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Research Article

Effects of Heat and Mass Flux to MHD Flow in Vertical Surface with Radiation Absorption

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Abstract: MHD flow of an electrically conducting, incompressible, viscous fluid past an impulsively moving isothermal vertical plate through porous medium in the presence of uniform suction, radiation absorption and chemical reaction taking in to an account in this analysis. A flow of this type represents a new class of boundary layer flow at a surface of finite length. The heat transfer coefficient is found to vary significantly with heat flux and vapor quality, but only slightly with saturation pressure and mass flux for the range of values investigated. The equations governing the flow field are solved by analytical method. The velocity, temperature, concentration and skin friction have been evaluated for variation in the different governing parameters.
Keywords: Chemical reaction, Heat generation/ absorption, Heat and Mass flux and Radiation absorption

INTRODUCTION

Heat transfer to objects in or near pool fires has been the subject of study for decades. Traditionally, the focus has been on determining a safe separation distance from the fire. Calculation with a conservatively high heat flux provided a good margin of safety. However, there are times when conservative estimations of heat flux are inadequate for determining the magnitude of the hazard, particularly when dealing with containers of energetic materials. For example, some energetic materials may detonate under slow heating (slow cook-off) conditions and deflagrate under rapid heating (fast cook-off) conditions. Overestimating the heat flux may underestimate the hazard, motivating the need for physically-based methods that accurately predict heat flux from pool fires to embedded objects. In this chapter, the hazard is characterized in terms of the time to ignition of the explosive device and the violence (measured as kinetic energy of the exploded container) of the event.

Magnotohydrodynamics (MHD) is the study of the dynamics of electrically conducting fluids. Examples of such fluids include plasmas, liquid metals, and salt water or electrolytes. The word magnetohydrodynamics is derived from magneto meaning magnetic field, hydro- meaning liquid, and -dynamics meaning movement. The fundamental concept behind MHD is that magnetic fields can induce currents in a moving conductive fluid, which in turn creates forces on the fluid and also changes the magnetic field itself. Engineering processes in which a fluid supports an exothermal chemical or nuclear reaction are very common today and the correct process design requires accurate correlation for the heat transfer coefficients at the boundary surfaces. Despite its increasing importance in technological and physical problems, the unsteady MHD free convection flows of dissipative fluids past an infinite plate have received much attention because of non-linearity of the governing equations. Without taking into account viscous dissipative heat and MHD, this problem was solved by Siegal [1] by integral method. The experimental confirmations of these results were presented by Goldstein and Eckert [2]. Other papers in this field are by Gebhart [3], Schetz and Eichhorn [4], Monold and Yang [5].

An understanding of the fundamental heat transfer processes in the cold plate evaporator is necessary in such applications to predict the heat transfer performance and pressure drop and optimize the design. The study of natural convection heat and mass transfer phenomenon in porous media is gaining attention due to its interesting applications. Processes involving heat and mass transfer in porous media are often encountered in the chemical industry, in reservoir engineering in connection with thermal recovery process and in the study of dynamics of hot and salty springs of a sea. Underground spreading of chemical wastes and other pollutants, grain storage, evaporation, cooling and solidification are the few other application areas where the combined thermo-solute natural convection in porous media is observed. Vajravelu [6] studied the exact solutions for hydrodynamic boundary layer flow and heat transfer over a continuous, moving, horizontal flat surface with uniform suction and internal heat generation/absorption. Girish Kumar [7] Chemical reaction effects on MHD flow of continuously moving vertical surface with heat and mass flux through porous medium. Karunakar et.al [8] MHD heat and mass transfer Flow of a viscoelastic fluid past an impulsively started infinite vertical plate with chemical reaction. Although many studies Chang and Pan [12]; Chen and Garimella [13]; Harirchian and Garimella [14]; Lee and Garimella [15]; Liu et al [16]; Qu and Mudawar [17]; Steinke and Kandlikar [18], and Wu and Cheng [19] have addressed this topic, flow boiling in microchannels has not yet been fully understood. While there has been general agreement in the published results that the heat transfer coefficient increases with increasing heat flux, the effect of several other parameters such as vapor quality and mass flux have received less attention and shown opposing trends in the literature in some cases.

