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EFFECTS OF VARIABLE VISCOSITY, HEAT AND MASS TRANSFER ON NONLINEAR MIXED CONVECTION FLOW OVER A POROUS WEDGE WITH HEAT RADIATION IN THE PRESENCE OF HOMOGENOUS CHEMICAL REACTION

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ABSTRACT

An analysis is carried out to study the variable viscosity and chemical reaction effects on flow, heat and mass transfer characteristics in a viscous fluid over a porous wedge in the presence of heat radiation. The wall of the wedge is embedded in a uniform Darcian porous medium in order to allow for possible fluid wall suction or injection. The governing boundary layer equations are written into a dimensionless form by similarity transformations. The transformed coupled nonlinear ordinary differential equations are solved numerically by using the R.K. Gill and shooting methods. The effects of different parameters on the dimensionless velocity, temperature and concentration profiles are shown graphically. Comparisons with previously published works are performed and excellent agreement between the results is obtained. The results are presented graphically and the conclusion is drawn that the flow field and other quantities of physical interest are significantly influenced by these parameters.

Keywords: flow, wedge, heat, viscosity, chemical, reaction, radiation.

INTRODUCTION

In many transport processes in nature and in industrial applications in which heat and mass transfer with heat radiation is a consequence of buoyancy effects caused by diffusion of heat and chemical species. The study of such processes is useful for improving a number of chemical technologies, such as polymer production and food processing. In nature, the presence of pure air or water is impossible. Some foreign mass may be present either naturally or mixed with the air or water. The present trend in the field of chemical reaction with heat radiation analysis is to give a mathematical model for the system to predict the reactor performance. A large amount of research work has been reported in this field. In particular, the study of chemical reaction, heat and mass transfer with heat source is of considerable importance in chemical and hydrometallurgical industries. Chemical reaction can be codified as either heterogeneous or homogeneous processes. This depends on whether they occur at an interface or as a single phase volume reaction.

The effect of the presence of foreign mass on the free convection flow past a semi-infinite vertical plate was studied by Gebhart and Para [1]. The presence of a foreign mass in air or water causes some kind of chemical reaction. During a chemical reaction between two species, heat is also generated [2]. In most of cases of chemical reaction, the reaction rate depends on the concentration of the species itself. A reaction is said to be first order if the rate of reaction is directly proportional to concentration itself [3]. The effects of heat and mass transfer on laminar boundary layer flow over a wedge have been studied by many authors [4-14] in different situations. Chemical reaction effects on heat and mass transfer laminar boundary layer flow have been discussed by many authors [15-18] in various situations. The previous studies are based on the constant physical properties of the fluid. For most realistic fluids, the viscosity shows a rather pronounced variation with temperature. It is known that the fluid viscosity changes with temperature [19]. Then it is necessary to take into account the variation of viscosity with temperature in order to accurately predict the heat transfer rates. The effect of temperature-dependent viscosity on the mixed convection flow from vertical plate is investigated by several authors [19-22].

The aim of this work was to study the effects of variable viscosity, heat and mass transfer on nonlinear mixed convection flow over a porous wedge with chemical reaction in the presence of heat radiation. The order of chemical reaction in this work is taken as first-order reaction. It is hoped that the results obtained will not only provide useful information for applications, but also serve as a complement to the previous studies.

NOMENCLATURE

u ,v	velocity components in x and y direction.
U	flow velocity away from the wedge.
g	acceleration due to gravity.
β^*	coefficient of volume expansion.
k_1	rate of chemical reaction.
K	permeability of the porous medium.
R	heat radiation parameter.
T	temperature of the fluid.
T_w	temperature of the wall.
T_∞	temperature far away from the wall.
β	coefficient of thermal expansion.
δ	heat source parameter.
C	species concentration of the fluid.
C_w	species concentration along the wall.

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C_∞ species concentration away from the wall.
ρ density of the fluid.
σ electric conductivity of the fluid.
α thermal diffusivity.

MATHEMATICAL ANALYSIS

Let us consider a steady, laminar, coupled heat and mass transfer by mixed convection flow in front of a stagnation point on a wedge plate embedded in porous medium. The fluid is assumed to be Newtonian and its property variations due to temperature are limited to density and viscosity. The density variation and the effects of the buoyancy are taken into account in the momentum equation (Boussinesq's approximation) and the concentration of species far from the wall, C_∞, is infinitesimally small [2]. Let the x-axis be taken along the direction of the wedge and y-axis normal to it. The chemical reactions are taking place in the flow and a constant suction or injection is imposed at the wedge surface (Figure-1).

