transfer, it was discovered that temperature increased with increasing radiation parameter and concentration decreased with increasing Schmidt number. Devi, Neeraj, and Reddy (2015) also presented studies on radiation effect on MHD slip flow past a stretching sheet with variable viscosity and heat source/sink. Amoo,Ajileye and Amoo (2018) presented Heat and Mass Transfer Effects on MHD Fluid Embedded in Darcy-Forchemmer Medium with Viscous Dissipation and Chemical Reaction.

In view of the above studies, the present study investigated radiation and chemical reaction effects of heat and mass transfer on convective Magnetohydrodynamics (MHD) slip flow in a porous medium over exponentially-stretching sheet in the presence of variable viscosity and heat generations. The effects of all independent variables on dependent variables were analysed.

2.0 MATHEMATICALANALYSIS

Consider the free convective thermal radiation and chemical reaction effects on heat and mass transfer of two dimensional MHD slip flow of an electrically conducting, steady, viscous and incompressible fluid flow past exponentially-stretching sheet under the action of thermal and solutal buoyancy forces. A uniform transverse variable magnetic field is applied perpendicular to the direction of flow with chemical reaction is taking place in the fluid flow. The flow is assumed to be in the



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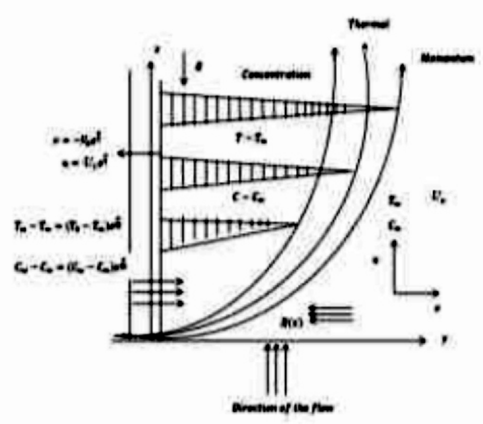

Figure 1: The physical model and coordinate system

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad (1)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\frac{1}{r}\frac{\partial m}{\partial T}\frac{\partial T}{\partial y}\frac{\partial u}{\partial y}+\frac{m}{r}\frac{\partial^2 u}{\partial y^2}-\frac{1}{r}sB^2(x)u+gb_T(T-T_\infty)+gb_C(C-C_\infty) \qquad (2)$$

$$rC_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=k\frac{\partial^2 T}{\partial y^2}-\frac{\partial q_r}{\partial y}+Q_0(T-T_\infty) \qquad (3)$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2}-g(C-C_\infty) \qquad (4)$$

Subject to the following boundary conditions:

$$u=U_0e^{\frac{x}{L}}=cx+L\frac{\partial u}{\partial y},v=-V_0e^{\frac{x}{L}},T=T_w=T_\infty+T_0e^{\frac{x}{2L}},C=C_w=C_\infty+C_0e^{\frac{x}{2L}}\ \ at\ \ y=0$$
$$u\to 0,T\to T_\infty,C\to C_\infty\ \ as\ \ y\to\infty \qquad (5)$$

where u, v, C, and T are velocity component in the x direction, velocity component in the y direction, concentration of the fluid species and fluid temperature respectively. L is the reference length, $B(x)$ is the magnetic field strength, U_0 is the reference velocity and V_0 is the permeability of the porous surface. The physical quantities K, r, n, s, D, k, C_p, Q_0 and g are the permeability of the porous medium, density, fluid kinematics viscosity, electric conductivity of the fluid, coefficient of mass diffusivity, thermal conductivity of the fluid, specific heat, rate of specific internal heat generation or absorption and reaction rate coefficient respectively. g is the gravitational acceleration, b_T and b_C are the thermal and mass expansion coefficients respectively. q_r is the radiative heat flux in the y direction. By using the Rosseland approximation according to Ibrahim and Suneetha (2015). The radiative heat flux q_r is given by

$$q_r=-\frac{4s_0}{3d}\frac{\partial T^4}{\partial y} \qquad (6)$$

where s_0 and d are the Stefan-Boltzmann and the mean absorption coefficient respectively. Assume the temperature difference within the flow are sufficiently small such that T^4 may be expressed as a linear function of temperature, using Taylor series to expand T^4 about the free stream T_∞ and neglecting higher order terms, this gives the approximation

$$T^4\cong 4T_\infty^3T-3T_\infty^4 \qquad (7)$$

The magnetic field $B(x)$ is assumed to be in the form

$$B(x)=B_0e^{\frac{x}{2L}}, \qquad (8)$$

where B_0 is the constant magnetic field.

Introducing the stream function $y(x,y)$ such that

$$u=\frac{\partial y}{\partial y},v=-\frac{\partial y}{\partial x} \qquad (9)$$

Temperature dependent viscosity according to Devi, et al (2015) is of the form:

$$m=m_1a+b(T_w-T) \qquad (10)$$

Where m_1 is the constant value of the coefficient of viscosity in the free stream and a, b are constants with $b(>0)$ having unit K^{-1}. Here viscosity temperature relation $m=a_1-b_1T$ which accords the relation $m = e^{-a_1 T}$ when second and higher order terms are neglected

Temperature dependent viscosity according to Devi, et al (2015) is of the form:

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Where m_1 is the constant value of the coefficient of viscosity in the free stream and a, b are constants with $b(>0)$ having unit K^{-1}. Here viscosity temperature relation $m = a_1 - b_1 T$ which accords the relation $m = e^{-a_1 T}$ when second and higher order terms are neglected from the expansion. The expression of kinematic viscosity becomes $u = u_1 . a + b(T_w - T)$, where $u_1 = \frac{m_1}{r}$ the constant value of the kinematic fluid viscosity.

