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Effects of Heat Generation/Absorption on Heat and Mass Transfer along a Moving Vertical Surface in the Presence of Chemical Reaction

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Abstract:
The aim of this work is to study the first order chemical reaction and heat source effects on unsteady viscous (laminar) flow over a continuously moving plate with constant heat and mass flux. The effects of various physical parameters of the flow, on velocity, temperature, concentration, Skin friction coefficient, Nusselt number and Sherwood number are presented through graphs and tables. It is observed
Keywords: Chemical Reaction, Heat source, Mass flux, vertical surface.

Introduction

Chemical reactions can be modified as either heterogeneous processes. This depends on whether they occur at an interface or as a single phase volume reaction. In well-mixed systems, the reaction is heterogeneous, if it takes place at an interface and homogeneous, if it takes place in solution. In most cases of chemical reactions, the reaction rate depends on the concentration of the species itself. A reaction is said to be of first order, if the rate of reaction is directly propotional to the concentration itself [1]. In many chemical engineering processes, there does occur the chemical reaction between a foreign mass and the fluid in which the plate is moving. These processes take place in numerous industrial applications like polymer production, manufacturing of ceramics or glassware and food processing. A polymer or metal sheet extruded continuously from a die, or a long fibre or filament travelling between a feed roller and a take-up roller is the typical example of moving continuous surface. Chambre and Young [2] have analyzed a first order chemical reaction in the neighbourhood of a horizontal plate. Das et al. [3] have studied the effect of homogeneous first order chemical reaction on the flow past an impulsively started infinite vertical plate with uniform heat flux and mass transfer. Again, mass transfer effects on moving isothermal vertical plate in the presence of chemical reaction studied by Das et al. [4].

Hydromagnetic incompressible viscous flow has many important engineering applications such as magneto hydrodynamic power generator and the cooling of reactors. Chen and Strobel [5] considered the effect of a buoyancy induced pressure gradient in a laminar boundary layer of a stretched sheet with constant velocity and temperature. Chakrabarti and Gupta [6] studied the MHD flow of Newtonian fluids initially at rest, over a stretching sheet at a different uniform temperature. Vajravelu and Hadjinicolaou [7] made analysis to flows and heat transfer characteristics in an electrically conducting fluid near an isothermal sheet. Xu and Liao [8] investigated the unsteady MHD flows of a non-Newtonian fluid over a non-impulsively stretching flat sheet and presented an accurate series solution. The dimensionless governing equations were solved by the perturbation technique and the solutions are valid only at lower time level.

However, the theoretical solution for hydrodynamic convection on continuously moving vertical surface with heat generation on heat and mass transfer of chemically reactive species was not studied in the literature. The present study deals with heat and mass transfer effects on continuously moving vertical surface in the presence of homogeneous chemical reaction of first order. The velocity, concentration and temperature profiles for different values of the Schmidt number, Chemical reaction parameter and Heat source parameter.

Mathematical Formulation:

A polymer or a metal sheet extruded continuously from a die, or a long fibre or filament travelling between a feed roller and a take-up roller, are typical examples of moving continuous surface. It is be assumed, that the quantity of fluid removed from the stream is so small that only fluid particles in the immediate neighborhood of the wall are sucked away. It is well known that the moving surface of finite length, the boundary layer grows in the direction opposite to the direction of the motion whereas on a moving continuous surface such as a long continuous polymer sheet or fibre extruded from a slot and taken up by a wind-up roller at a finite distance away, the boundary layer on the sheet or fibre originates at the slot and grows in the direction of motion of the surface.

A chemically reactive species is emitted from the moving vertical surface in a hydrodynamic flow field. It diffuses into the fluid where it under goes a simple homogeneous chemical reaction. The reaction is assumed to take place entirely in the stream. Consider the steady, two dimensional, incompressible flow of a viscous fluid on a continuously moving vertical surface, issuing from a slot moving with a uniform velocity u_w , in a fluid at rest. Let the x-axis be taken along the direction of motion of the surface in the upward direction and the y-axis is taken normal to it. The temperature and concentration level near the surface are raised at an uniform rate . All the fluid properties are considered constant except the influence of the density variation with temperature in the body force term. Under the above assumptions, the governing equations for boundary layer flow are as follows:

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=g\beta(T'-T'_\infty)+g\beta^*(C'-C'_\infty)+v\frac{\partial^2 u}{\partial y^2} \tag{2}$$

$$\rho C_p\left(u\frac{\partial T'}{\partial x}+v\frac{\partial T'}{\partial y}\right)=k\frac{\partial^2 T'}{\partial y^2}-Q(T'-T'_\infty) \tag{3}$$

$$u\frac{\partial C'}{\partial x}+v\frac{\partial C'}{\partial y}=D\frac{\partial^2 C'}{\partial y^2}-k_1C' \tag{4}$$

The initial and boundary conditions

$$u=u_w, v=-v_0=const.<0$$
$$\frac{\partial T'}{\partial y}=-\frac{q}{k},\frac{\partial C'}{\partial y}=-\frac{j''}{D}\ at\ y=0 \tag{5}$$
$$u\to 0, T'\to T'_\infty, C'\to C'_\infty\ \ as\ \ y\to\infty$$

We make use of the assumptions that the velocity and concentration fields are independent of the distance parallel to the surface

On introducing the following non-dimensional quantities

$$Y=\frac{yv_0}{v},U=\frac{u}{u_w},$$

$$T=\frac{T'-T'_\infty}{\left(\frac{qv}{kv_0}\right)},Gr=\frac{vg\beta\left(\frac{qv}{kv_0}\right)}{u_wv_0^2},C=\frac{C'-C'_\infty}{\left(\frac{j''v}{Dv_0}\right)},Gc=\frac{vg\beta^*\left(\frac{j''v}{Dv_0}\right)}{u_wv_0^2},Pr=\frac{\mu C_p}{k},Sc=\frac{v}{D},K=\frac{k_1v}{v_0^2} \tag{6}$$

Equations (1)-(4) are reduced to the following non-dimensional form

$$\frac{d^2U}{dY^2}+\frac{dU}{dY}+GrT+GcC=0 \tag{7}$$

$$\frac{d^2T}{dY^2}+Pr\frac{dT}{dY}-QT=0 \tag{8}$$

$$\frac{d^2C}{dY^2}+Sc\frac{dC}{dY}-KSc\ C=0 \tag{9}$$

The corresponding initial and boundary conditions in non-dimensional form are

$$U=1,\ \frac{\partial T}{\partial Y}=-1,\frac{\partial C}{\partial Y}=-1\ \ at\ Y=0$$
$$U\to 0, T\to 0, C\to 0\ \ as\ \ Y\to\infty \tag{10}$$

Solving equations (7) to (9) with boundary conditions (10), we get

$$U=\left(1+\frac{Gr}{b^2(b-2)}+\frac{Gc}{a^2(a-2)}\right)e^{-Y}-\frac{8Gr}{b^2(b-2)}e^{-\frac{b}{2}Y}-\frac{8Gc}{a^2(a-2)}e^{-\frac{a}{2}Y} \tag{11}$$

Where, $a=Sc+\sqrt{(Sc^2+4KSc)}$, $b=Pr+\sqrt{(Pr^2+4Q)}$

$$T=\frac{2}{b}e^{-\frac{b}{2}Y} \tag{12}$$

$$C=\frac{2}{a}e^{-\frac{a}{2}Y}$$

(13)

The dimensionless skin-friction at the surface are given by

$$\tau=\left(\frac{dU}{dY}\right)_{Y=0}=-\left(1+\frac{8Gr}{b^2(b-2)}+\frac{8Gc}{a^2(a-2)}\right)+\frac{4Gr}{b(b-2)}+\frac{4Gc}{a(a-2)} \tag{14}$$

Results and discussion

The mass diffusion equation (9) can be adjusted to meet these circumstances if one takes

(i) $K>0$ for the destructive reaction .
(ii) $K=0$ for no reaction.
(iii) $K<0$ for the generative reaction.
(iv) The computed solutions for the velocity, concentration and Skin-friction are valid at some distance from the slot, even though suction is applied from the slot onward. This is due to the assumption that the velocity and concentration fields are independent of the distance parallel to the surface. The fluids considered in this study are air (Pr=0.71) and water (Pr=7.0).The effect of the velocity, temperature and concentration are studied in the presence of chemical reaction parameter.

The equations (7)-(9) subject to the boundary condition (10), which describes heat and mass transfer along a moving vertical surface in the presence of chemical reaction, are solved analytically by perturbation technique. In order to get physical insight into the problem, the effects of various parameters encountered in the equations of the problem are analyzed on velocity, concentration and temperature fields with the help of figures.

The effect of the temperature profiles for different values of prandtl number Pr, heat absorption parameter Q, are presented through figures 1 and 2. From these figures it is seen that the temperature decreases with an increase in Pr and Q.