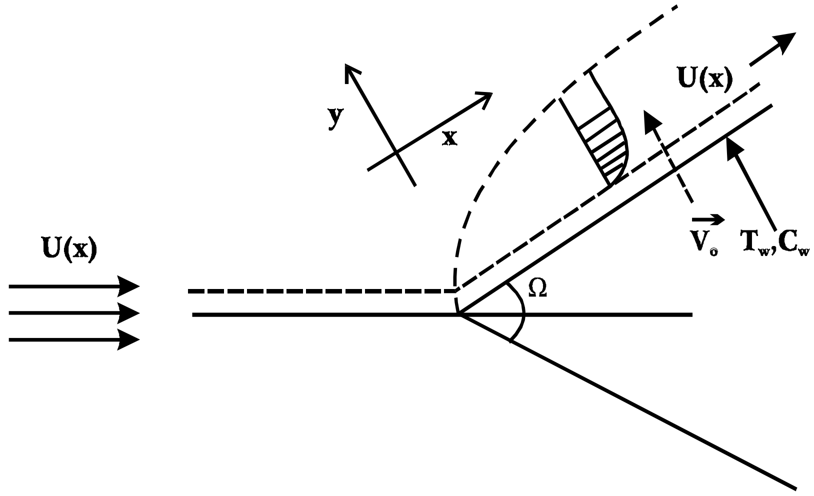

Figure-1. Flow analysis along the wall of the wedge.

For steady, two-dimensional flow under Boussinesq's approximation including variable viscosity are

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\frac{1}{\rho}\frac{\partial}{\partial y}(\mu\frac{\partial u}{\partial y})+U\frac{dU}{dx}+[g\beta(T-T_\infty)+g\beta^*(C-C_\infty)]\sin\frac{\Omega}{2}-\frac{\nu}{K}(u-U) \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}-\frac{\partial q_r}{\partial y}+Q(T_\infty-T) \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2}-k_1 C \tag{4}$$

The boundary conditions are,

$$u=0, v=-v_0, T=T_w, C=C_w \ at \ y=0$$
$$u=U(x), T=T_\infty, C=C_\infty \ at \ y\to\infty \tag{5}$$

By using the Rosseland diffusion approximation, [25] and [26], the radiative heat flux q_r is given by $q_r=-\frac{4\sigma}{3\mu}\frac{\partial T^4}{\partial y}$ and the term Q (T_∞ - T) is assumed to be the amount of heat generated absorbed per unit volume. Q is a constant, which may take on either positive or negative values. When the wall temperature T_w exceeds the free stream temperature T_∞, the source term represents the heat source when Q < 0 and heat sink when Q > 0. For the condition that $T_w < T_\infty$, the opposite relationship is true and D is the effective diffusion coefficient. Assuming that the temperature differences within the flow are sufficiently small such that T^4 may be expressed as a linear function of temperature

$$T^4 \cong 4T_\infty^3 - 3T_\infty^4 \tag{6}$$

Following the lines of Kafoussias *et.al.*, [5], the following change of variables are introduced

$$\psi = \sqrt{\frac{2U\nu x}{1+m}}\, f(x,\eta) \tag{7}$$

$$\eta = y\sqrt{\frac{(1+m)U}{2\nu x}} \tag{8}$$

The viscosity is assumed to be an inverse linear function of temperature given by the following [24]

$$\frac{1}{\mu} = \frac{1}{\mu_a}[1+\chi(T-T_a] \tag{9}$$

where μ_a is the ambient fluid dynamic viscosity and χ is a thermal property of the fluid. Equ. (9) can be written as follows

$$\frac{1}{\mu} = a(T-T_r] \tag{10}$$

where $a = \frac{\chi}{\mu_a}$ and $T_r = T_a - \frac{1}{\chi}$ are constants and their values depend on the reference state and the thermal property of the fluid.

Under this consideration, the potential flow velocity can be written as

$$U(x) = A\, x^m, \quad \beta_1 = \frac{2m}{1+m} \tag{11}$$

where A is a constant and β_1 is the Hartree pressure gradient parameter that corresponds to $\beta_1 = \frac{\Omega}{\pi}$ for a total angle Ω of the wedge.

The continuity equation (1) is satisfied by the stream function ψ defined by

$$u = \frac{\partial\psi}{\partial y} \text{ and } v = -\frac{\partial\psi}{\partial x} \tag{12}$$

To transform Eqs. (2), (3) and (4) into a set of ordinary differential equations, we introduce the following dimensionless parameters and variables,

$$\theta = \frac{T-T_\infty}{T_w-T_\infty} \tag{13}$$

$$\phi = \frac{C-C_\infty}{C_w-C_\infty} \tag{14}$$

$$Gr_1 = \frac{\nu g\beta(T_w-T_\infty)}{U^3} \quad \text{(Grashof number)} \tag{15}$$

$$Gc_1 = \frac{\nu g\beta^*(C_w-C_\infty)}{U^3} \quad \text{(Modified Grashof number)} \tag{16}$$

$$N = \frac{\beta^*(C_w-C_\infty)}{\beta(T_w-T_\infty)} \quad \text{(Buoyancy ratio)} \tag{17}$$

$$Re_x = \frac{Ux}{\nu} \quad \text{(Reynolds number)} \tag{18}$$

$$Pr = \frac{\nu}{\alpha} \quad \text{(Prandtl number)} \tag{19}$$

$$Sc = \frac{\nu}{D} \quad \text{(Schmidt number)} \tag{20}$$

$$S = v_0\sqrt{\frac{(1+m)x}{2\,\nu\,U}} \quad \text{(Suction or injection parameter)} \tag{21}$$

$$\gamma = \frac{\nu\, k_1}{U^2} \quad \text{(Chemical reaction parameter)} \tag{22}$$

