Effects of chemical reaction, heat and mass transfer on boundary layer flow over a porous wedge with heat radiation in the presence of suction or injection

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Abstract

The effect of chemical reaction, heat and mass transfer on boundary layer flow over a porous wedge with heat radiation has been studied in the presence of suction or injection. An approximate numerical solution for the steady laminar boundary-layer flow over a wall of the wedge in the presence of species concentration and mass diffusion has been obtained by solving the governing equations using numerical technique. The fluid is assumed to be viscous and incompressible. Numerical calculations are carried out for different values of dimensionless parameters and an analysis of the results obtained shows that the flow field is influenced appreciably by the chemical reaction, the buoyancy ratio between species and thermal diffusion and suction / injection at wall surface. Effects of these major parameters on the transport behaviors are investigated methodically and typical results are illustrated to reveal the tendency of the solutions. Representative results are presented for the velocity, temperature, and concentration distributions, as well as the skin

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friction, rate of heat transfer and mass transfer. Comparisons with previously published works are performed and excellent agreement between the results is obtained.

Key words: Chemical reaction,porous wedge, heat radiation, buoyancy ratio and mixed convection.

1   Introduction

The present trend in the field of chemical reaction 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 heat and mass transfer with chemical reaction 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. Frequently the transformations proceed in a moving fluid, a situation encountered in a number of technological fields. A common area of interest in the field of aerodynamics is the analysis of thermal boundary layer problems for two dimensional steady and incompressible laminar flow passing a wedge. Simultaneous heat and mass transfer from different geometries embedded in porous media has many engineering and geophysical applications such as geothermal reservoirs, drying of porous solids, thermal insulation, enhanced oil recovery, packed-bed catalytic reactors, cooling of nuclear reactors, and under ground energy transport. A very significant area of research in radiative heat transfer, at the present time is the numerical simulation of combined radiation and convection/conduction transport processes. The effort has arisen largely due to the need to optimize industrial system such as furnaces, ovens and boilers and the interest in our environment and in no conventional energy sources, such as the use of salt-gradient solar ponds for energy collection and storage. In particular, natural convection induced by the simultaneous action of buoyancy forces resulting from thermal and mass diffusion is of considerable interest in nature and in many industrial applications such as geophysics, oceanography, drying processes, solidification of binary alloy and chemical engineering. Frequently the transformations proceed in a moving fluid, a situation encountered in a number of technological fields. In previous investigations, Chambre and Acrivos [1], analysed catalytic surface reactions in hydrody-

namic flows. The paper was concerned with its counterpart, namely, an investigation of a certain special class of homogeneous volume reactions in flow systems. Chambre et al.[2] had studied the diffusion of a chemically reactive species in a laminar boundary layer flow. Goddard and Acrivos [3] analyzed the laminar forced convection mass transfer with homogeneous chemical reaction. A unified boundary layer analysis was applied to the problem of steady state mass transfer of a chemical species, diffusing from a surface and reacting isothermally in a linear fluid stream.

Stagnation flows are found in many applications such as flows over the tips of rockets, aircrafts, submarines and oil ships. In these types of problems, the well known Falkner-Skan transformation is used to reduce boundary-layer equations into ordinary differential equations for similar flows. It can also be used for non-similar flows for convenience in numerical work because it reduces, even if it does not eliminate, dependence on the x-coordinate. The solutions of the Falkner-Skan equations are sometimes referred to as wedge-flow solutions with only two of the wedge flows being common in practice. The dimensionless parameter, β_1 plays an important role in such type of problems because it denotes the shape factor of the velocity profiles. It has been shown [4] that when $\beta_1 < 0$ (increasing pressure), the velocity profiles have point of inflexion whereas when $\beta_1 > 0$ (decreasing pressure), there is no point of inflexion. This fact is of great importance in the analysis of the stability of laminar flows with a pressure gradient.

Yih [5] presented an analysis of the forced convection boundary layer flow over a wedge with uniform suction/blowing, whereas Watanabe [10] investigated the behavior of the boundary layer over a wedge with suction or injection in forced flow. Recently, MHD laminar boundary layer flow over a wedge with suction or injection had been discussed by Kafoussias and Nanousis [6] and Kumari[7] discussed the effect of large blowing rates on the steady laminar incompressible electrically conducting fluid over an infinite wedge with a magnetic field applied parallel to the wedge. Anjali Devi and Kandasamy [8] have studied the effects of heat and mass transfer on nonlinear boundary layer flow over a wedge with suction or injection. The effect of induced magnetic field is included in the analysis. Chamkha and Khaled [11] investigated the problem of coupled heat and mass transfer by MHD free convection from an inclined plate in the presence of internal heat generation or absorption. For the problem of coupled heat and

mass transfer in MHD free convection, the effects of viscous dissipation and Ohmic heating with chemical reaction are not studied in the above investigation. However, it is more realistic to include these effects to explore the impact of the magnetic field on the thermal transport in the buoyancy layer. With this awareness, the effect of Ohmic heating on the MHD free convection heat transfer has been examined for a Newtonian fluid [12] and for a micro polar fluid [13]. Kuo Bor-Lih [14] studied the effect of heat transfer analysis for the Fakner- Skan wedge flow by the differential transformation method. Cheng and Lin[15] analyzed the non-similarity solution and correlation of transient heat transfer in laminar boundary layer flow over a wedge. Pantokratoras [16] discussed the Falkner-Skan flow with constant wall temperature and variable viscosity. Hossain et.al.,[19] analyzed the effects of radiation on free convection from a porous plate.These effects on combined heat and mass transfer on free convection flow past a wedge in the presence of suction or injection have not yet been studied. This study is therefore initiated to investigate the problem of natural convection flow over a wedge, taking in to consideration the effects of viscous dissipation and Ohmic heating.