The effect of the concentration profiles for different values of Schmidt number Sc, Chemical reaction parameter K, are presented through figures 3 and 4. From these figures it is seen that the concentration decreases with an increase in Sc and K.

The effect of the velocity profiles for different values of Schmidt number Sc, thermal Grashof number Gr, mass Grashof number Gc, heat absorption parameter Q are presented through figures 5,6,7 and 8. From these figures it is seen that the velocity increases with an increase in Sc, Gr, Gc and Q, while it decreases with Chemical reaction parameter K.

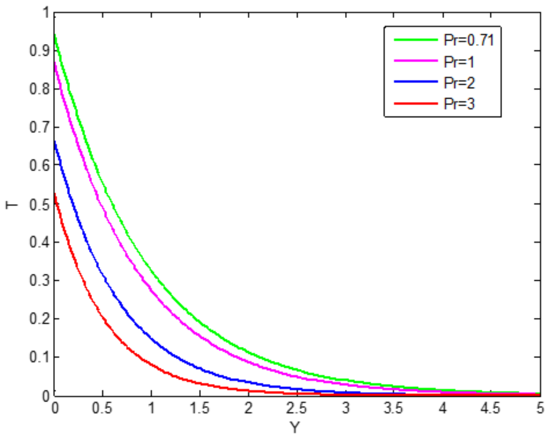

Fig 1 Effects of Pr on temperature profiles

Q=2;

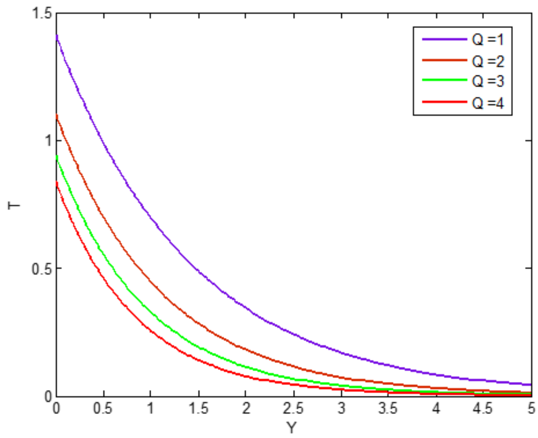

Fig 2 Effects of Q on temperature profiles

Pr=0.71;

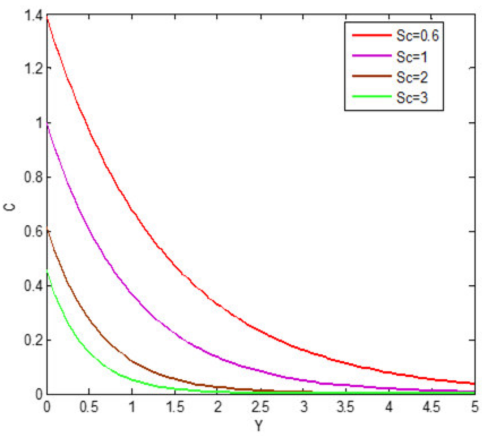

Fig 3 Effects of Sc on concentration profiles

K=2;

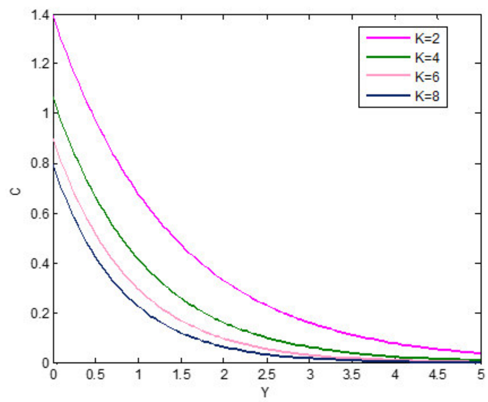

Fig 4 Effects of K on concentration profiles

Sc=0.6;

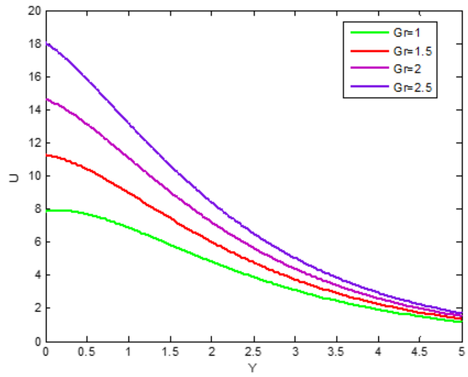

Fig 5 Effects of Gr on concentration profiles
Sc=0.6;k=0.5;Gc=1;Q=1;Pr=0.71;