Substituting equation (9) in equation (1), continuity equation satisfied Chauchy-Riemann equation and equations (2)-(4), give

$$\frac{\partial y}{\partial y}\frac{\partial^2 y}{\partial x \partial y} - \frac{\partial y}{\partial x}\frac{\partial^2 y}{\partial y^2} = -nb\frac{\partial T}{\partial y}\frac{\partial^2 y}{\partial y^2} + n(a + b(T_w - T))\frac{\partial^3 y}{\partial y^3} - \frac{s}{r}B_0 e^{\frac{x}{2L}}\left(\frac{\partial y}{\partial y}\right) + gb_T(T - T_\infty) + gb_C(C - C_\infty) \quad (11)$$

$$\frac{\partial y}{\partial y}\frac{\partial T}{\partial x} - \frac{\partial y}{\partial x}\frac{\partial T}{\partial y} = \left(\frac{k}{rC_p} + \frac{16 s_0 T_\infty^3}{3 rC_p d}\right)\frac{\partial^2 T}{\partial y^2} + \frac{Q_0}{rC_p}(T - T_\infty) \quad (12)$$

$$\frac{\partial y}{\partial y}\frac{\partial C}{\partial x} - \frac{\partial y}{\partial x}\frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial y^2} - g(C - C_\infty) \quad (13)$$

The corresponding boundary conditions become:

$$\begin{aligned} &\frac{\partial y}{\partial y} = U_0 e^{\frac{x}{L}} = cx + L\frac{\partial u}{\partial y},\ \frac{\partial y}{\partial x} = V_0 e^{\frac{x}{L}}, T = T_w = T_\infty + T_0 e^{\frac{x}{2L}}, \\ &C = C_w = C_\infty + C_0 e^{\frac{x}{2L}} \quad at \quad y = 0 \\ &\frac{\partial y}{\partial y} \to 0, T \to T_\infty, C \to C_\infty \quad as \quad y \to \infty \end{aligned} \quad (14)$$

In order to transform the equations (11), (12) and (13) as well as the boundary conditions (14) into an ordinary differential equations, the following similarity transformations variables were introduced following Sajid and Hayat (2008) and after several manipulations by substituting equation(15) transformed into equations (16) –(18).

$$\begin{aligned} &y(x, y) = \sqrt{2nU_0 L e^{\frac{x}{2L}}} f(h), h = y\sqrt{\frac{U_0}{2nL}} e^{\frac{x}{2L}}, T = T_\infty + T_0 e^{\frac{x}{2L}} q(h), \\ &C = C_\infty + C_0 e^{\frac{x}{2L}} f(h) \end{aligned} \quad (15)$$

In view of equation (15), the equations become

$$(a + A - Aq)f''' + ff'' - Aqf' - f'^2 - Mf' + G_r q + G_c f = 0 \quad (16)$$

$$\left(1 + \frac{4}{3}R\right)q'' + P_r fq' - P_r f' q + P_r Qq = 0 \quad (17)$$

$$f'' + S_c f f' - S_c f' f - S_c / f = 0 \quad (18)$$

The corresponding boundary conditions take the form:

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$$f = f_w, f' = 1 + d f'', q = 1, \varphi = 1 \ at \ h = 0$$
$$f' = 0, q = 0, \varphi = 0 \ as \ h \to \infty \quad (19)$$

where $d = L(\frac{c}{u_1})^{\frac{1}{2}}$ is the slip parameter, $A = b(T_w - T)$ is the viscosity parameter, $M = \frac{2sLB_0}{rU_0}e^{\frac{x}{2L}}$ is the magnetic parameter, $Gc = \frac{2Lgb_T T_0}{U_0^2}e^{\frac{3x}{2L}}$ is the thermal Grashof number, $Gc = \frac{2Lgb_C C_0}{U_0^2}e^{\frac{3x}{2L}}$ is the solutal Grashof number, $Pr = \frac{rnC_p}{k} = \frac{m_1 c_r}{k}$ is the Prandtl number, $R = \frac{4s_0 T_\infty^3}{dk}$ is the thermal radiation parameter, $Q = \frac{2LQ_0}{U_0 rC_p}e^{-\frac{x}{L}}$ is the heat generation parameter, $Sc = \frac{n_1}{D}$ is the Schmidt number, $l = \frac{2Lg}{U_0}e^{-\frac{x}{L}}$ is the chemical reaction parameter, $f_w = V_0\sqrt{\frac{2L}{nU_0}}e^{\frac{3x}{2L}}$ is the permeability of the plate.