Since no attempt has been made to analyze the effects of chemical reaction, heat and mass transfer on boundary layer flow over a porous wedge surface with heat radiation in the presence of suction or injection, we have investigated it in this article. The similarity transformation has been utilized to convert the governing partial differential equations into ordinary differential equations and then the numerical solution of the problem is drawn using Runge Kutta Gill method,[18]. Numerical calculations up to third level of truncation were carried out for different values of dimensionless parameters of the problem under consideration for the purpose of illustrating the results graphically. Examination of such flow models reveals the influence of chemical reaction and buoyancy ratio on velocity, temperature and concentration profiles. The analysis of the results obtained shows that the flow field is influenced appreciably by the presence of heat radiation and buoyancy ratio in the presence of suction or injection at the wall of the wedge. 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.
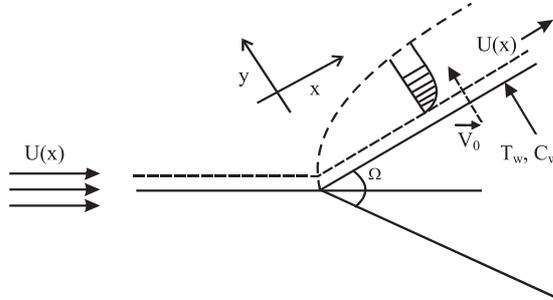
2   Mathematical Analysis

Figure 1: Flow analysis along the wall of the wedge

Two dimensional laminar boundary layer flow of an incompressible, viscous and Boussinesq fluid over a wall of the wedge with suction or injection is considered. x-axis is taken parallel to the wedge and y-axis is taken normal to it as cited in Fig.1. The fluid is assumed to be Newtonian, electrically conducting, heat generation or absorbing 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 [9]. The chemical reactions are taking place in the flow and a constant suction or injection is imposed at the wedge surface, see Fig.1. In writing the following equations, Now the governing boundary layer equations of momentum, energy and diffusion for the flow under Boussinesq's approximation,[14] and [15] are

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

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

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

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

where u, v - velocity components in x and y direction.

U - Flow velocity of the fluid away from the wedge.

D - The effective diffusive coefficient

g - Acceleration due to gravity.

β - Coefficient of volume expansion.

k_1 - Rate of chemical reaction.

K - Permeability of the porous medium

T - Temperature of the fluid.

T_w - Temperature of the wall.

T_∞ - Temperature of the fluid far away from the wall.

$\beta*$ - Coefficient of expansion with concentration.

C - Species concentration of the fluid.

C_w - Species concentration of the fluid along the wall.

C_∞ - Species concentration of the fluid away from the wall.

ρ - Density of the fluid.

σ - Stefan Boltzman constant.

α - Thermal diffusivity.

The boundary conditions are,

$$u = 0, \quad v = v_0, \quad C = C_w, \quad T = T_w \quad at y = 0 \qquad (5)$$

$$u = U(x), \quad C = C_\infty, T = T_\infty \quad as y \rightarrow \quad \infty \qquad (6)$$

where $q_r = -\frac{4\sigma}{3\mu}\frac{\partial T^4}{\partial y}$ and the term $Q(T_\infty - T)$ is assumed to be the amount of heat generated or 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

$$T^4 \cong 4T_\infty^3 - 3T_\infty^4$$

Following the lines of Bansal[17], the following change of variables are introduced

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

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

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

$$U(x) = Ax^m, \quad \beta_1 = \frac{2m}{1 + m} \tag{9}$$

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. Both the wall temperature and concentration are assumed to have power-law variation forms as shown by the following equations:

$$T_w = T_\infty + c_1 x^n \quad and \quad C_w = C_\infty + c_2 x^n$$

where c_1 and c_2 are constants and n is the power of index of the wall temperature and concentration. Both the wall temperature and concentration are assumed to have the same power index n.

The continuity equation (1) is satisfied by the stream function $\psi(x, y)$ defined by

$$u = \frac{\partial \psi}{\partial y} \quad and \quad v = -\frac{\partial \psi}{\partial x} \tag{10}$$

and we set $C_\infty = 0$. To transform Eqs.(2),(3) and (4) into a set of ordinary differential equations, the following dimensionless variables are introduced [15]:

$$\theta = \frac{T - T\infty}{T_w - T_\infty} \tag{11}$$

$$\phi = \frac{C - C_\infty}{C_w - C_\infty} \tag{12}$$

$$Gr_1 = \frac{\nu g\beta(T - T_\infty)}{U^3} \quad \text{(Grashof number)} \tag{13}$$

$$Gc_1 = \frac{\nu g\beta * (T - T_\infty)}{U^3} \quad \text{(Modified Grashof number)} \tag{14}$$

$$N = \frac{\beta^*(C_w - C_\infty)}{\beta(T_w - T_\infty)} \quad \text{(Buoyancy ratio)} \tag{15}$$

$$Pr = \frac{\mu \, c_p}{K} \quad \text{(Prandtl number)} \tag{16}$$

$$Sc = \frac{\nu}{D} \quad \text{(Schmidt number)} \tag{17}$$

$$S = -v_0\sqrt{\frac{(1+m)x}{2\nu U}} \quad \text{(suction or injection parameter)} \tag{18}$$

$$\gamma = \frac{\nu \, k_1}{U^2} \quad \text{(chemical reaction parameter)} \tag{19}$$

$$\delta = \frac{Q}{A\rho c_p} \quad \text{(internal heat generation or absorption coefficient)} \tag{20}$$

$$\lambda = \frac{\alpha}{KA} \quad \text{(Dimension less porous medium parameter)} \tag{21}$$

$$R = \frac{3k\nu}{16\sigma \, T_\infty^3} \quad \text{(Radiation parameter)} \tag{22}$$

Now the equations (2) to (4)

$$\frac{\partial^3 f}{\partial \eta^3} = -f\frac{\partial^2 f}{\partial \eta^2} - \frac{2m}{1+m}(1 - (\frac{\partial f}{\partial \eta})^2 - \frac{2}{1+m}\frac{N\phi + \theta}{1+N}\sin\frac{\Omega}{2}$$
$$+ \frac{2x}{1+m}(\frac{\partial f}{\partial \eta}\frac{\partial^2 f}{\partial x\partial \eta} - \frac{\partial f}{\partial x}\frac{\partial^2 f}{\partial \eta^2}) - \frac{2}{m+1}\lambda(\frac{\partial f}{\partial \eta} - 1) \tag{23}$$

$$(1 + \frac{1}{R})\frac{\partial^2 \theta}{\partial \eta^2} = -Pr\frac{\partial \theta}{\partial \eta} + \frac{2\,Pr}{1+m}\theta\frac{\partial f}{\partial \eta} +$$
$$Pr\frac{2x}{1+m}(\frac{\partial f}{\partial \eta}\frac{\partial \theta}{\partial x} - \frac{\partial f}{\partial x}\frac{\partial \theta}{\partial \eta}) - \frac{2\,Pr}{m+1}\delta\,\theta \tag{24}$$

$$\frac{\partial^2 \phi}{\partial \eta^2} = -Sc\,f\frac{\partial \phi}{\partial \eta} + \frac{2\,Sc\,x}{1+m}\gamma\,\phi + \frac{2\,Sc}{1+m}\phi\frac{\partial f}{\partial \eta} +$$
$$\frac{2xSc}{1+m}(\frac{\partial f}{\partial \eta}\frac{\partial \phi}{\partial x} - \frac{\partial f}{\partial x}\frac{\partial \phi}{\partial \eta}) \tag{25}$$