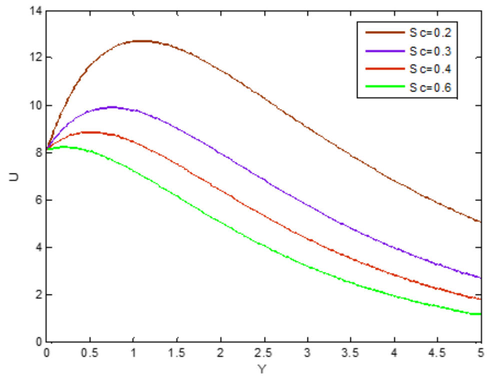

Fig 6 Effects of Sc on velocity profiles
when k=1; Gr=1; Gc=1; Q=0.5; Pr=0.71;

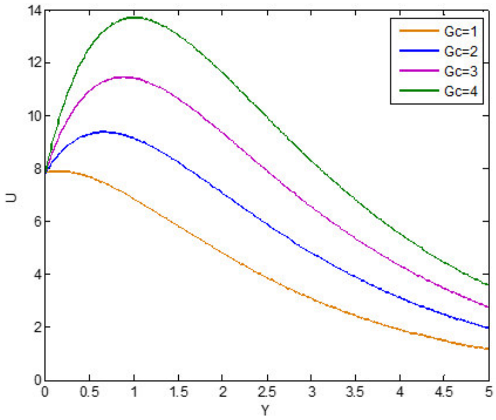

Fig 7 Effects of Gc on velocity profiles

when Sc=0.6;Gr=1;Gc=1;Q=1;Pr=1;

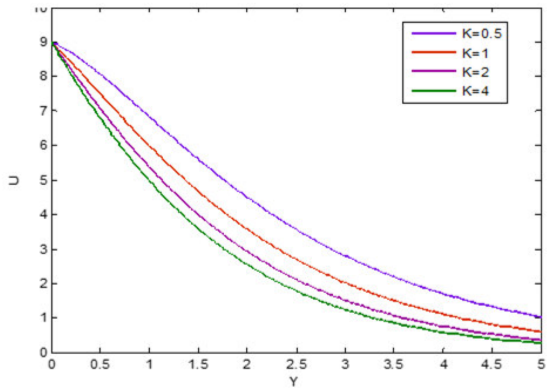

Fig 8 Effects of K on velocity profiles

when Sc=0.6;k=0.5;Gr=1;Q=1;Pr=0.71;

when Sc=0.6;Gr=1;Gc=1;Q=1;Pr=1; when Sc=0.6;k=0.5;Gr=1;Q=1;Pr=0.71;

Table 1. Values of the skin friction τ

K	Sc	Gr	Gc	Q	Pr	$\lvert\tau\rvert$
0.5	2	1	1	1	0.71	**1.6808**
1	2	1	1	1	0.71	**1.5305**
2	2	1	1	1	0.71	**1.3765**
2	**0.6**	1	1	1.5	0.71	**2.4456**
2	**1.2**	1	1	1.5	0.71	**1.2875**
2	**2**	1	1	1.5	0.71	**0.8872**
2	2	**1**	1	1	0.71	**1.3765**
2	2	**1.5**	1	1	0.71	**2.3738**
2	2	**2**	1	1	0.71	**3.3711**
2	2	1	**1**	1	0.71	**1.3765**
2	2	1	**1.5**	1	0.71	**1.5675**
2	1	1	**2**	1	0.71	**1.7585**
2	1	1	1	**1**	0.71	**1.5305**
2	1	1	1	**2**	0.71	**0.7527**
1	2	1	1	**3**	0.71	**0.4233**
1	2	1	1	2	**0.71**	**0.7527**
1	2	1	1	2	**1.2**	**0.4124**
1	2	1	1	2	**3**	**0.1488**

Table 1 represents numerical values of the skin-friction coefficient $|\tau|$ for variation in K, Sc, Gr, Gc, Q, and Pr. It is observed that, an increase in K, Sc, Q and Pr leads to decrease in the value of magnitude of skin-friction coefficient. It is noticed that $|\tau|$ increases with increasing Gr and Gc. Moreover the effect of skin-friction is more in the presence of destructive reaction than generative reaction.

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