The skin friction coeficient was $C_f\left(\frac{\mathrm{Re}_x}{2}\right)^{\frac{1}{2}} = f''(0)$, the local Nusselt number was written as $Nu\left(\frac{\mathrm{Re}_x}{2}\right)^{-\frac{1}{2}} = -q'(0)$ and the local Sherwood number stood as $Sh\left(\frac{\mathrm{Re}_x}{2}\right)^{-\frac{1}{2}} = -\varphi(0)$

1. Method of Solution

The equations (16), (17) and (18) are highly non-linear coupled differential equations and its satisfying the boundary conditions (19). The problem being a boundary value problem, applying a shooting technique (guessing the unknown values) to change the conditions to initial value problem. Equations (16-18) along with the boundary conditions (19) were solved numerically by applying Nachtsheim-Swigert shooting iteration technique along with Runge-Kutta fouth-order integration scheme. The computations were performed using a symbolic program and computational computer language Maple 18. The step size was taken to be $\Delta h = 0.001$ to satisfy the relative convergence requirement of 10^{-5} in all cases. The value of h_∞ was noticed to the iteration loop by $h_\infty = h_\infty + \Delta h$. The highest value of h_∞ to each parameter was determined when the values of the unknown boundary conditions at $h = 0$ did not change after successful loop with error less than 10^{-5}.

3.0 RESULTS AND DISCUSSION

From the process of numerical computation, the skin-friction coefficient, the local Nusselt number and the local Sherwood number, which were respectively proportional to $f''(0)$, $q'(0)$ and $\varphi(0)$, at the plate were examined for different values of the parameters. The comparison of the present study with the skin friction of the existing works are presented in Table 1 for values of d when A=0.

Table 1: Comparison of the present study with the skin friction of the existing works

Values	Present study	Devi et al (2015)	Anderson (2002)	Bhattacharyya, and Layek (2010).
Values	$f''(0)$	$f''(0)$	$f''(0)$	$f''(0)$
0.0	-0.000000	-1.000480	-1.0000	-1.000000
0.1	-0.8768	-0.8725	-0.8721	-0.872083

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	89	71		
0.5	- 0.6464 94	- 0.5916 83	-0.5912	-0.591105

Table 1 shows numerical values of skin friction when compared with the existing literature and were in close agreement. The present study shows improvement over the previous studies.

The following parameter values were adopted for computation as default number: $Gr = 1, Gc = 0.01$, $Q = 0.5$, $M = 0.001$, $f_w = 1$, $R = 1$, $Sc = 0.35$, $\lambda = 0.5$, $a = 0.1$, $A = 0.2$, $Pr = 0.72$. All graphs correspond to the value except otherwise indicated on the graph.

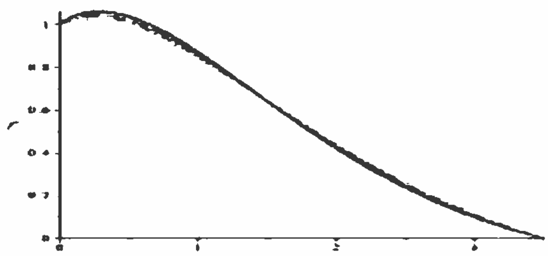
Table 1: Effect of f_w, G_r, G_c, S_c, P_r, and R on $f''(0)$, $\theta'(0)$ and $f(0)$ (P-Parameters)

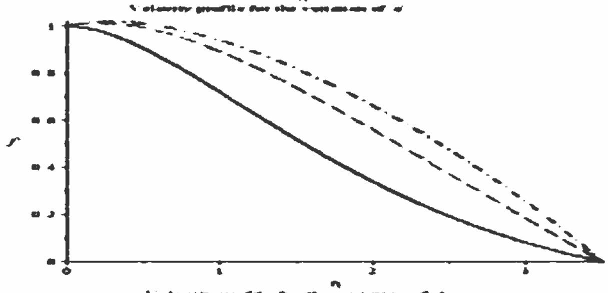
P	Values	$f''(0)$	$-\theta'(0)$	$-f(0)$	P	Values	$f''(0)$	$-\theta'(0)$	$-f(0)$
a	0.1	0.4836	1.0189	0.7068	A	0.2	0.1021	0.9856	0.6929
	0.2	0.3904	1.0132	0.7045		0.3	0.1009	0.9862	0.6927
	0.3	0.3231	1.0086	0.7026		0.5	0.0987	0.9874	0.6934
	0.5	0.2281	1.0013	0.6995		0.7	0.0963	0.9883	0.6940
M	0.001	-0.0035	0.9561	0.6786	Sc.	0.35	1.9616	1.0854	1.1419
	2.0	0.1282	1.0105	0.7061		0.62	1.8367	1.0639	1.6056
	3.0	0.1337	1.0228	0.7135		1.50	1.6166	1.03509	2.8293
	5.0	0.1374	1.02295	0.7181		2.00	1.5408	1.0276	3.4472
G_r	1	0.0547	0.9745	0.6872	P_r,	0.72	1.8367	1.06394	1.6056
	2	0.3344	1.0080	0.7021		0.78	1.7924	1.1168	1.6020
	3	0.6007	1.0368	1.1045		0.84	1.7502	1.1687	1.5986
	4	1.1045	1.0851	0.7376		0.90	1.7098	1.2198	1.5954
G_c.	0.01	-0.2068	0.9404	0.6727	R	0.5	1.8367	1.0639	1.6656
	3.1	0.6829	1.0678	0.7322		1.7	2.1514	0.7265	1.6328
	3.8	0.8696	1.0892	0.7429		4.7	2.3947	0.5015	1.6551