The boundary conditions can be written as

$$\eta = 0 : \frac{\partial f}{\partial \eta} = 0, \quad \frac{f}{2}(1 + \frac{x}{U}\frac{dU}{dx}) + x\frac{\partial f}{\partial x} =$$

$$-v_0 \sqrt{\frac{(1+m)x}{2\nu U}}, \quad \theta = 1, \quad \phi = 1;$$

$$\eta \to \infty : \frac{\partial f}{\partial \eta} = 1, \quad \theta = 0, \quad \phi = 0. \tag{26}$$

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 (23) to (25) and boundary conditions (26) can be written as

$$\frac{\partial^3 f}{\partial \eta^3} + (f + \frac{1-m}{1+m}\xi\frac{\partial f}{\partial \xi})\frac{\partial^2 f}{\partial \eta^2} - \frac{1-m}{1+m}\xi\frac{\partial^2 f}{\partial \xi \partial \eta}\frac{\partial f}{\partial \eta} +$$

$$\frac{2m}{1+m}(1 - (\frac{\partial f}{\partial \eta})^2) + \frac{2}{1+m}\frac{N\phi+\theta}{1+N}\sin\frac{\Omega}{2} + \frac{2}{m+1}\lambda(\frac{\partial f}{\partial \eta} - 1) = 0 \tag{27}$$

$$(1 + \frac{1}{R})\frac{\partial^2 \theta}{\partial \eta^2} + \Pr(f + \frac{1-m}{1+m}\xi\frac{\partial f}{\partial \xi})\frac{\partial \theta}{\partial \eta} - \frac{2\Pr}{1+m}\theta\frac{\partial f}{\partial \eta} -$$

$$\frac{1-m}{1+m}\xi\frac{\partial \theta}{\partial \xi}\frac{\partial f}{\partial \eta} + \frac{2\Pr}{m+1}\delta\,\theta = 0, \tag{28}$$

$$\frac{\partial^2 \phi}{\partial \eta^2} + Sc\,f\,\frac{\partial \phi}{\partial \eta} - \frac{2Sc}{1+m}\xi^2\gamma\,\phi +$$

$$Sc\frac{1+m}{1-m}(\frac{\partial \phi}{\partial \eta}\xi\frac{\partial f}{\partial \xi} - \frac{\partial f}{\partial \eta}\xi\frac{\partial \phi}{\partial \xi}) - \frac{2Sc}{1+m}\phi\frac{\partial f}{\partial \eta} = 0, \tag{29}$$

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

$$\eta \to \infty : \frac{\partial f}{\partial \eta} = 1, \quad \theta = 0, \quad \phi = 0, \tag{30}$$

where S is the suction parameter if $S > 0$ and injection if $S < 0$ and $\xi x^{\frac{1-m}{2}}$ [6], is the dimensionless distance along the wedge ($\xi > 0$). In this

system of equations $f(\xi\eta)$ is the dimensionless stream function ; $\theta(\xi\eta)$ be the dimensionless temperature; $\phi(\xi\eta)$ be the dimensionless concentration ; Pr, the Prandtl number, Re_x, Reynolds number etc. which are defined in (10) to (20). 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 $\xi_{\iota+1}$ 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 [6], R.K.Gill,[18] and Shootuing numerical solution scheme are utilized for obtaining the solution of the problem. Now, due to the above mentioned factors, the equations (27) to (??) are changed to

$$f'''+f\,f''+\frac{2m}{1+m}(1-f'^2)+\frac{2}{1+m}\frac{N\phi+\theta}{1+N}\sin\frac{\Omega}{2}-\frac{2}{1+m}\lambda(f'-1)=0 \quad (31)$$

$$(1+\frac{1}{R})\,\theta''+\Pr f\,\theta'-\frac{2\Pr}{1+m}f'\,\theta+\frac{2\Pr}{m+1}\delta\,\theta=0 \qquad (32)$$

$$\phi''+Sc\,f\,\phi'-\frac{2Sc}{1+m}f'\phi-\frac{2\,Sc}{1+m}\xi^2\gamma\,\phi=0 \qquad (33)$$

with boundary conditions

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

$$\eta\ \to\infty:f'(\infty)\ =1,\quad \theta(\infty)=0,\quad \phi(\infty)=0, \qquad (34)$$

3 Numerical Solution

The set of non-linear ordinary differential equations (31) to (33) with boundary conditions (34) have been solved by using the R.K. Gill method, [18] along with Shooting Technique with $\alpha, \gamma, \Omega, \mathrm{Pr}, Sc, R$ and N as prescribed parameters. The computational were done by a program which uses a symbolic and computational computer language Matlab. A step size of $\Delta\eta = 0.001$ was selected to be satisfactory for a convergence criterion of 10^{-7} in nearly all cases. The value of η_∞ was found to each iteration loop by assignment statement $\eta_\infty = \eta_\infty + \Delta\eta$. The maximum value of η_∞, to each group of parameters $\alpha, \gamma, \Omega, \mathrm{Pr}, Sc, R$ and N, determined when the values of unknown boundary conditions at $\eta = 0$ not change to successful loop with error less than 10^{-7}. Effects of chemical reaction, heat and mass transfer are studied for different values of suction / injection at the wall of the wedge and the strength of applied magnetic field with heat radiation .In the following section, the results are discussed in detail.

4 Results and Discussion

The computations have been carried out for various values of variables of variable viscosity (α), chemical reaction (γ), Schmit number (Sc), Prandtl number (Pr), heat radiation (R), porous medium (λ), buoyancy ratio (N) and power index of the wall temperature (n). The edge of the boundary layer $\eta_\infty = 8$ depending on the values of parameters.