$$\lambda = \frac{\alpha}{KA} \quad \text{(Porous medium parameter)} \tag{23}$$

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$$R = \frac{3k\nu}{16\sigma T_\infty^{\ 3}} \quad \text{(Heat radiation parameter)} \tag{24}$$

$$\delta = \frac{Q}{A\rho\, c_p} \quad \text{(Heat source parameter)} \tag{25}$$

Now the equations (2) to (4)

$$(\theta-\theta_r)\frac{\partial^3 f}{\partial\eta^3} = \frac{(\theta-\theta_r)^2}{\theta_r}[-f\frac{\partial^2 f}{\partial\eta^2} - \frac{2m}{1+m}(1-(\frac{\partial f}{\partial\eta})^2) - \frac{2}{1+m}\frac{N\phi+\theta}{1+N}Gr\,\mathrm{Re}_x \sin\frac{\Omega}{2} + \frac{2x}{1+m}(\frac{\partial f}{\partial\eta}\frac{\partial^2 f}{\partial x\partial\eta} - \frac{\partial f}{\partial x}\frac{\partial^2 f}{\partial\eta^2}) + \frac{2}{m+1}\lambda(\frac{\partial f}{\partial\eta}-1)] + \frac{2}{1+m}\frac{\partial\theta}{\partial\eta}\frac{\partial^2 f}{\partial\eta^2} \tag{26}$$

$$(1+\frac{1}{R})\frac{\partial^2\theta}{\partial\eta^2} = -\Pr\frac{\partial\theta}{\partial\eta} + \frac{2\Pr}{1+m}\theta\frac{\partial f}{\partial\eta} + \Pr\frac{2x}{1+m}(\frac{\partial f}{\partial\eta}\frac{\partial\theta}{\partial x} - \frac{\partial f}{\partial x}\frac{\partial\theta}{\partial\eta}) - \frac{2\Pr}{m+1}\delta\,\theta \tag{27}$$

$$\frac{\partial^2\phi}{\partial\eta^2} = -Sc\, f\frac{\partial\phi}{\partial\eta} + \frac{2\,Sc\,x}{1+m}\gamma\,\phi + \frac{2\,Sc}{1+m}\phi\frac{\partial f}{\partial\eta} + \frac{2xSc}{1+m}(\frac{\partial f}{\partial\eta}\frac{\partial\phi}{\partial x} - \frac{\partial f}{\partial x}\frac{\partial\phi}{\partial\eta}) \tag{28}$$

The boundary conditions can be written as

$$\eta = 0:\ \frac{\partial f}{\partial\eta} = 0,\ \frac{f}{2}(1+\frac{x}{U}\frac{dU}{dx}) + x\frac{\partial f}{\partial x} = -v_0\sqrt{\frac{(1+m)x}{2\nu U}}\ \ \theta = 1,\ \phi = 1$$

$$\eta \to \infty:\ \frac{\partial f}{\partial\eta} = 1,\ \theta = 0,\ \phi = 0 \tag{29}$$

where v_0 is the velocity of suction if $v_0 < 0$ and injection if $v_0 > 0$ and $Gr = Gr_1 + Gc_1$

The equations (26) to (28) and boundary conditions (29) can be written a

$$\frac{\partial^3 f}{\partial\eta^3} + \frac{(\theta-\theta_r)}{\theta_r}[(f+\frac{1-m}{1+m}\xi\frac{\partial f}{\partial\xi})\frac{\partial^2 f}{\partial\eta^2} - \frac{1-m}{1+m}\xi\frac{\partial^2 f}{\partial\xi\,\partial\eta}\frac{\partial f}{\partial\eta} + \frac{2m}{1+m}(1-(\frac{\partial f}{\partial\eta})^2) + \frac{2}{1+m}\frac{N\phi+\theta}{1+N}Gr\,\mathrm{Re}_x\sin\frac{\Omega}{2} - \frac{2}{m+1}\lambda(\frac{\partial f}{\partial\eta}-1)] - \frac{2}{1+m}\frac{1}{\theta-\theta_r}\frac{\partial\theta}{\partial\eta}\frac{\partial^2 f}{\partial\eta^2} = 0 \tag{30}$$

$$(1+\frac{1}{R})\frac{\partial^2\theta}{\partial\eta^2} + \Pr(f+\frac{1-m}{1+m}\xi\frac{\partial f}{\partial\xi})\frac{\partial\theta}{\partial\eta} - \frac{2\Pr}{1+m}\theta\frac{\partial f}{\partial\eta} - \frac{1-m}{1+m}\xi\frac{\partial\theta}{\partial\xi}\frac{\partial f}{\partial\eta} + \frac{2\Pr}{m+1}\delta\,\theta = 0 \tag{31}$$

$$\frac{\partial^2\phi}{\partial\eta^2} + Sc\, f\frac{\partial\phi}{\partial\eta} - \frac{2Sc}{1+m}\xi^2\gamma\,\phi + Sc\frac{1+m}{1-m}(\frac{\partial\phi}{\partial\eta}\xi\frac{\partial f}{\partial\xi} - \frac{\partial f}{\partial\eta}\xi\frac{\partial\phi}{\partial\xi}) - \frac{2Sc}{1+m}\phi\frac{\partial f}{\partial\eta} = 0 \tag{32}$$