Absorption is the transformation of radiant power to another type of energy, usually heat, by interaction with matter. When radiant flux is incident upon a surface or medium, three processes occur, they are transmission, absorption and reflection. The study of heat generation or absorption effects in moving fluids is important in fluids undergoing exothermic or endothermic chemical reactions. Heat generation effects may alter the temperature distribution and consequently, the particle deposition rate in nuclear reactors, electric chips and semiconductor wafers. Patil and Kulkarni [9] studied the effects of chemical reaction on free convective flow of a polar fluid through porous medium in the presence of internal heat generation. Effect of viscous dissipative heat and uniform magnetic field on the free convective flow through a porous medium with heat generation/absorption was studied by Amakiri and Ogulu [10]. Hady et al. [11] have analyzed the MHD free convection flow along a wavy surface with heat generation or absorption effect.

The aim of the present works we contemplate to study the chemical reaction and heat generation/absorption effects on MHD flow of an electrically conducting, incompressible, viscous fluid past an impulsively moving isothermal vertical plate through porous medium in the presence of radiation absorption, uniform heat and mass flux.

FORMULATION OF THE PROBLEM

We consider the steady, two-dimensional laminar, incompressible viscous fluid on a continuously moving vertical surface in the presence of a uniform magnetic field, radiation absorption, chemically reacting with heat source, uniform heat and mass flux effects issuing a slot and moving with uniform velocity in a fluid at rest. Let the x-axis be taken along the direction of motion of the surface in the upward direction and y-axis is normal to the surface. The temperature and concentration levels near the surface are raised uniformly. The induced magnetic field, viscous dissipation is assumed to be neglected. Now, under the usual Boussinesq's approximation, the flow field is governed by the following equations.

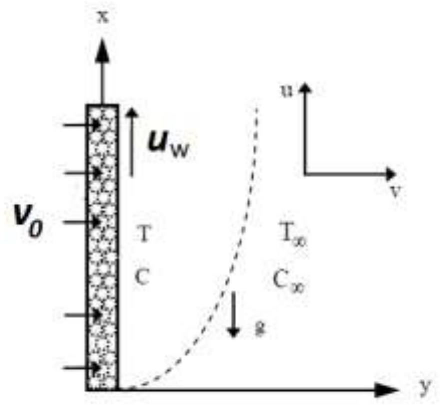

Figure-a: Flow configuration and coordinate system

Continuity equation

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

Momentum equation

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=g\beta\left(T'-T'_\infty\right)+g\beta^*\left(C'-C'_\infty\right)+\nu\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B_0^2}{\rho}u-\frac{\nu}{K_p}u \tag{2}$$

Energy equation

$$\rho C_p\left(u\frac{\partial T'}{\partial x}+v\frac{\partial T'}{\partial y}\right)=k\frac{\partial^2 T'}{\partial y^2}-Q_0\left(T'-T'_\infty\right)+Q_l'\left(C'-C'_\infty\right) \tag{3}$$

Diffusion Equation

$$u\frac{\partial C'}{\partial x}+v\frac{\partial C'}{\partial y}=D\frac{\partial^2 C'}{\partial y^2}-Kr'\left(C'-C'_\infty\right) \tag{4}$$

The relevant boundary conditions are

$$u=u_w, v=-v_0=const<0$$

$$\frac{\partial T}{\partial y}=-\frac{q}{k},\ \frac{\partial C}{\partial y}=-\frac{j''}{D} \qquad at \quad y=0 \tag{5}$$

$$u\to 0, T\to T_\infty, C\to C_\infty \qquad as \quad y\to\infty$$

In order to write the governing equations and the boundary conditions the following non dimensional quantities are introduced.

$$u=\frac{u}{u_w},Y=\frac{yv_0}{\nu},\ T=\frac{T'-T_\infty'}{\left(\frac{q\nu}{kv_0}\right)},C=\frac{C'-C_\infty'}{\left(\frac{j''\nu}{kv_0}\right)}$$

$$M=\frac{\sigma B_0{}^2\nu}{\rho v_0{}^2},\quad Q_l=\frac{Q_l'\,j''\nu}{qv_0^2\rho C_p},\quad Q=\frac{\nu Q_0}{\rho C_p v_0{}^2}\quad (6)$$

$$\Pr=\frac{\mu C_p}{k},Kr=\frac{Kr'\nu}{v_0^2},Sc=\frac{\nu}{D_M},k=\frac{K_p v_0{}^2}{\nu^2}$$

$$Gr=\frac{\nu g\beta\left(\frac{q\nu}{kv_0}\right)}{u_w v_0^2},\qquad Gc=\frac{\nu g\beta^*\left(\frac{j''\nu}{kv_0}\right)}{u_w v_0^2}$$