In order to validate our method, we have compared steady state results of velocity, temperature and concentration profiles for various values of Pr with those of [5],[6], [7] and [10] and for various values of Sc with those of [8] and for various of N and R with those of [8], [10],[14] and [15], and found in excellent agreement. We have also compared the skin friction $f''(0)$ for various values of Pr with those of [6],[8],[14] and [15], and found them in good agreement.

Figure 2 represents the dimensionless velocity profiles for different values of chemical reaction parameter. In the presence of uniform strength of the heat radiation, it is clear that the velocity and temperature of the fluid decrease and concentration of the fluid increases with increase of chemical reaction and these are shown in the Figs.2,3 and 4 respectively. All these physical behavior are due to the combined effects of the strength of the
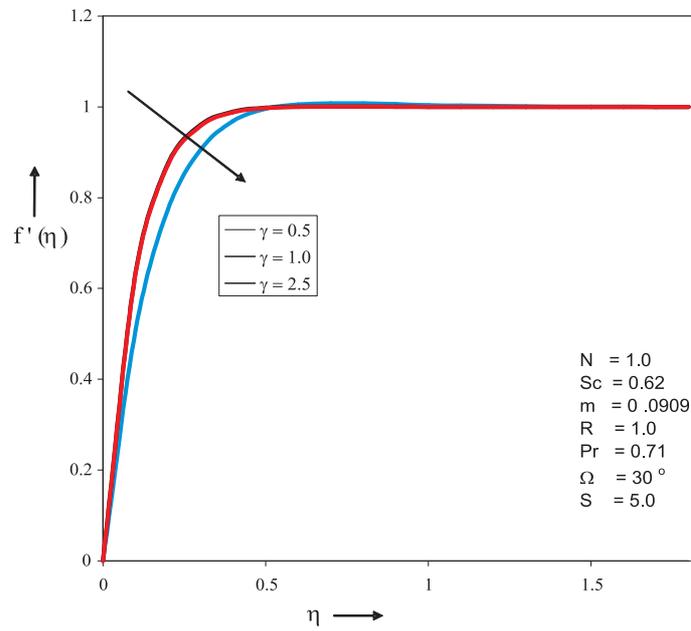
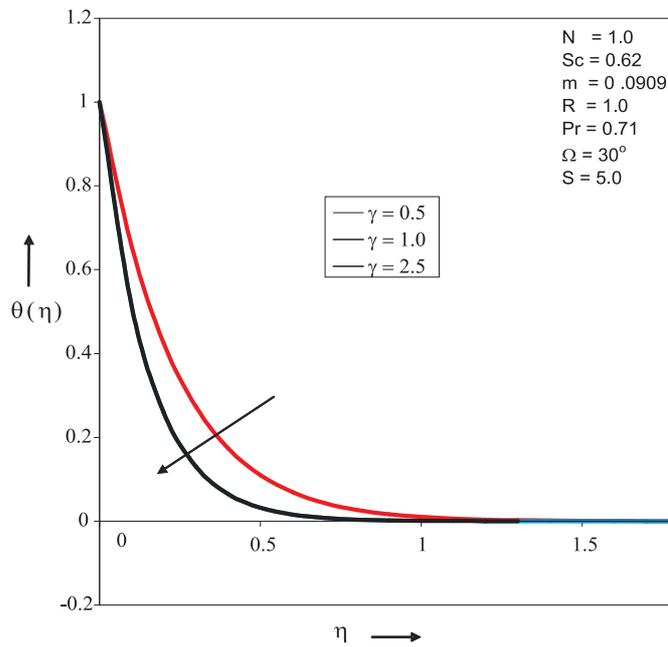Figure 2: Chemical reaction over the velocity profiles

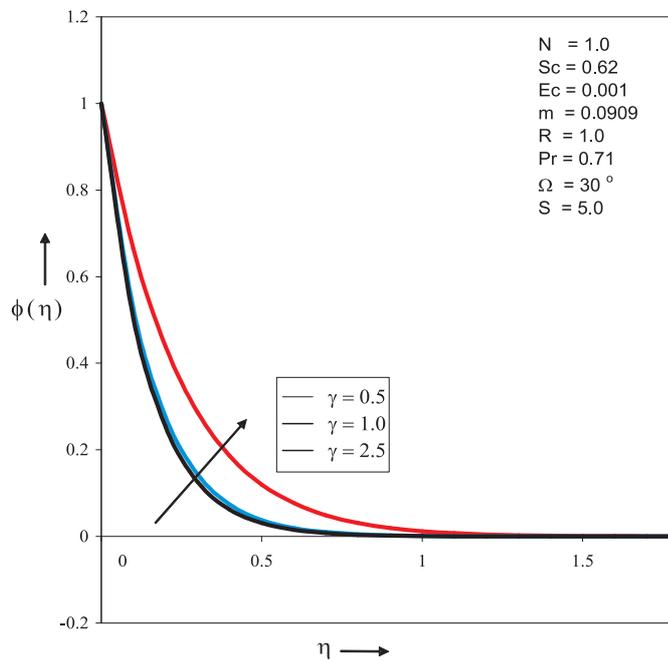Figure 3: Chemical reaction over the temperature profiles

Figure 4: Chemical reaction over the concentration profiles

heat radiation and suction at the wall of the wedge.

Figure 5 represents the dimensionless velocity profiles for different buoyancy ratio. Due to the uniform chemical reaction, it is clear that the velocity of the fluid decreases with increase of buoyancy ratio.

Figure 6 demonstrates the dimensionless temperature profiles for different values of buoyancy ratio. In the presence of uniform chemical reaction, it is seen that the temperature of the fluid slightly decreases and the concentration of the fluid increases with increase of buoyancy ratio and these are shown through Figs.6 and 7 respectively.