$$\eta = 0:\ \frac{\partial f}{\partial\eta} = 0, \frac{(1+m)f}{2} + \frac{1-m}{2}\xi\frac{\partial f}{\partial\xi} = -S, \theta = 1, \phi = 1$$

$$\eta \to \infty:\ \frac{\partial f}{\partial\eta} = 1, \theta = 0, \phi = 0 \tag{33}$$

where S is the suction parameter if S > 0 and injection if S < 0 and $\xi = k\,x^{\frac{1-m}{2}}$ [5], is the dimensionless distance along the wedge ($\xi > 0$). In this system of equations f (ξ,η) is the dimensionless stream function ; θ (ξ,η) be the dimensionless temperature; φ (ξ, η) be the dimensionless concentration; Pr, the Prandtl number, Re_x, Reynolds number etc. which are defined in (13) to (25). The parameter ξ indicates the dimensionless distance along the wedge ($\xi > 0$). It is obvious that to retain the ξ–derivative terms, it is necessary to employ a numerical scheme suitable for partial differential equations for the solution. In addition, owing to the coupling between adjacent stream wise location through the ξ–derivatives, a locally autonomous solution, at any given stream wise location can not be obtained. In such a case, an implicit marching numerical solution scheme is usually applied proceeding the solution in the ξ–direction, i.e., calculating unknown profiles at ξ_{i+1}

when the same profiles at ξ_ι are known. The process starts at $\xi = 0$ and the solution proceeds from ξ_ι to $\xi_{\iota+1}$ but such a procedure is time consuming.

However, when the terms involving $\frac{\partial f}{\partial \xi}, \frac{\partial \theta}{\partial \xi}$ and $\frac{\partial \phi}{\partial \xi}$ and their η derivatives are deleted, the resulting system of equations resembles, in effect, a system of ordinary differential equations for the functions f, θ and ϕ with ξ as a parameter and the computational task is simplified. Furthermore a locally autonomous solution for any given ξ can be obtained because the stream wise coupling is severed. So, following the lines of [5], R.K. Gill [23] and Shooting numerical solution scheme are utilized for obtaining the solution of the problem. Now, due to the above mentioned factors, the equations (30) to (32) are changed to

$$f''' + \frac{\theta-\theta_r}{\theta_r} f\ f'' + \frac{2m}{1+m}\frac{\theta-\theta_r}{\theta_r}(1-f'^2) + \frac{2}{1+m}\frac{\theta-\theta_r}{\theta_r}\frac{N\phi+\theta}{1+N} Gr\,\mathrm{Re}_x \sin\frac{\Omega}{2} - \frac{\theta-\theta_r}{\theta_r}\frac{2}{1+m}\lambda(f'-1) - \frac{2}{1+m}\frac{1}{\theta-\theta_r}\theta'\ f'' = 0 \quad (34)$$

$$(1+\frac{1}{R})\theta'' + \Pr f\ \theta' - \frac{2\Pr}{1+m}\theta\ f' + \frac{2\Pr}{m+1}\delta\,\theta = 0 \quad (35)$$

$$\phi'' + Sc\ f\ \phi' - \frac{2Sc}{1+m} f'\phi - \frac{2\,Sc}{1+m}\xi^2\gamma\,\phi = 0 \quad (36)$$

with boundary conditions

$$\eta = 0:\ f(0) = -\frac{2}{1+m}S,\ f'(0)=0, \theta(0)=1, \phi(0)=1$$

$$\eta \to \infty:\ f'(\infty)=1, \theta(\infty)=0, \phi(\infty)=0 \quad (37)$$

NUMERICAL SOLUTION AND DISCUSSION

Equations (34) to (36) with boundary condition (37) were solved numerically using Runge Kutta Gill and shooting methods [23]. The computations have been carried out for various values of variable viscosity θ_r, chemical reaction (γ), heat radiation R, heat source δ and porous medium (λ). In order to validate our method, we have compared steady state results of skin friction $f''(0)$ and rate of heat transfer $-\theta'(0)$ for various values of θ_r (Table-1) with those of [24] and found them in excellent agreement.

Table-1. Comparison of the values of $f''(0)$ and $-\theta'(0)$ for various values of θ_r with $\lambda = 0$, $\Omega = 30^0$, N = 0, m = 0.0909, Sc = 0 and $\delta = \gamma = S = 0$.

Pantoskratoras, [24]			Present work		
θ_r	$f''(0)$	$-\theta'(0)$	$f''(0)$	$-\theta'(0)$	Pr
2.0	0.2642	-0.7341	0.2651	-0.7345	20.00
4.0	0.3785	-0.7888	0.3791	-0.78921	13.33
6.0	0.4145	-0.8042	0.4167	-0.8061	12.00
8.0	0.4322	-0.8112	0.4341	-0.8127	11.43
10	0.4426	-0.8162	0.4452	-0.8171	11.11

The velocity, temperature and concentration profiles obtained in the dimensionless form are presented in Figures 2-8 for Pr = 0.71 which represents air at temperature 20 ^{0}C and Sc = 0.62 which corresponds to water vapor that represents a diffusion chemical species of most common interest in air. Grashof number for heat transfer is chosen to be Gr = 4.0, since these values correspond to a cooling problem and Reynolds number Rex = 3.0. The value of γ is chosen to be 0.5, 1.0 and 3.0. It is important to note that θ_r is negative for liquids and positive for gases when $T_w - T_\infty$ is positive. The value of θ_r (for air $\theta_r > 0$) is chosen to be 1.0, 3.0 and 5.0 and the value of suction, S is chosen to be 3.0. The value of the heat radiation is chosen to be 0.5, 1.0 and 3.0 and heat source, δ is chosen to be 0.5, 3.0 and 5.0.

