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Effects of thermal Diffusion on Hydrodynamic Free Convective, Radiative and Chemically Reactive Dissipative Fluid Flow Past a Vertical Porous Surface With Heat Absorption and Constant Suction

R.Swetha[1]N.Chaturvedi [2]G.Viswanatha Reddy[3]S.Vijaya Kumar Varma[3]

[1]Department of Mathematics, Gudalvalleru Engineering College, Gudlavalleru.
[2]Department of Mathematics, University of Botswana,
PvtBag 00704, Gaborone, Botswana.
[3]Department of Mathematics, S V University, Tirupati.

Corresponding Author: **N.Chaturvedi**

Abstract

In the present article, the analytical solution of MHD dissipative and free convective boundary layer flow past a porous vertical surface under the influence of uniform magnetic field in the presence of thermal radiation, heat absorption chemical reaction and thermal diffusion is studied. The said study has been carried out in two cases of boundary conditions;1) when the plate is subjected to suction with constant velocity and 2) when the permeable plate has a moving velocity in the direction of fluid flow. The governing equations are solved by using a perturbation technique by making some simplifying assumptions. The solutions for temperature, concentration and velocity are obtained and presented in graphs. Also, the exact solutions for the temperature, concentration and velocity fields in the form of heat and mass transfer rates, shear stress are obtained and presented in tables. The effects of various flow parameters on concentration, temperature, velocity are analyzed and illustrated graphically and the effects of their gradients are shown through tables. The present study has a wide range of applications in Science and Technology. The problem under consideration can further be studied for different positions of the plate with variable suction.

Keywords: soret effect; heat absorption; chemical reaction; porous media; mhd; eckert number.

INTRODUCTION

Soret effect is a mass flux due to a temperature gradient and appears in the species continuity equation when there is a multi-component mixture where each species has its own diffusion velocity. This phenomenon is observed in mixtures of mobile particles where the various particle types showseveral responses to the force of a temperature gradient and this term normally applies to liquid mixtures, aerosol mixtures. Similarity solution of mixed convective boundary layer slips flow over a vertical plate was studied by Bhattacharya et.al (2013). Chamka and Camille (2000) examined the consequences of heat generation or absorption and thermophoresis on hydro magnetic flow with mass and heat transfer over a flat surface. Mass and heat transfer for thermo-diffusion effects on mixed convective boundary layer flow in a porous medium over a vertical stretching surface filled with a visco-elastic fluid has been analyzed by Hayat et. Al (2010).

Mahapatra(2010) considered the chemical reaction consequences on free convective flow bounded by a vertical surface through a porous medium. Free convective flow past a vertical moving porous plate with thermal radiation and mass transfer was studied by Makinde and Mhone (2005). The effects of radiation and chemical reaction on isothermal oscillating vertical plate with variable mass diffusion werestudied by Manivannanet. Al (2009). Mass and heat transfer results on MHD flow of a visco-elastic fluid with oscillatory suction and heat source through porous medium was discussed by Mishra et.al (2013). Muthucumaraswamy and Ganesan (2011) presented the chemical reaction of first order on the flow past an impulsively started vertical plate with uniform mass and heat flux. Rajuet. Al (2014) investigated the analytical study of MHD free convective, dissipative boundary layer flow past a vertical porous surface in the presence of thermal radiation, chemical reaction and constant suction. The effects of porosity parameter and radiation on MHD flow in porous media due to stretching surface have been identified by Singh et.al (2010).

The purpose of the present study is to investigate the effects of thermal radiation, heat absorption, thermal diffusion and chemical reaction on MHD steady two dimensional, dissipative, free convective boundary layer flows past a porous vertical surface, under the influence of uniform magnetic field, in two different cases of boundary conditions. 1) When the plate is subjected to suction with constant velocity.2) When the permeable plate has a moving velocity in the direction of fluid flow. In these cases, the solutions for velocity, temperature concentration and their corresponding gradients are derived by using perturbation technique. Effects of various parameters involved in this flow on the concentration, temperature, velocity are analyzed with the help of graphs. The effects of their gradients are discussed through tables.