Figure 8 represents the dimensionless velocity profiles for different values of heat radiation.. In the presence of uniform chemical reaction and suction, it is clear that the velocity decreases and the concentration of the fluid is slightly decreases and the temperature $\theta(\eta)$ of the fluid increases with increase of heat radiation and these are shown in the Figs.8, 10 and 9 respectively. All these physical behavior are due to the combined effect of buoyancy ratio between species and thermal diffusion and the strength of the chemical reaction along with uniform suction at wall surface.
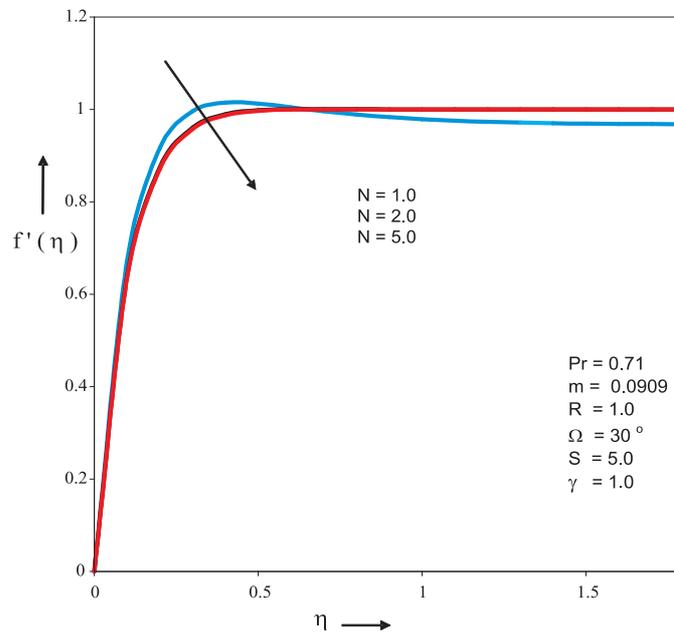
Figure 5: Effects of buoyancy ratio over the velocity profiles
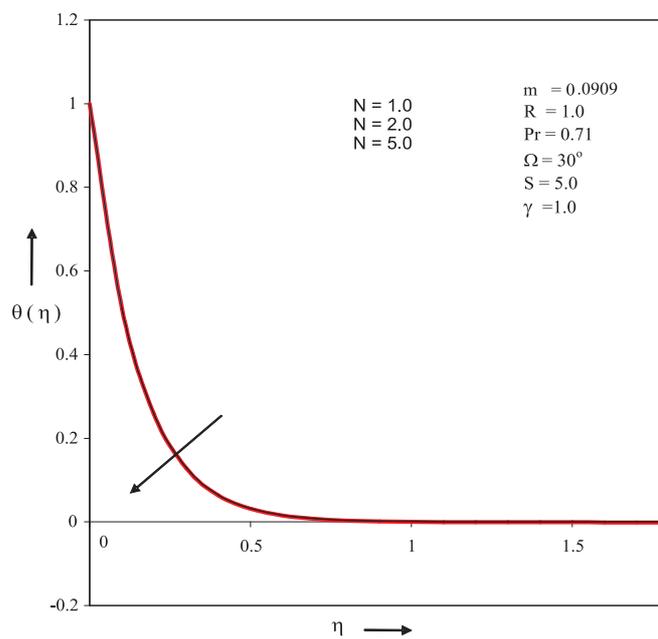

Figure 6: Effects of buoyancy ratio over the temperature profiles
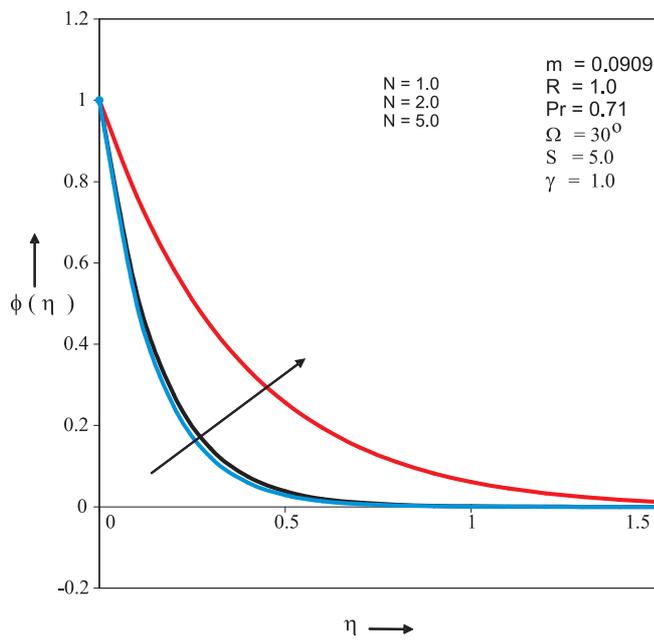
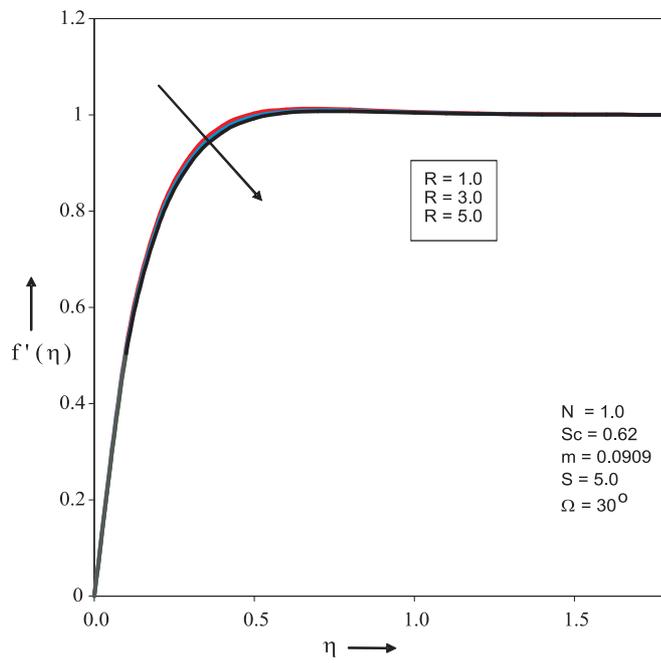Figure 7: Effects of buoyancy ratio over the concentration profiles

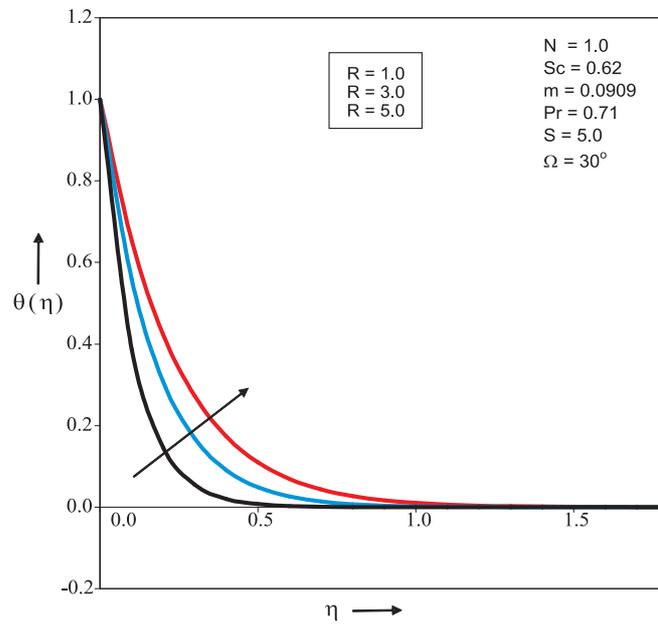Figure 8: Influence of heat radiation over the velocity profiles