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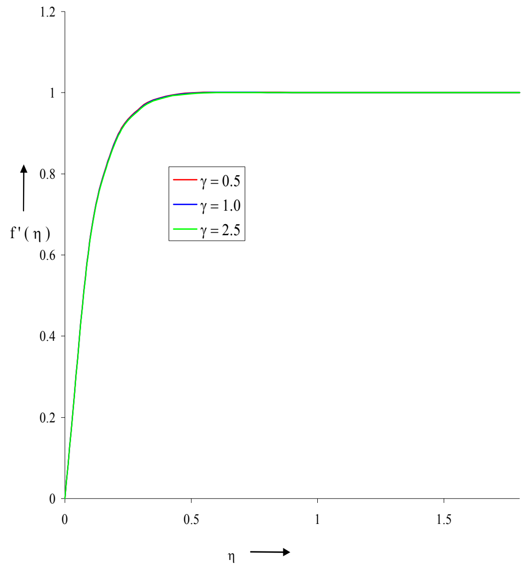
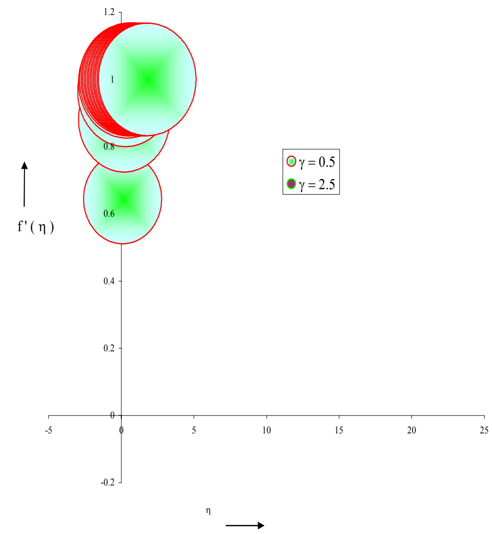


Fig.2: Influence of chmical reaction over the velocity profiles



Mod.2: Influence of chmical reaction over the velocity profiles

with Pr = 0.71, Sc = 0.62, m = 0.0909, N = R = 1.0, λ = 0.1, S = 3.0, δ = Gr = 1.0, Rex = 3.0, ξ = 1.0, θ_r = 0.1 and Ω = 30^0

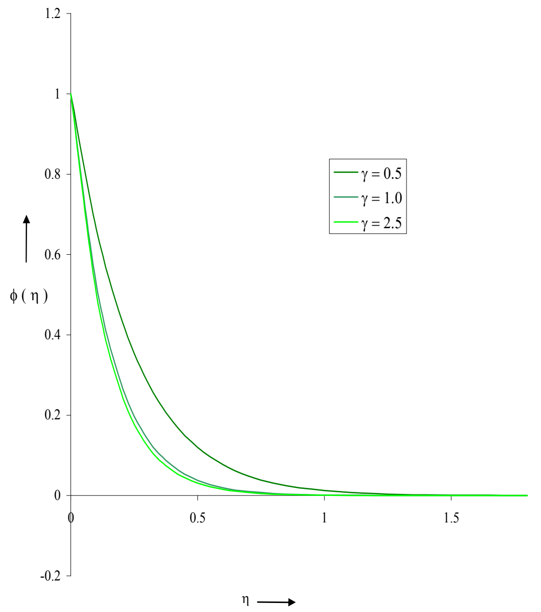
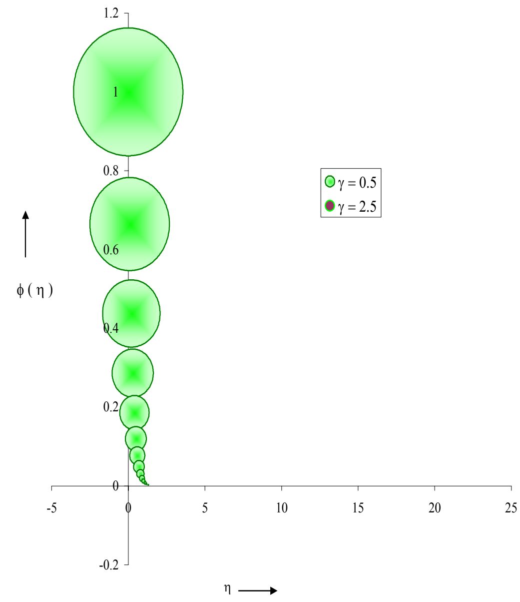


Fig.3: Chemical reaction over the concentration profiles



Mod.3: Chemical reaction over the concentration profiles

with Pr = 0.71, Sc = 0.62, m = 0.0909, N = R = 1.0, λ = 0.1, S = 3.0, θ_r = 0.5, δ = Gr = 1.0, Rex = 3.0, ξ = 1.0 and Ω = 30^0

The dimensionless velocity profiles for different values of chemical reaction are plotted in Figure-2. Due to the uniform viscosity, $\theta_r = 0.1$, it is clear that the velocity of the fluid decreases with increase of chemical reaction and this is displayed through Figure-2. It is also observed from the Mod.2 that the velocity of the fluid changes from higher value (centre) to lower value (zz boundary).