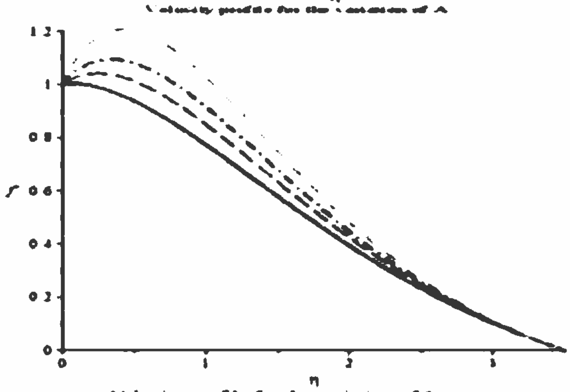
	5.0	1.1805	1.1221	0.7596		7.0	2.4645	0.4433	1.6616
f_w	1	1.8367	1.0639	1.6056	Q	0.5	1.8367	1.0639	1.6056
	2	1,6342	1.3392	2.0137		1.5	1.9013	0.9937	1.6099
	3	1.3254	1.6509	2.4711		2.5	1.9484	0.9443	1.6131
	4	0.9630	1.9952	2.9696		4.0	2.0831	0.8099	1.6221
λ	0.5	1.8367	1.0639	1.6056	λ	2.5	1.7622	1.0537	2.0014
	1.5	1.7959	1.0582	1.8152		4.0	1.7208	1.0484	2.2498

Table 2 represents the numerical results of variation in Skin friction, Nusselt and Sherwood numbers at the surface with a, A, M, Gr, Gc, , f_w, Q, Sc , Pr, R and λ which are of physical and engineering interest. It could be observed from the results that an increase in the values of a, A, M, f_w, Sc and Pr. decreased the flow boundary layer while increase in M, Gc. Gr. Q and R increase the flow boundary layer. R, Sc., Q and a decreased thermal boudary layer. The table depicts that an increase in the values of M, Q, Gr, Gc, and R thicken the thermal boundary layer by reducing the rate at which heat diffuse out of the system while increase in f_w, Sc, λ and Pr reduce the thickness of the thermal boundary layer. Also, the results show that increase in Pr, causes thinning in the concentration boundary layer while $M, R, Gr, Gc, Sc, Q, fw,$ and λ thicken the mass boundary layer. The grahical representations of the study were discussed on the basis of velocity, temperature and concentration profiles respectively.

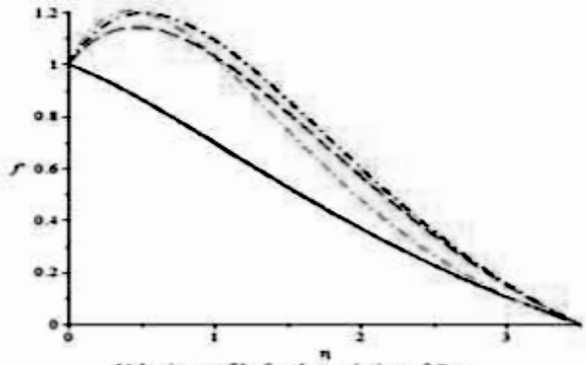
Figures 2 to 11 represent the effects of a, A, M, Gc. Gr. Q, λ , Sc, Pr, fw, R magnetic field parameter M on the flow, figures 12 to 22 presented the effects of variations of a, A, M, Gc. Gr. Q, λ, Sc, Pr, fw, R on temperature profiles and figures 23 to 31 explained the effects of the variations of a, A, M, Gc. Gr. Q, λ, Sc, Pr, fw, R parameters on the concentration profiles respectively.







Velocity profile for the variation of Gr



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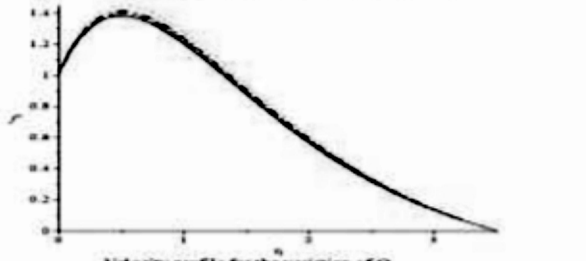
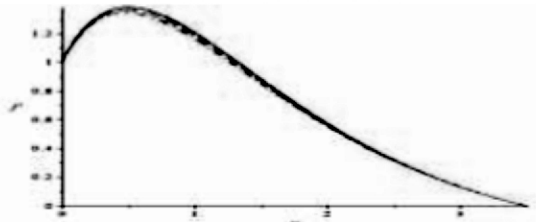
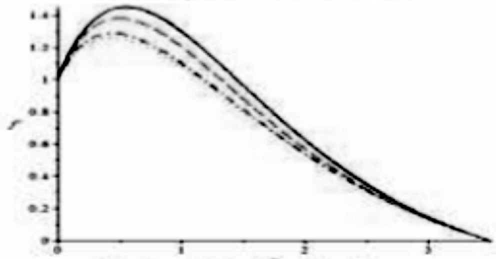