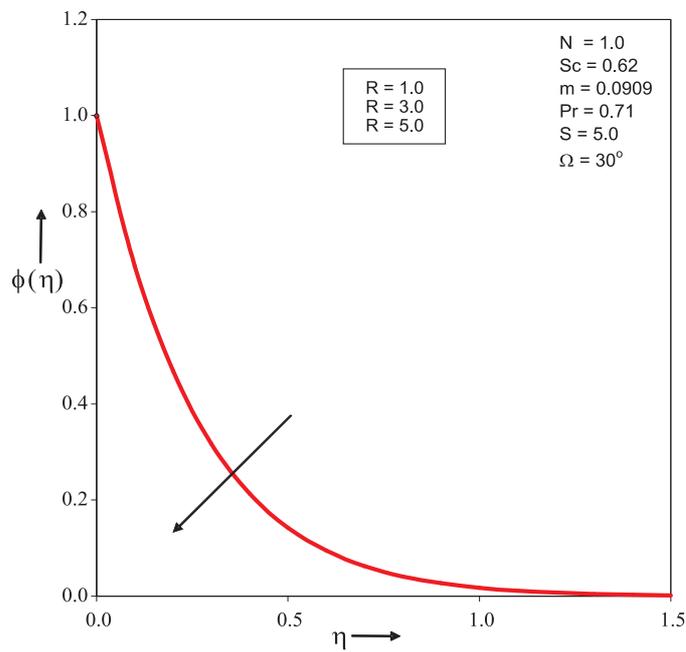Figure 9: Effects of heat radiation over the temperature profiles

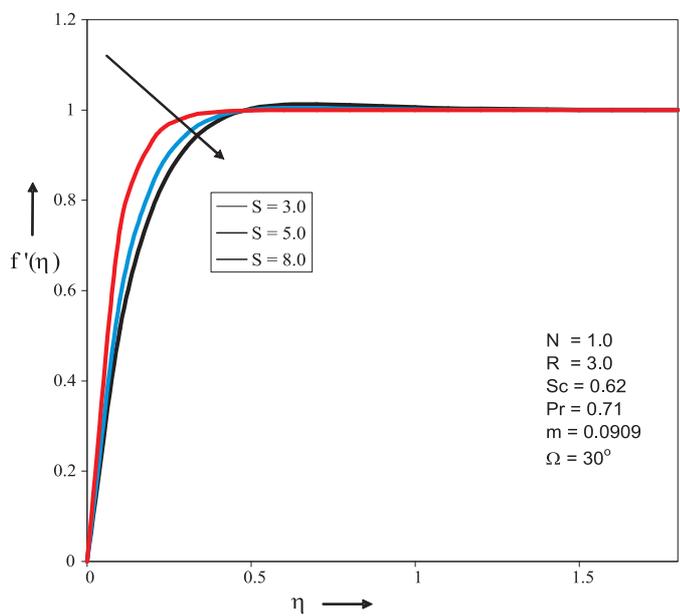Figure 10: Effects of heat radiation on the concentration profiles

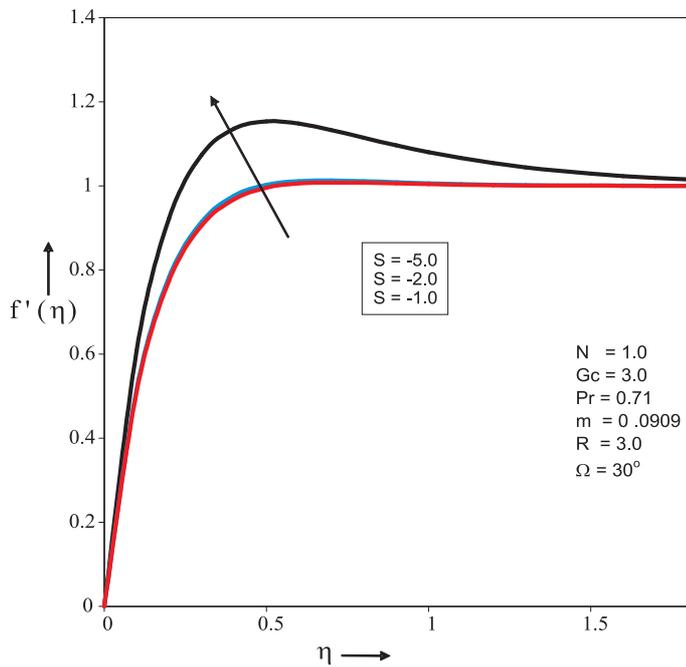Figure 11: Influence of Suction over the velocity profiles

Figure 12: Effects of injection over the velocity profiles

Figure 11 demonstrates the dimensionless velocity profiles for different values of suction parameter. In the presence of uniform heat radiation and chemical reaction, it is seen that the velocity of the fluid decreases with increase of suction and increases with increases of injection and these are shown in the Figs.11 and 12 respectively.
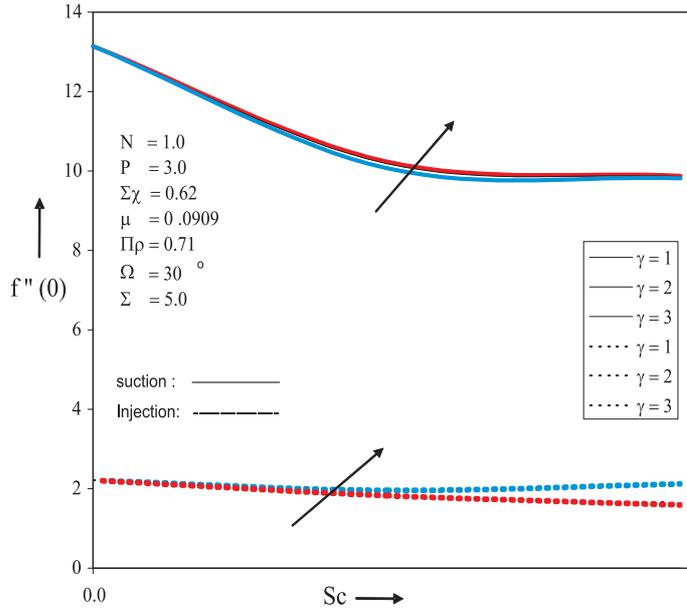