MATHEMATICAL ANALYSIS

A viscous, isochoric (incompressible), radiating and electrically conducting fluid occupying the space of semi- infinite region through porous medium bounded by a vertical surface has been considered. Along the surface, $\tilde{x}$axis is taken in the upward direction and $\tilde{y}$axistaken normal to the plate. A uniform magnetic field B_0 is applied in a perpendicular direction to the surface. Fluid properties are presumed to be constant andthe density in the terms of body force. In addition to these, thermal diffusion and chemical reactive species are presumed. The governing equations for the problem under consideration are;

$$\frac{\partial \tilde{v}}{\partial \tilde{y}} = 0 \quad (1)$$

$$\tilde{v}\frac{\partial \tilde{u}}{\partial \tilde{y}} = \nu \frac{\partial^2 \tilde{u}}{\partial \tilde{y}^2} + g\beta_T(\tilde{T} - \tilde{T}_\infty) + g\beta_C(\tilde{C} - \tilde{C}_\infty) - \frac{\sigma B_0^2 \tilde{u}}{\rho} - \frac{\nu \tilde{u}}{\mathcal{K}_P} \quad (2)$$

$$\tilde{v}\frac{\partial \tilde{T}}{\partial \tilde{y}} = \frac{\kappa}{\rho C_P}\frac{\partial^2 \tilde{T}}{\partial \tilde{y}^2} + \frac{\nu}{C_P}\left(\frac{\partial \tilde{u}}{\partial \tilde{y}}\right)^2 - \frac{1}{\rho C_P}\frac{\partial \tilde{q}_r}{\partial \tilde{y}} - \frac{Q_0}{\rho C_P}(\tilde{T} - \tilde{T}_\infty) \quad (3)$$

$$\tilde{v}\frac{\partial \tilde{C}}{\partial \tilde{y}} = D_m \frac{\partial^2 \tilde{C}}{\partial \tilde{y}^2} - K_c(\tilde{C} - \tilde{C}_\infty) + \frac{D_m K_T}{T_m}\frac{\partial^2 \tilde{T}}{\partial \tilde{y}^2} \quad (4)$$

with the relevant conditions

CASE 1:

$$\left.\begin{aligned} &\tilde{u} = 0, \quad \tilde{T} = \tilde{T}_w, \tilde{C} = \tilde{C}_w \quad \text{at } \tilde{y} = 0 \\ &\tilde{u} \to 0, \quad \tilde{T} \to \tilde{T}_\infty, \tilde{C} \to \tilde{C}_\infty \quad \text{as } \tilde{y} \to \infty \end{aligned}\right\} \quad (5)$$

CASE 2:

$$\left.\begin{aligned} &\tilde{u} - \tilde{u}_p, \quad \tilde{T} = \tilde{T}_w, \tilde{C} = \tilde{C}_w \quad \text{at } \tilde{y} = 0 \\ &\tilde{u} \to 0, \quad \tilde{T} \to \tilde{T}_\infty, \tilde{C} \to \tilde{C}_\infty \quad \text{as } \tilde{y} \to \infty \end{aligned}\right\} \quad (6)$$

From eqn. (1), we get $\tilde{v} = \mathcal{V}_0$ (7)

In the case of thick optical limit, the fluid is not absorbing its own emitted radiation in which there was no self absorption, but it absorbs radiation emitted by the boundaries. Hence the thick optical limit near the equilibrium for a non gray gas is

$$\frac{\partial \tilde{q}_r}{\partial \tilde{y}} = 4(\tilde{T} - \tilde{T}_\infty)\int_0^\infty K_{\lambda w}\left(\frac{d e_{b\lambda}}{d\tilde{T}}\right)_w d\lambda = 4I_1(\tilde{T} - \tilde{T}_\infty) \quad (8)$$

We introduce the following non dimensional quantities,

$$U = \frac{\tilde{u}}{\mathcal{V}_0}, U = \frac{\tilde{u}}{\mathcal{V}_0}, \quad U_p = \frac{\tilde{u}_p}{\mathcal{V}_0} y = \frac{\mathcal{V}_0 \tilde{y}}{\nu}, \quad \theta = \frac{\tilde{T} - \tilde{T}_\infty}{\tilde{T}_w - \tilde{T}_\infty}, \quad C = \frac{\tilde{C} - \tilde{C}_\infty}{\tilde{C}_w - \tilde{C}_\infty},$$

$$P_r = \frac{\mu C_P}{\kappa}, \quad S_c = \frac{\nu}{D}, K = \frac{\mathcal{V}_0^2 \mathcal{K}_P}{\nu^2}, \quad k_0 = \frac{\nu K_c}{\mathcal{V}_0^2}, \quad F = \frac{4I_1 \nu^2}{\kappa \mathcal{V}_0^2},$$