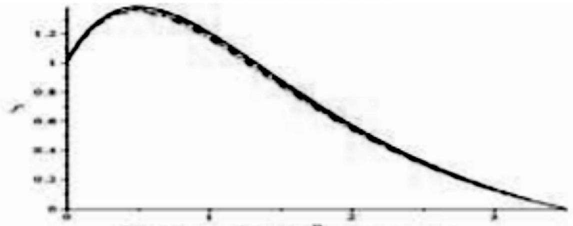
Velocity profile for the variation of Q



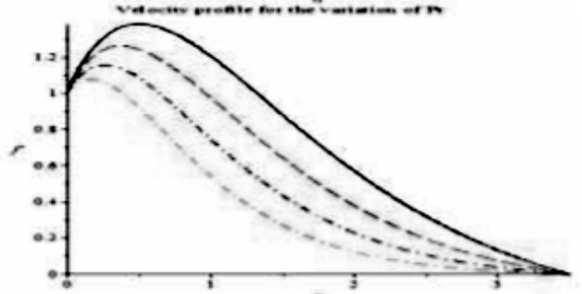
Velocity profile for the variation of A



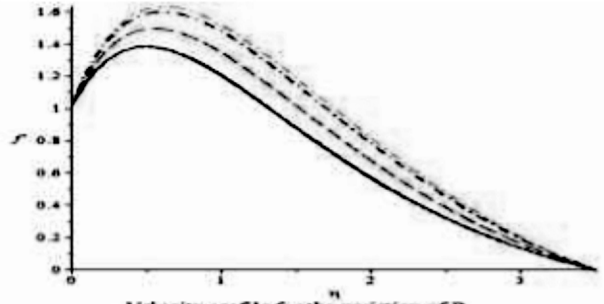
Velocity profile for the variation of Sc



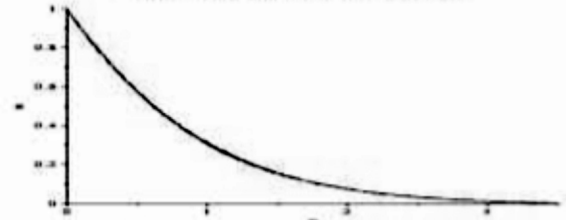
Velocity profile for the variation of Pr



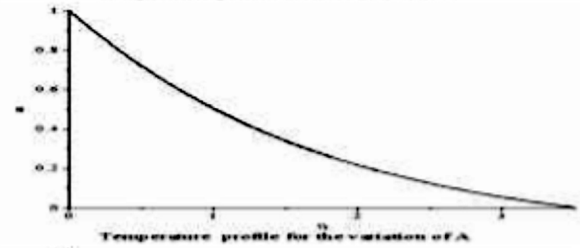
Velocity profile for the variation of fw



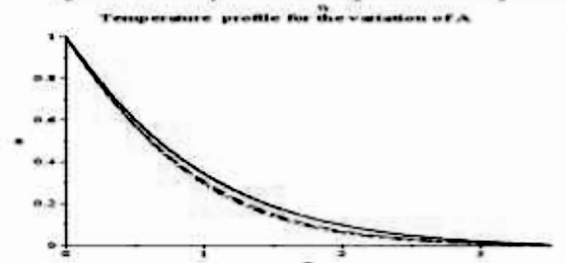
Velocity profile for the variation of R



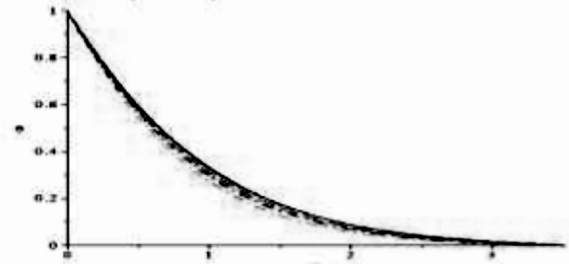
Temperature profile for the variation of a



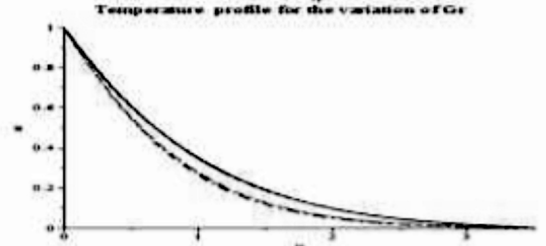
Temperature profile for the variation of A



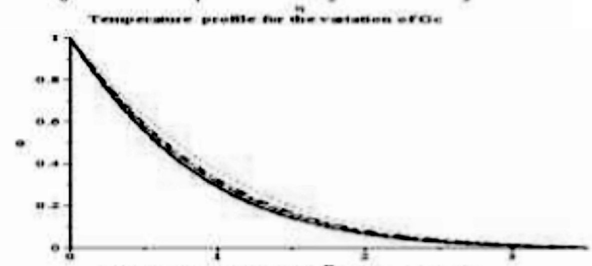
Temperature profile for the variation of M