Figure 13: Chemical reaction over the skin friction

Skin friction, rate of heat and mass transfer are displayed in the Figs.13, 14 and 15 for different values of chemical reaction parameter. In both the cases of suction and injection, it is seen that skin friction increases as chemical reaction increases and this is shown in Fig.13

The rate of heat transfer for various values of chemical reaction is portrayed through Fig.14. The effect of chemical reaction over the rate of heat transfer is less dominant in the cases of suction and injection.

Figure 15 illustrates the effect of chemical reaction over the rate of mass transfer. Unlike its effect over skin friction, it increases the rate of mass transfer in the case of suction while it decreases the rate of mass transfer in the case of injection for increasing values of chemical reaction parameter.

Figure 16 represents the dimensionless velocity profiles for different values of angle of inclination of wedge. In the presence of uniform strength
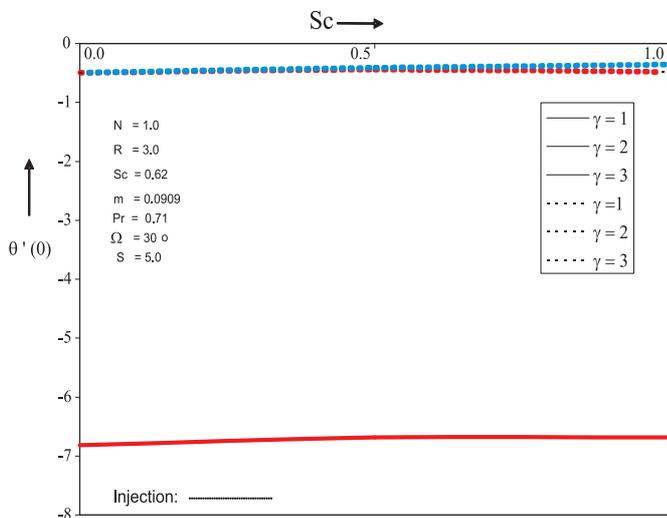
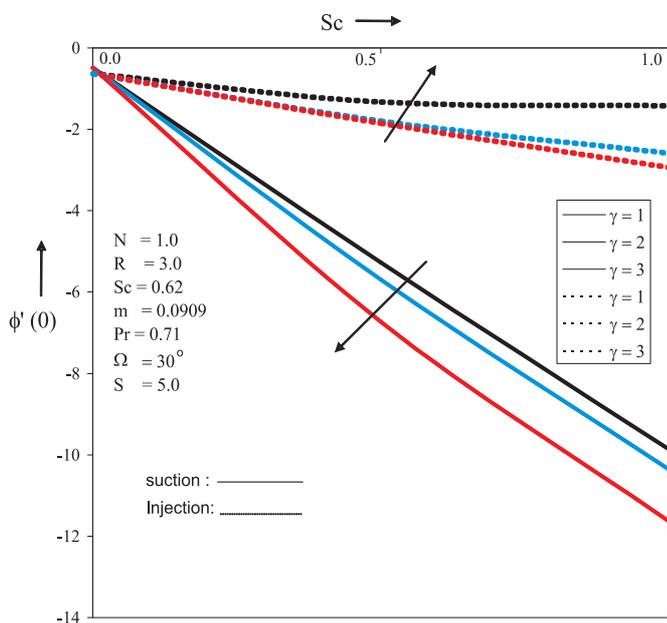Figure 14: Chemical reaction over the rate of heat transfor

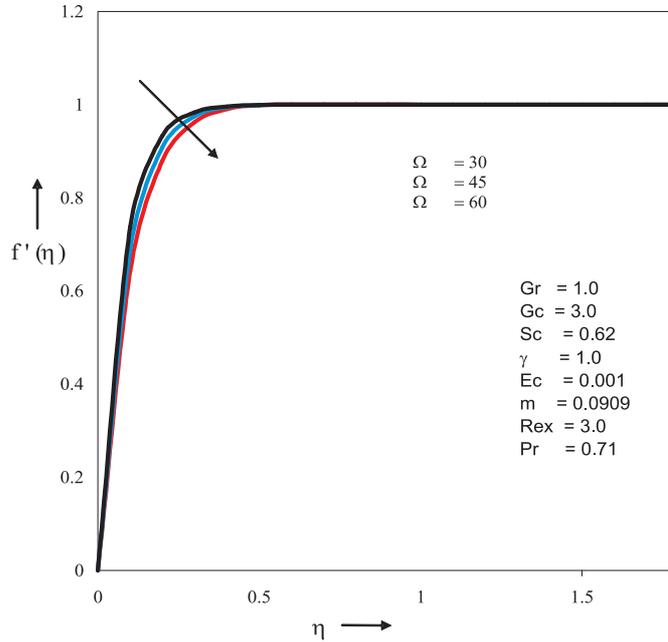Figure 15: Chemical reaction over the rate of mass transfor

Figure 16: Effects of inclination of wedge over the velocity profiles

of the heat radiation, it is clear that the velocity and concentration of the fluid decrease and temperature of the fluid increases with increase of angle of inclination of wedge and these are shown in the

Figs. 16,17 and 18 respectively. All these physical behavior are due to the combined effects of the strength of the heat radiation and chemical reaction.