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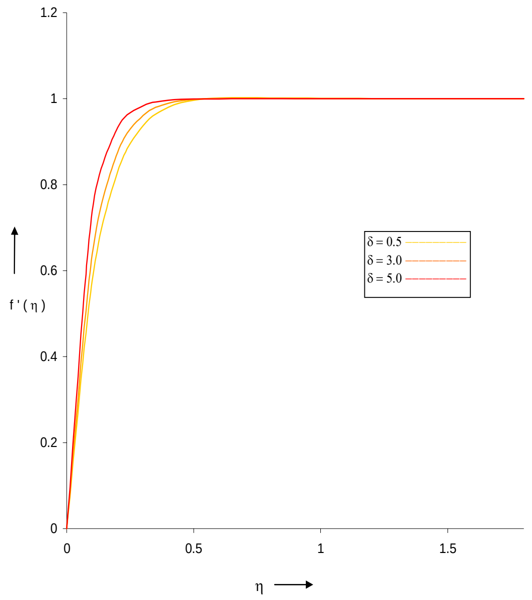
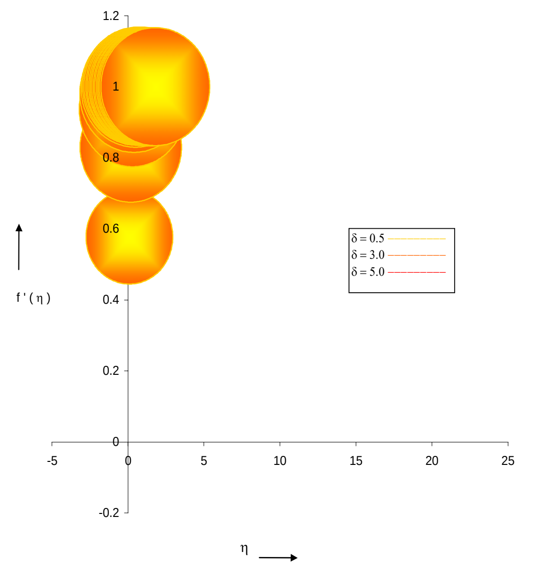


Fig.4: Influence of heat source over the velocity profiles



Mod.**4: Influence of heat source over the velocity profiles**

with Pr = 0.71, Sc = 0.62, m = 0.0909, γ = 1.0, N = R = 1.0, λ = 0.1, S = 3.0, θ_r = 0.5, Gr = 1.0, Rex = 3.0, ξ = 1.0 and Ω = 30^0

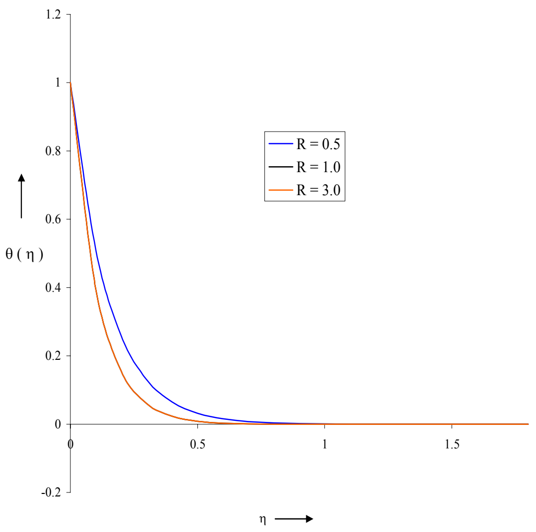
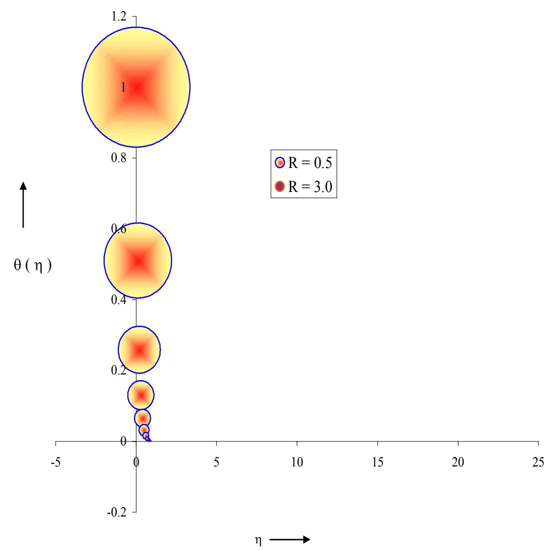


Fig.5: Effects of heat radiation over the temperature profiles



Mod.5: Effects of heat radiation over the temperature profiles

with Pr = 0.71, Sc = 0.62, m = 0.0909, γ = 1.0, N = 1.0, λ = 0.1, S = 3.0, θ_r = 0.5, δ = Gr = 1.0, Rex = 3.0, ξ = 1.0 and Ω = 30^0

The effects of the chemical reaction γ on concentration profiles are shown through Figure-3. It is seen from the figure that the concentration decreases with increase of chemical reaction, while the profiles for temperature is not significant with increase of chemical reaction. It is also evident that the concentration of the fluid changes higher value (centre) to lower value (outer boundary) and this is shown through Mod.3. Figure-4 and Mod.4 display the influence of the heat source effects on velocity profiles. It is clear that the velocity increases with increase of the strength of the heat source, while the temperature and concentration are not significant with increase of heat source.