Where u,v are the velocity along the x,y -axis, is constant obtained after integration conservation of mass in pre-non dimensional form not mentioned, ν is the kinematic viscosity, g is the acceleration due to gravity, T' is the temperature of the fluid, is the coefficient of volume expansion, C_p is the specific heat at constant pressure, is a constant, σ is the Stefan-Boltzmann constant, T_w' exceeds the free steam temperature T_∞', C' is the species concentration, is the wall temperature, C_w' is the concentration at the plate, T_∞' is the free steam temperature far away from the plate, C_∞' is the free steam concentration in fluid far away from the plate, $\Pr$ is the Prandtl number, Gr is the Grashoff number, k is the thermal conductivity of the fluid, B_0 is uniform magnetic field strength, M is the magnetic field parameter which is the ratio of magnetic force to the inertial force. It is a measure of the effect of flow on the magnetic field, Q_l is radiation absorption parameter. The term $Q_0\left(T'-T_\infty'\right)$ is assumed to be the amount of heat generated or absorbed per unit volume. Q_0 is a constant, which may take on either positive or negative values.

SOLUTION OF THE PROBLEM

In view of (6) the equations (2), (3) and (4) are reduced to the following non-dimensional form

$$\frac{d^2U}{dY^2}+\frac{dU}{dY}-\left(M-\frac{1}{k}\right)U=-GrT-GcC \qquad (7)$$

$$\frac{d^2T}{dY^2}+\Pr\frac{dT}{dY}-Q\Pr T=-Q_l\Pr C \qquad (8)$$

$$\frac{d^2C}{dY^2}+Sc\frac{dC}{dY}-KrScC=0 \qquad (9)$$

The corresponding boundary conditions can be written as

$$\begin{aligned}&U=1,\ \frac{\partial T}{\partial Y}=-1,\ \frac{\partial C}{\partial Y}=-1 && at\ Y=0\\ &u_0\to 0,T\to 0,C=0 && as\ Y\to\infty\end{aligned}\qquad (10)$$

Where Gr is the thermal Grashof number, Gc is the solutal Grashof number, $\Pr$ is the fluid Prandtl number, Sc is the Schmidt number and Kr is the chemical reaction, Q Heat source parameter, Q_l heat absorption.

The study of ordinary differential equations (7), (8) and (9) along with their initial and boundary conditions (10) have been solved by using the method of ordinary linear differential equations with constant coefficients. We get the following analytical solutions for the velocity, temperature and concentration

$$U=D_1e^{m_2y}+D_2e^{m_4y}+D_3e^{m_2y}+D_4e^{m_6y}$$

$$T=B_1e^{m_2y}+B_2e^{m_4y}$$

$$C=A_1e^{m_2y}$$

The computed solution for the velocity is valid at some distance from the slot, even though suction is applied from the slot onward. This is due to the assumption that velocity field is independent of the distance parallel to the plate. The fluids considered in this study are air (Pr = 0.71) and water (Pr = 7.0).

Skin friction

$$\tau=\left(\frac{\partial U}{\partial y}\right)_{y=0}=D_1m_2+D_2m_4+D_3m_2+D_4m_6$$

Nusselt number

$$Nu=\left(\frac{\partial T}{\partial y}\right)_{y=0}=B_1m_2+B_2m_4$$

Sherwood number

$$Sh=\left(\frac{\partial C}{\partial y}\right)_{y=0}=A_1m_2$$

APPENDIX

$$m_2=-\left(\frac{Sc+\sqrt{Sc^2+4KrSc}}{2}\right)$$

$$m_4=-\left(\frac{\Pr+\sqrt{\Pr^2+4Q\Pr}}{2}\right)$$

$$m_2=-\left(\frac{1+\sqrt{1+4\beta}}{2}\right),\alpha=\left(M+\frac{1}{K}\right)$$

$$A_1 = -\frac{1}{m_2}, B_1 = -\frac{Q_l A_1 \Pr}{m_2^2 + \Pr m_2 - Q \Pr}$$

$$B_2 = -\left(\frac{m_2 B_1 + 1}{m_4}\right), D_1 = -\frac{Gr B_1}{m_2^2 + m_2 - \alpha}$$