5   Conclusions

This paper studied the effect of chemical reaction, heat and mass transfer on natural convection adjacent to a porous wedge surface is analyzed, taking into account the effects of heat radiation in the presence of suction or injection. The governing equations are approximated to a system of non-linear ordinary differential equations by similarity transformation. Numerical calculations are carried out for various values of the dimensionless parameters of the problem. Comparisons with previously published works are performed and excellent agreement between the results is ob-
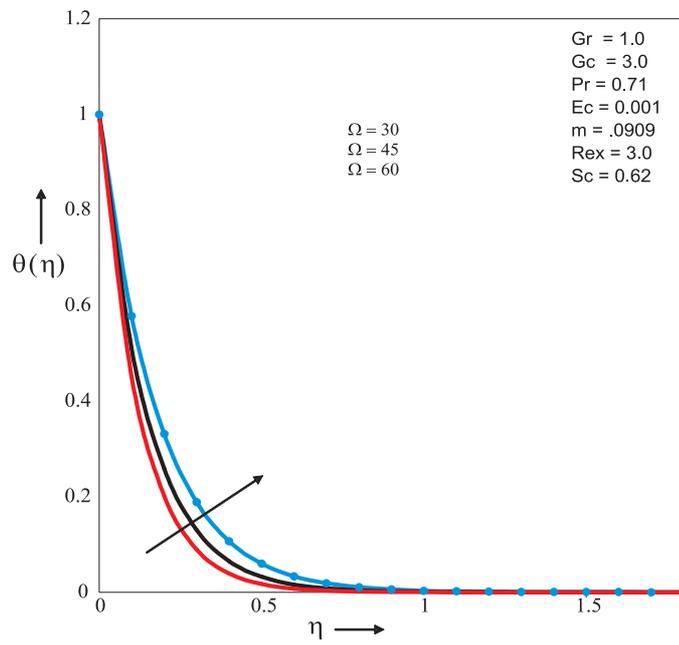
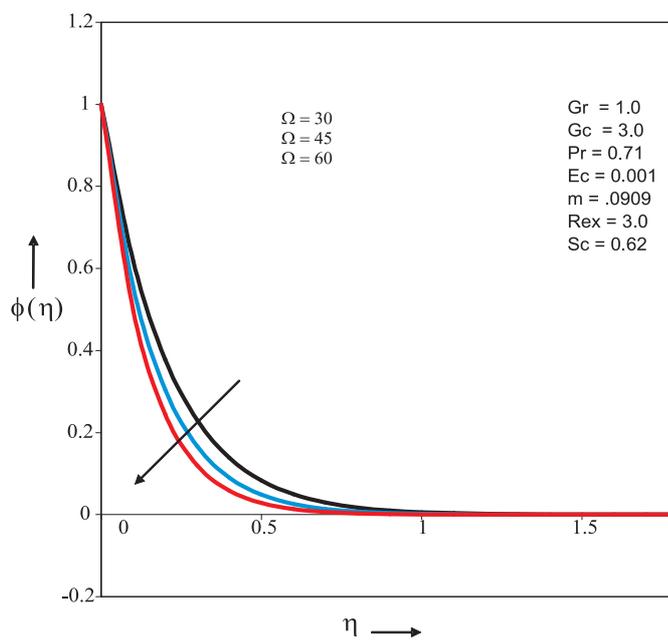Figure 17: Effects of inclination of wedge over the temperature profiles

Figure 18: Influence of inclination of wedge over the concentration profiles

tained. 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.

We conclude the following from the results and discussions:

- In the presence of uniform heat radiation, it is clear that the velocity and temperature of the fluid decrease and concentration of the fluid increases with increase of chemical reaction . All these physical behavior are due to the combined effects of the strength of the heat radiation and suction at the wall of the wedge.

- In presence of uniform chemical reaction with constant heat radiation, the velocity of the fluid decreases with increase of suction and increases with increase of injection at the wall of the wedge. All these facts clearly depict the combined effects of the chemical reaction and the strength of the heat radiation along the wall of the wedge surface.

- Due to the uniform chemical reaction and the suction at the wall of the wedge surface, it is observed that the velocity decreases and the concentration of the fluid is slightly decreases and the temperature of the fluid increases with increase of heat radiation along the wall of the wedge. All these physical behavior are due to the combined effect of buoyancy ratio between species and thermal diffusion and the strength of the chemical reaction along with uniform suction at wall surface.

- It is interesting to note that the comparison of velocity profiles shows that the velocity increases near the plate and thereafter remains uniform in all the cases.

- In both the cases of suction and injection, it is seen that skin friction increases as chemical reaction increases. Unlike its effect over skin friction, it increases the rate of mass transfer in the case of suction while it decreases the rate of mass transfer in the case of injection for increasing values of . The effect of chemical reaction over the rate of heat transfer is less dominant in the case of suction and injection at the wall of the wedge.

- In the presence of uniform heat radiation and constant suction, it is seen that the velocity and the concentration of the fluid decrease and

the temperature of the fluid increases with increase of heat radiation. All these physical behavior are due to the combined effect of buoyancy ratio between species and thermal diffusion and the strength of the chemical reaction along with uniform suction at wall surface.

- In the presence of uniform strength of the heat radiation, it is clear that the velocity and concentration of the fluid decrease and temperature of the fluid increases with increase of angle of inclination of wedge. All these physical behavior are due to the combined effects of the strength of the heat radiation and chemical reaction.

It is hoped that the present investigation of the study of physics of flow over a wedge can be utilized as the basis for many scientific and engineering applications and for studying more complex vertical problems involving the flow of electrically conducting fluids. The findings 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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Uticaj hemijke reakcije, prenosa toplote i mase na tečenje u graničnom sloju preko poroznog klina sa toplotnom radijacijom u prisustvu usisavanja i ubrizgavanja

UDC 536.7

Efekat hemijske reakcije, prenosa toplote i mase na tečenje u graničnom sloju preko poroznog klina sa toplotnom radijacijom u prisustvu usisavanja i ubrizgavanja. Približno numeričko rešenje stacionarnog laminarnog tečenje u graničnom sloju preko klina u prisistvu koncentracije i masene difuzije je dobijeno rešavanjem jednačina problema. Za fluid se pretpostavlja da je viskozan i nestišljiv. Izračunavanja se izvode za razne vrednosti bezdimenzionih parametara. Analiza rezultata pokazuje da na polje tečenja značajno utiču hemijska reakcija, odnos plutanja izmedju vrsta, termička difuzija kao i usisavanje / ubrizgavanje na površi zida. Uticaji ovih najvažnijih parametara na transportna ponašanja se metodički proučavaju i tipični rezultati se ilustrativno prikazuju. Reprezentativni rezultati su prikazani za brzinu, temperaturu i rasporede koncentracija kao i za trenje, brzinu prenosa toplote i prenosa mase. Uporedjenja sa prethodno objavljenim radovima pokazuju veoma dobro slaganje sa dobijenim rezultatima u ovom radu.