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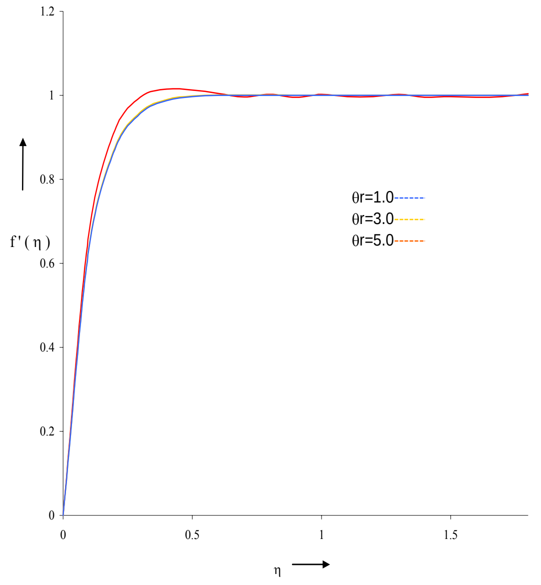
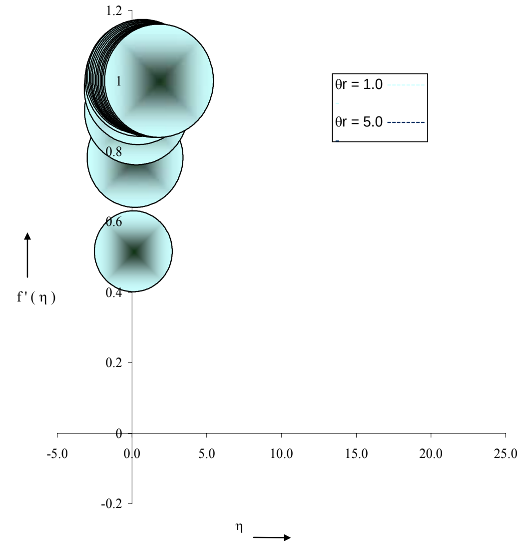


Fig.6: Influence of viscosity over the velocity profiles



Mod.6: Influence of viscosity over the velocity profiles

with Pr = 0.71, Sc = 0.62, m = 0.0909, γ = 1.0, N = R = 1.0, λ = 0.1, S = 3.0, δ = Gr = 1.0, Rex = 3.0, ξ = 1.0 and Ω = 30^0

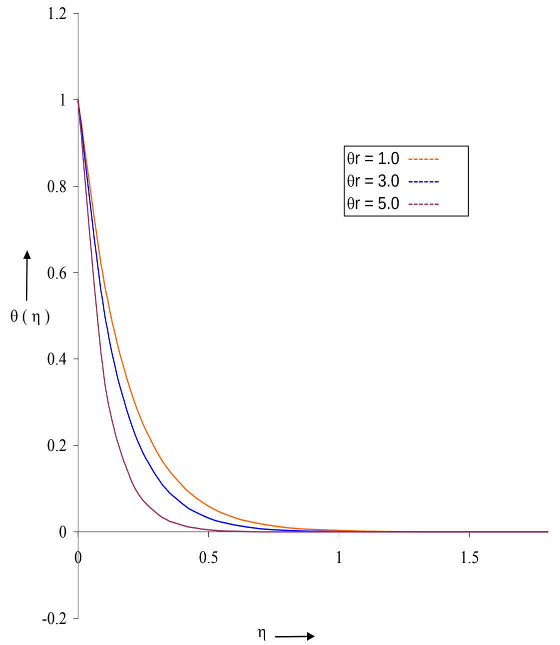
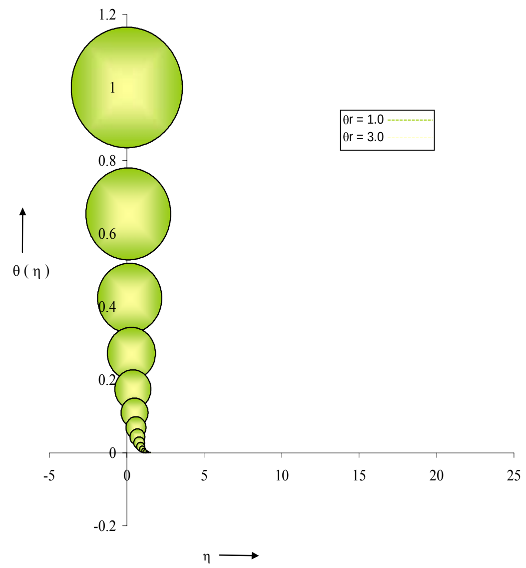