Temperature profile for the variation of Gr



Temperature profile for the variation of Gc



Temperature profile for the variation of Q

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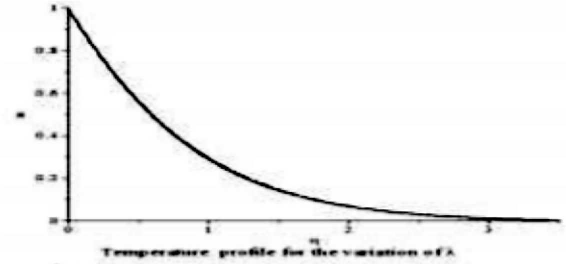
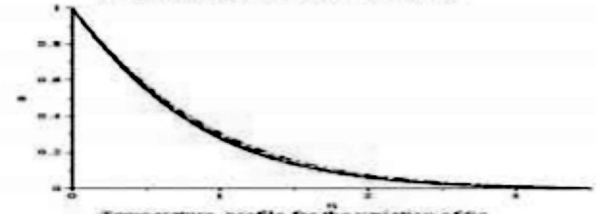
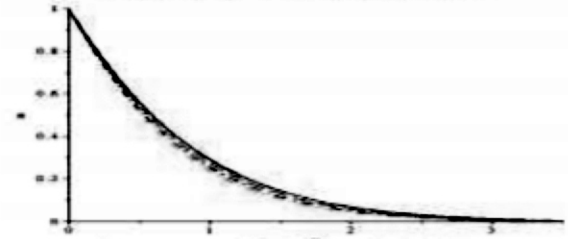


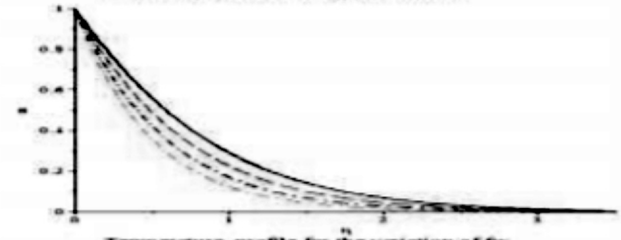
Temperature profile for the variation of λ



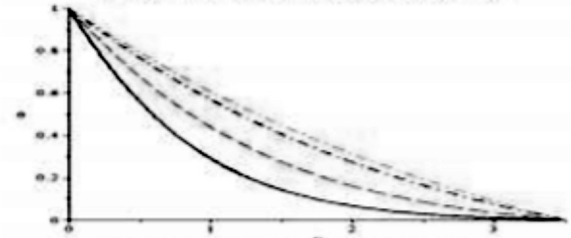
Temperature profile for the variation of Sc



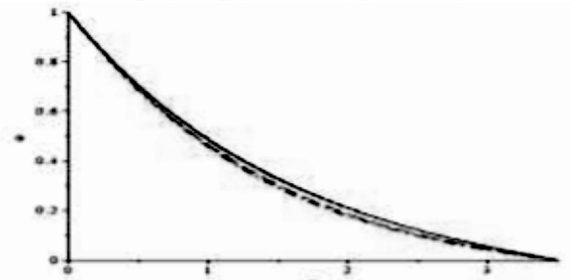
Temperature profile for the variation of Pr



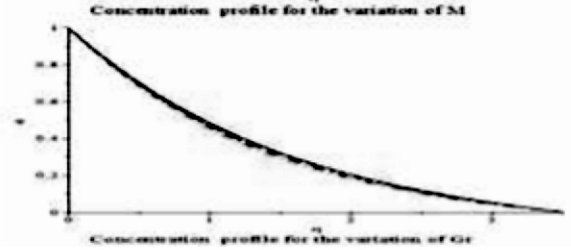
Temperature profile for the variation of fw



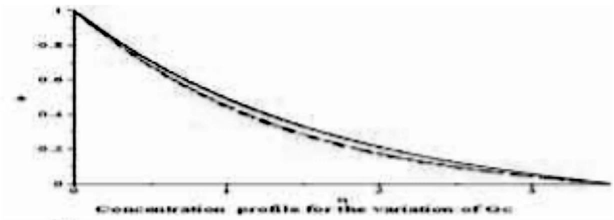
Temperature profile for the variation of R



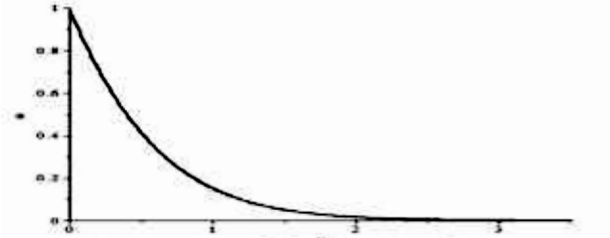
Concentration profile for the variation of M



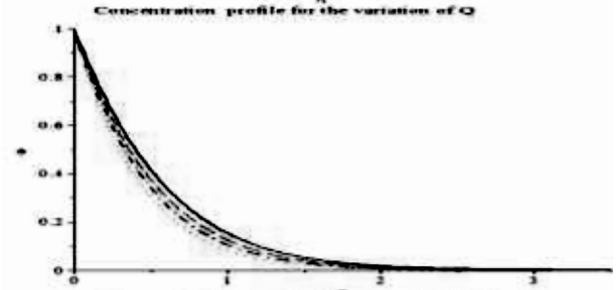
Concentration profile for the variation of Gr