$$D_2 = -\frac{Gr B_2}{m_4^2 + m_4 - \alpha}, D_3 = -\frac{Gc A_1}{m_2^2 + m_2 - \alpha}$$

$$D_4 = \left(1 - D_1 - D_2 - D_3\right)$$

RESULTS AND DISCUSSION

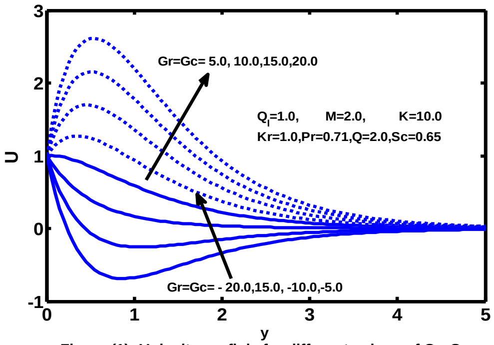

Figure (1): Velocity profiels for different values of Gr, Gc

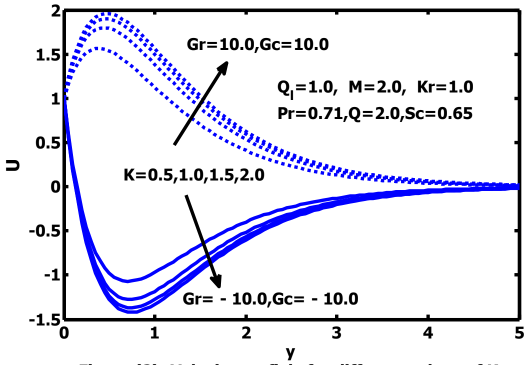

Figure (2): Velocity profiels for different values of K,

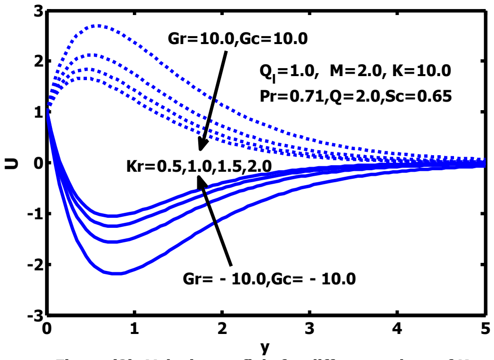

Figure (3): Velocity profiels for different values of Kr

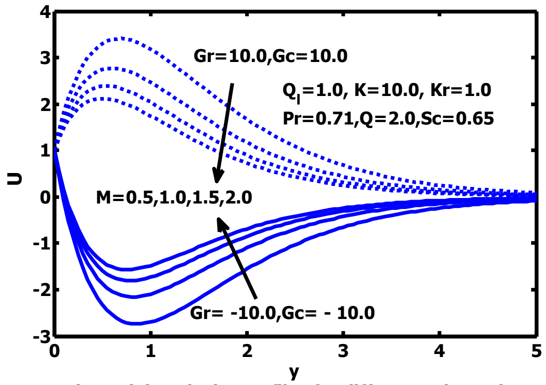

Figure (4): Velocity profiles for different values of M

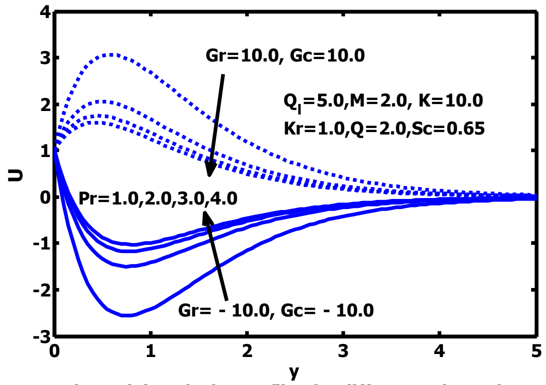

Figure (5): Velocity profiles for different values of Pr

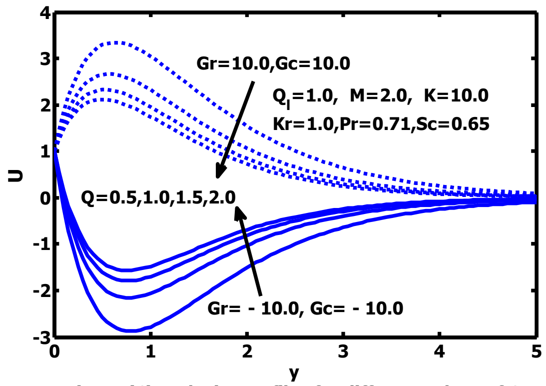

Figure (6): Velocity profiles for different values of Q

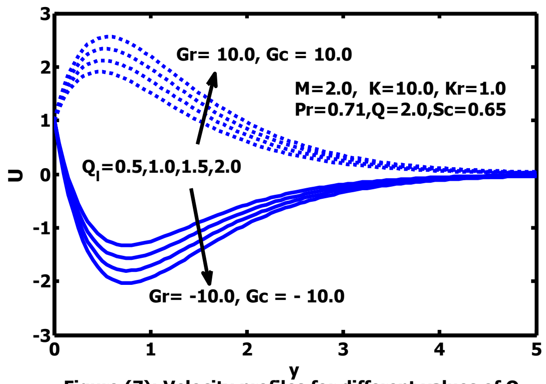

Figure (7): Velocity profiles for different values of Q_l

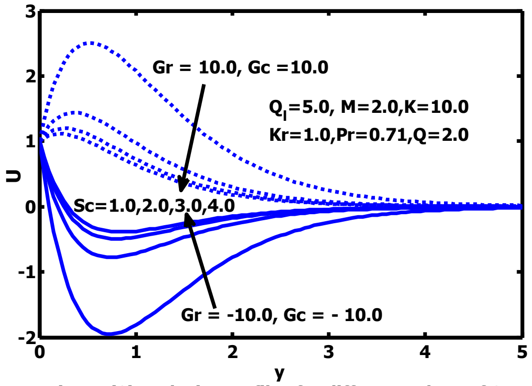