Fig.7: Effects of viscosity over the temperature profiles



Mod.7: influence of viscosity over the temperature profiles

with Pr = 0.71, Sc = 0.62, m = 0.0909, γ = 1.0, N = R = 1.0, λ = 0.1, S = 3.0, δ = Gr = 1.0, Rex = 3.0, ξ = 1.0 and Ω = 30^0

The dimensionless temperature profiles for different values of heat radiation are plotted in Figure-5. Due to the uniform viscosity, $\theta_r = 0.1$, it is clear that the temperature of the fluid decreases with increase of heat radiation while the velocity and concentration are not significant with increase of heat radiation effects and found them excellent agreement with the Mod.5. The effects of the viscosity parameter θ_r on velocity and temperature profiles are shown through Figures 6 and 7 and Models 6 and 7. It is seen that the velocity increases with increase of viscosity and the thermal boundary layer thickness decreases as the viscosity increases while the concentration of the fluid is almost not affected with increase of the viscosity. So, the increase of viscosity accelerates the fluid motion and reduces the temperature of the fluid along the wall and also found them excellent agreement between the Figures and Models.

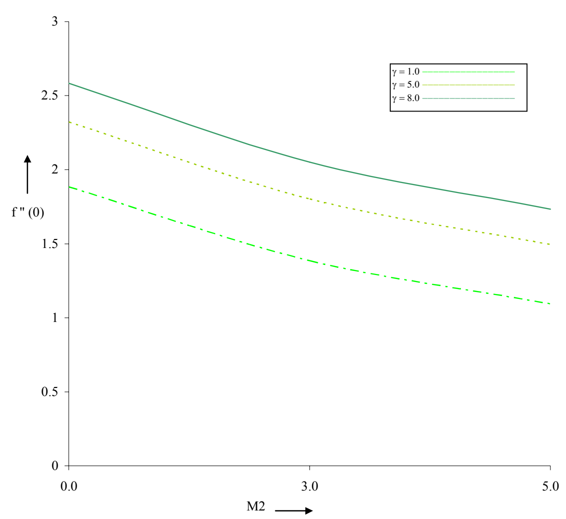
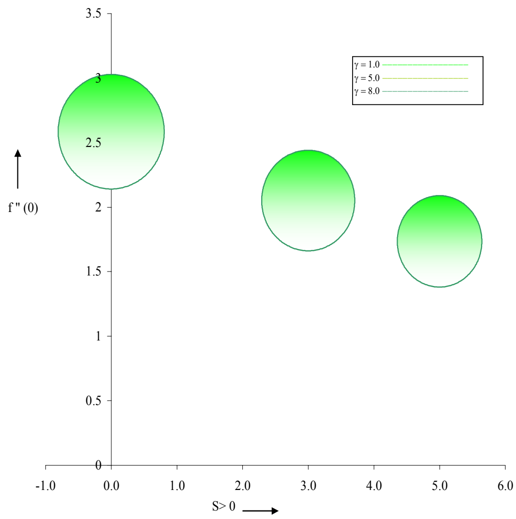


Fig.8 : Chemical reaction over the skin friction



Mod.8 : Chemical reaction over the skin friction

with Pr = 0.71, Sc = 0.62, m = 0.0909, N = R = 1.0, λ = 0.1, δ = Gr = 1.0, Rex = 3.0, ξ = 1.0, θ_r = 0.5, and $\Omega = 30^0$

The effects of the strength of the chemical reaction on skin friction for suction are shown in Figure-8 and Model-8. In the cases of suction, it is seen that the skin friction increases with increase of the strength of the chemical reaction. It is seen that increasing the chemical reaction effect is to decrease the velocity in the boundary layer and thus increase the skin friction at wall, but the opposite trend is true when the chemical reaction strength is increased. All these physical behavior are due to the combined effect of the strength of heat source and viscosity at the wall of the wedge.

CONCLUSIONS

This paper studied the effects of variable viscosity, heat and mass transfer on nonlinear mixed convection flow over a porous wedge with chemical reaction and heat radiation in the presence of suction or injection The results are presented graphically (Figures and Models) and the conclusion is drawn that the flow field and other quantities of physical interest are significantly influenced by these parameters. Comparisons with previously published works are performed and excellent agreement between the results is obtained.

We conclude the following from the results and discussions:

- Velocity and concentration of the fluid decrease with increase of chemical reaction.
- Velocity of the fluid increases with increase of the strength of the heat source. All these physical behavior are due to the combined effects of the strength of the viscosity and chemical reaction.
- Increase of the viscosity accelerates the fluid motion and reduces the temperature of the fluid along the wall of wedge.
- In the presence of uniform chemical reaction, temperature decreases with increase of heat radiation.
- In the cases of suction, skin friction increases with increase of the strength of the chemical reaction. It is interesting to note that increasing the chemical reaction effect is to decrease the velocity in the boundary layer and thus increase the skin friction at wall, but the opposite trend is true when the chemical reaction strength is increased. All these physical behavior are due to the combined effect of the strength of heat source and viscosity at the wall of the wedge

It is hoped that the present investigation may be useful for the study of movement of oil or gas and water through the reservoir of an oil or gas field, in the migration of underground water and in the filtration and water purification processes. The results of the problem are also of great interest in geophysics in the study of interaction of the geomagnetic field with the fluid in the geothermal region.

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