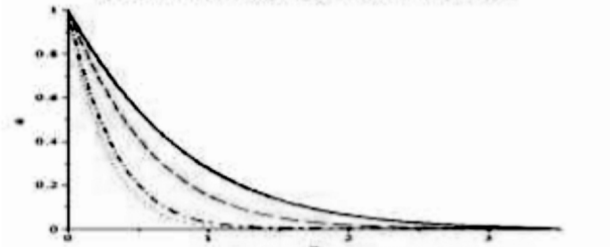
Concentration profile for the variation of Gc



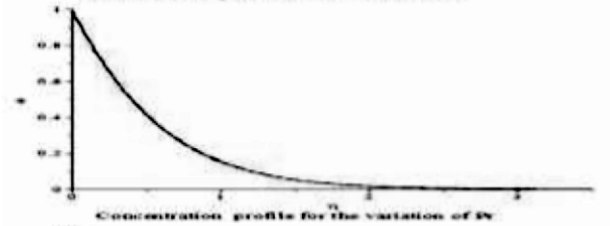
Concentration profile for the variation of Q



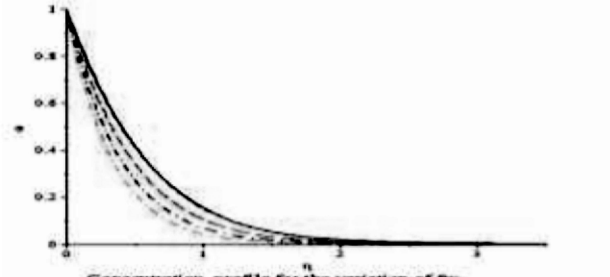
Concentration profile for the variation of λ



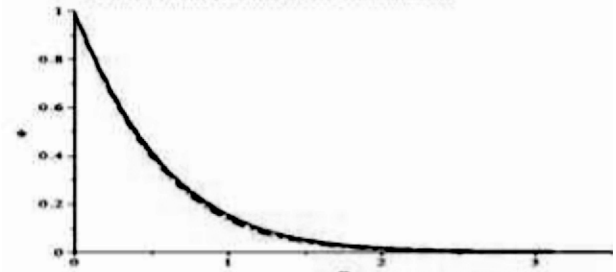
Concentration profile for the variation of Sc



Concentration profile for the variation of Pr



Concentration profile for the variation of fw



Concentration profile for the variation of R

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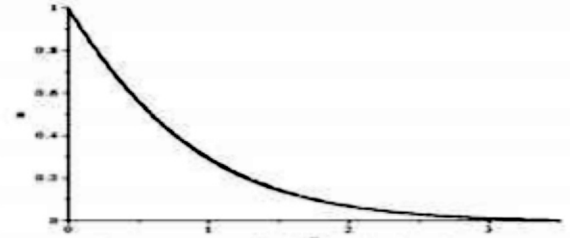
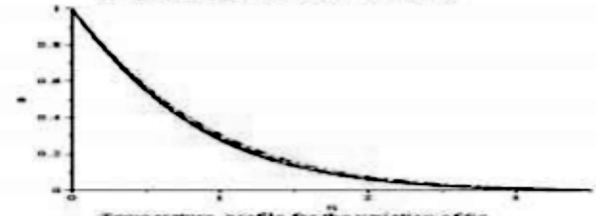
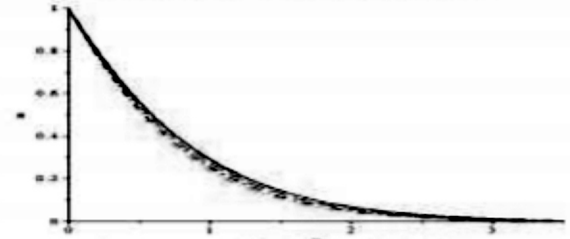


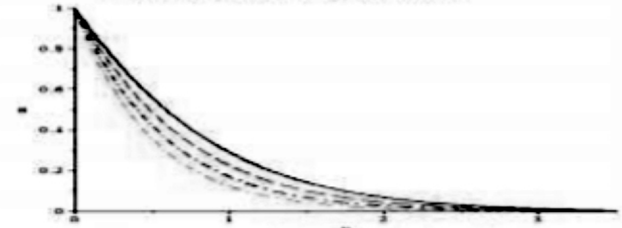
Temperature profile for the variation of λ



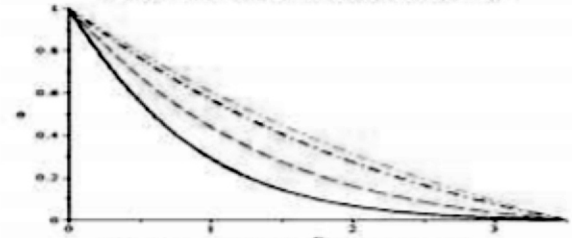
Temperature profile for the variation of Sc



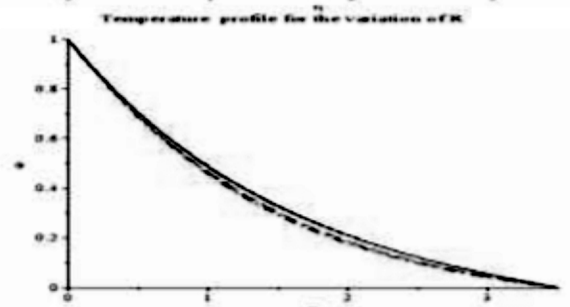
Temperature profile for the variation of Pr