Figure (8): Velocity profiles for different values of Sc

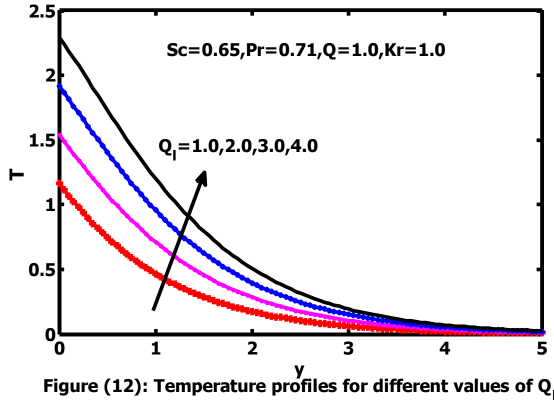

Figure (12): Temperature profiles for different values of Q_l

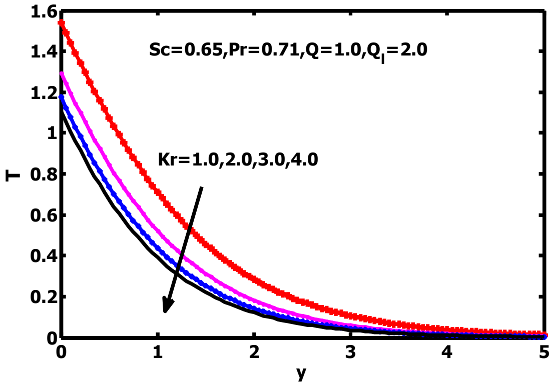

Figure (9): Temperature profiles for different values of Kr

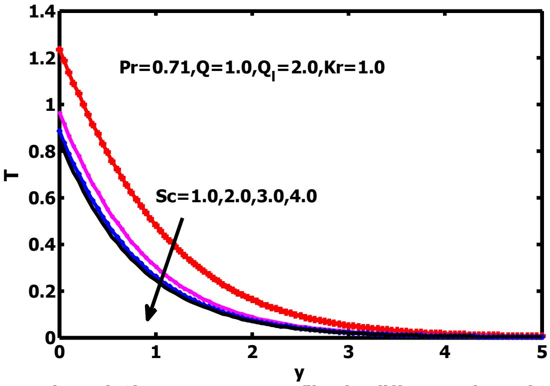

Figure (13): Temperature profiles for different values of Sc

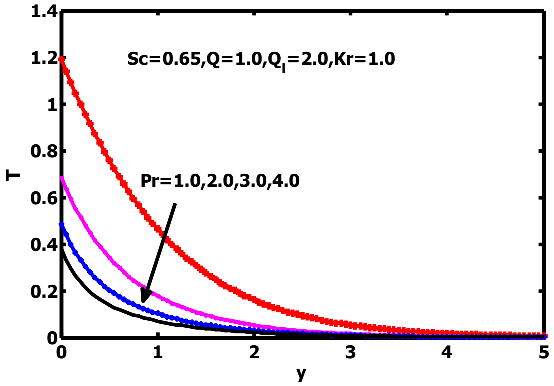

Figure (10): Temperature profiles for different values of Pr

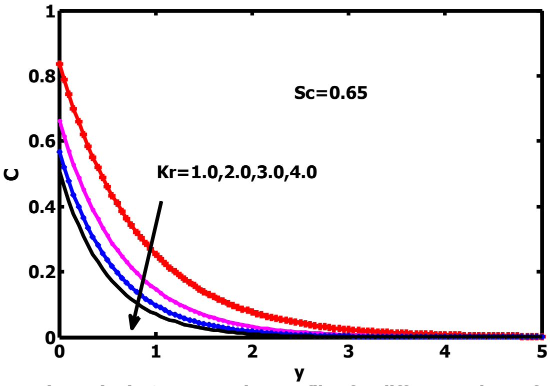

Figure (14): Concentration profiles for different values of Kr

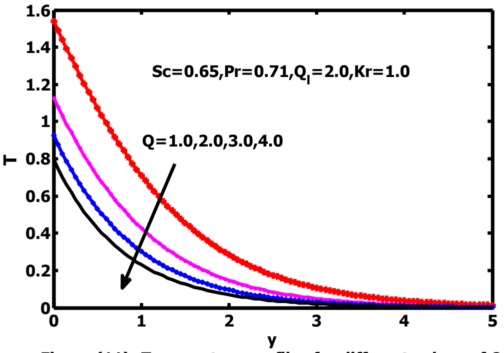

Figure (11): Temperature profiles for different values of Q

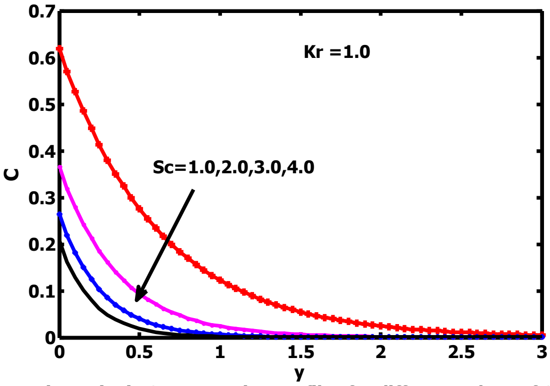

Figure (15): Concentration profiles for different values of Sc

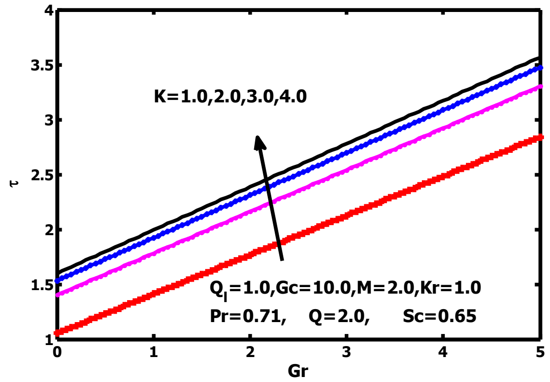

Figure (16): Skin friction for different values of K versus Gr

A representative set of numerical results is shown graphically in figures to illustrate the influence of physical parameter viz., Chemical reaction parameter, Magnetic parameter, Prandtl number, Schmidt number, Permeability parameter, thermal Grashof number $(Gr > 0, Gr < 0)$, solutal Grashof number $(Gc > 0, Gc < 0)$, Heat source parameter and radiation absorption parameter on velocity, temperature and concentration profiles. The thermal Grashof number Gr and solutal Grashof number Gc represents here the effects of free convection currents, and receives positive, zero or negative values. The case $Gr < 0$ and $Gc < 0$ corresponds physically to an externally heated surface as the free convection currents are moving towards the surface. The case $Gr > 0$ and $Gc > 0$ corresponds to an externally cooled surface and the case $Gr = 0$ and $Gc = 0$ corresponds to absence of the free convection currents.