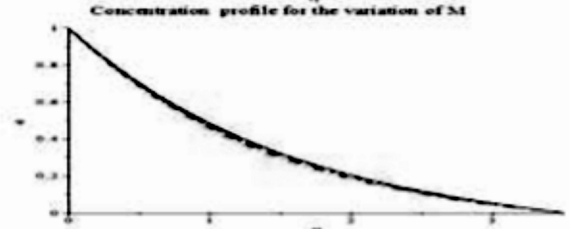
Temperature profile for the variation of fw



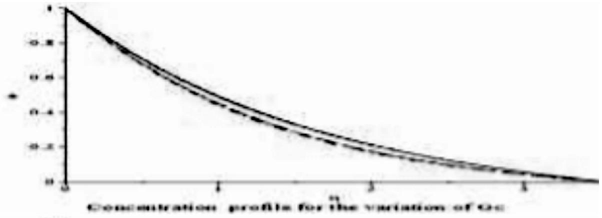
Temperature profile for the variation of R



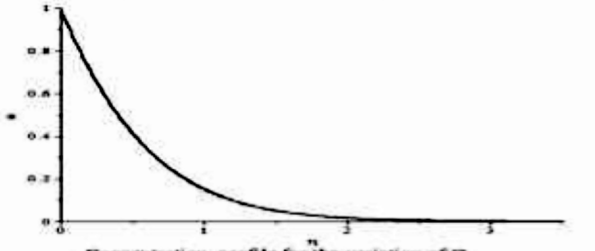
Concentration profile for the variation of M



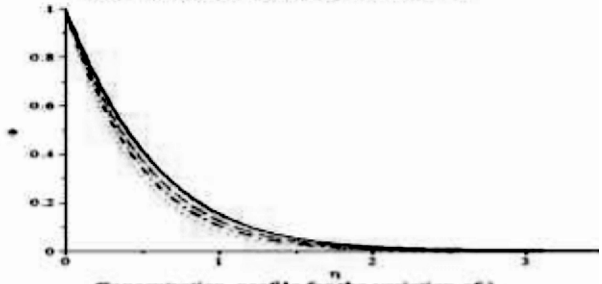
Concentration profile for the variation of Gr



Concentration profile for the variation of Gc

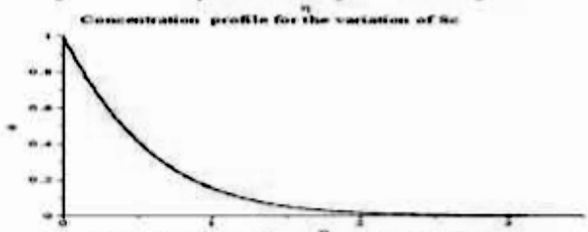


Concentration profile for the variation of Q

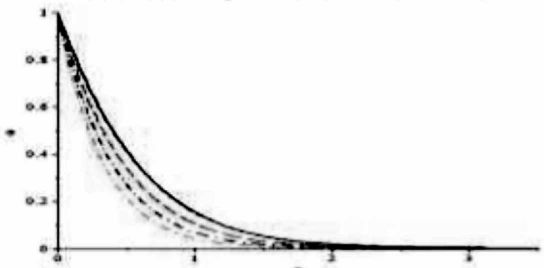


Concentration profile for the variation of λ

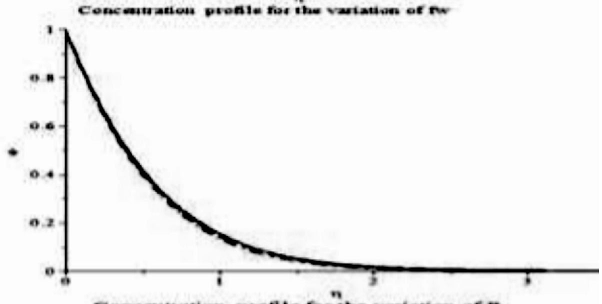
Concentration profile for the variation of Sc



Concentration profile for the variation of Pr



Concentration profile for the variation of fw



Concentration profile for the variation of R

4.0 CONCLUSIONS

In the present study, radiation and chemical reaction effects of heat and mass transfer on convective MHD slip flow with variable viscosity in porous media. Convective MHD boundary flow past a porous medium over exponentially-stretching sheet with thermal radiation of heat transfer by taking mass transfer, heat source/sink and chemical reaction into account were analyzed. The governing equations of the model are approximated to a system coupled non-linear ordinary differential equations by similarity transformation. Numerical analyses were carried out for various values of the dimensionless parameters of the modeled problems. The results showed that the momentum boundary layer thickness decreased, while both thermal and mass boundary layer thicknesses increase with an increase in the magnetic field and porosity parameters. The flow velocity, temperature and concentration boundary layers decreased with an increase in the porosity of the plate, Prandtl and Schmidt numbers. It was also observed that the velocity profiles increased with corresponding increase in the thermal and solutal Grashof numbers. An increase in the velocity and temperature distribution was also recorded in the variation in the values of radiation parameter. Moreover, it was found that concentration decreased with increasing in chemical reaction parameter while temperature increased with increase in heat source parameter.

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