Figure (1) presents typical velocity profiles in the boundary layer for various values of the thermal Grashof number Gr and Solutal Grashof number Gm, while all other parameters are kept at some fixed values. The thermal Grashof number Gr and Solutal Grashof number Gm defines the ratio of the species buoyancy force to the viscous hydrodynamic force. As expected, the fluid velocity increases and the peak value is more distinctive due to increase in the species buoyancy force. The velocity distribution attains a distinctive maximum value in the vicinity of the plate and then decreases properly to approach the free stream value. Figure (2) illustrate the variation of velocity distribution across the boundary layer for various values of the permeability parameter *K*. The velocity increases with an increase in permeability parameter *K*. Figure (3) display the effects of the chemical reaction parameter (Kr) on the velocity profiles respectively. As the Kr increases the velocity decreases. This causes the concentration buoyancy effects to decrease yielding a reduction in the fluid velocity for different values of the magnetic field parameter (M), the velocity profiles are plotted in figure (4). It is obvious that the effect of increasing values of the magnetic field parameter results in a decreasing velocity distribution across the boundary layer. Figure (5) illustrate the velocity profiles for different values of the Prandtl number $(\Pr)$. The Prandtl number defines the ratio of momentum diffusivity to thermal diffusivity. The numerical results show that the effect of increasing values of Prandtl number results in a decreasing velocity. The effect of heat source parameter (Q) on the velocity field illustrated n figure (6). Heat source parameter (Q) is increased the velocity field decreases. Further, it is seen that a backward flow is possible in such a situation; while the reverse effects observed for different values of radiation absorption parameter (Q_l) in figure (7). Figure (8) display the effects of the Schmidt number Sc on the velocity profiles respectively. As the Schmidt number increases the velocity decreases. This causes the concentration buoyancy effects to decrease yielding a reduction in the fluid velocity. Figure (9) display the effects of the chemical reaction parameter (Kr) on the temperature profiles respectively. As the Kr increases the temperature decreases. From figure (10), it is observed that an increase in the Prandtl number $(\Pr)$ results a decrease of the thermal boundary layer thickness and in general lower average temperature within the boundary layer. The reason is that smaller values of $\Pr$ are equivalent to increasing the thermal conductivities, and therefore heat is able to diffuse away from the heated plate more rapidly than for higher values of $\Pr$. Hence in the case of smaller Prandtl numbers as the boundary layer is thicker and the rate of heat transfer is reduced. The effect of heat source parameter (Q) on the temperature field illustrated n figure (11). If Q is increased the temperature field decreases. Further, it is seen that a backward flow is possible in such a situation; while the reverse effects observed for different values of radiation absorption parameter (Q_l) in figure (12). Figure (13) display the effects of the Schmidt number Sc on the temperature profiles respectively. As the Schmidt number increases the temperature decreases. This causes the concentration buoyancy effects to decrease yielding a reduction in the fluid velocity. Figures (14) and (15) display results for the concentration distributions respectively for various values of Kr, Sc. It is seen, that the concentration decreases with increasing values of Kr, Sc. Figure (16) displays the effect of K on shear stress with respect to Groshof number $\left(Gr\right)$, it is obvious that there is a slight changes in shear stress, also, it is seen that shear stress increases with an increasing of K.

CONCLUSION

The plate velocity was maintained at a constant value and the flow was subjected to a transverse magnetic field. The resulting partial differential equations were transformed into a set of ordinary differential equations using perturbation method. Numerical results were performed and some graphical results were obtained to illustrate the details of the flow and heat and mass transfer characteristic and their dependence on some of the physical parameters. It was found that the velocity profiles decreased due to increase in chemical reaction parameter, the Schmidt number, magnetic field and Prandtl number parameters while it increased due to increases in thermal Grashof number, Solutal Grash of number and Permeability parameters. However, an increase temperature profile is a function of an decrease due to increases in Prandtl number. Also, it was found that the concentration profile increased due to decreases in the chemical reaction parameter and the Schmidt number.

The flow boiling heat transfer coefficient strongly increases with increasing heat flux and seems to be dominated by nucleate boiling. It also shows a strong dependence on thermodynamic vapor quality with a rapid decrease at qualities above 0.5. The maximum heat transfer coefficient occurs at vapor qualities between 0.1 and 0.5 depending on fluid, geometry and flow conditions. The heat transfer coefficient increases weakly with increasing mass flux and is almost constant for the range of saturation temperatures investigated in this study. The smaller hydraulic diameter leads to marginally higher heat transfer coefficients.

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