$$M = \frac{\sigma B_0^2 \nu}{\rho \mathcal{V}_0^2}, \quad G_r = \frac{\nu g \beta_T(\tilde{T}_w - \tilde{T}_\infty)}{\mathcal{V}_0^3}, \quad G_m = \frac{\nu g \beta_c(\tilde{C}_w - \tilde{C}_\infty)}{\mathcal{V}_0^3}, \quad E = \frac{\mathcal{V}_0^2}{C_P(\tilde{T}_w - \tilde{T}_\infty)},$$

$$Q = \frac{Q_0 \nu}{\rho C_P \mathcal{V}_0^2}, \quad S_0 = \frac{D_m K_T}{T_m \nu}\frac{\tilde{T}_w - \tilde{T}_\infty}{\tilde{C}_w - \tilde{C}_\infty}.$$

Then equations (2)-(4) reduce to the following form.

$$U'' + U' = -G_r\theta - G_m C + M_1 U \quad (9)$$

$$\theta'' + P_r\theta' = -P_r E U'^2 + F\theta + Q P_r \theta \quad (10)$$

$$C'' + S_c C' = k_0 S_c C - S_0 S_c \theta'' \quad (11)$$

With the conditions

CASE 1:

$$\left.\begin{aligned} &U = 0, \theta = 1, C = 1 \quad \text{at } y = 0 \\ &U \to 0, \theta \to 0, C \to 0 \quad \text{as } y \to \infty \end{aligned}\right\} \quad (12)$$

CASE 2:

$$\left.\begin{aligned} &U = U_p, \ \theta = 1, C = 1 \quad \text{at } y = 0 \\ &U \to 0, \ \theta \to 0, C \to 0 \quad \text{as } y \to \infty \end{aligned}\right\} \quad (13)$$

Solution of the Problem:

The above system of coupled non – linear equations (9) - (11) with the conditions (12) and (13) are solved by using the following perturbation technique.

$$\mathbb{U} = u_0 + E u_1 + O(E^2)$$
$$\theta = \theta_0 + E\theta_1 + O(E^2)$$
$$\mathbb{C} = C_0 + E C_1 + O(E^2) \quad (14)$$

Substituting equation (14) into the equations (9) - (13) and equating the coefficients of corresponding powers of E, neglecting the higher powers of E, we get the following set of equations.

$$\theta_0'' + P_r\theta_0' - (F + QP_r)\theta_0 = 0 \quad (15)$$
$$C_0'' + S_c C_0' - k_0 S_c C_0 = -S_0 S_c \theta_0'' \quad (16)$$
$$u_0'' + u_0' = -G_r\theta_0 - G_m C_0 + M_1 u_0 \quad (17)$$
$$\theta_1'' + P_r\theta_1' - (F + QP_r)\theta_1 = -P_r u_0'^2 \quad (18)$$
$$C_1'' + S_c C_1' - k_0 S_c C_1 = -S_0 S_c \theta_1'' \quad (19)$$
$$u_1'' + u_1' = -G_r\theta_1 - G_m C_1 + M_1 u_1 \quad (20)$$

With the conditions,

CASE 1:

$$\left.\begin{aligned} &u_0 = 0, \ u_1 = 0, \theta_0 = 1, \ \theta_1 = 0, C_0 = 1, C_1 = 0 \quad \text{at } y = 0 \\ &u_0 \to 0, \ u_1 \to 0, \theta_0 \to 0, \ \theta_1 \to 0, C_0 \to 0, \ C_1 \to 0 \quad \text{as } y \to \infty \end{aligned}\right\} \quad (21)$$

CASE 2:

$$\left.\begin{aligned} &u_0 = U_p, \ u_1 = 0, \ \theta_0 = 1, \ \theta_1 = 0, C_0 = 1, C_1 = 0 \quad \text{at } y = 0 \\ &u_0 \to 0, \ u_1 \to 0, \theta_0 \to 0, \ \theta_1 \to 0, C_0 \to 0, C_1 \to 0 \quad \text{as } y \to \infty \end{aligned}\right\} \quad (22)$$

On solving equations (14) – (20) with the help of conditions (21) and (22), we get the exact solutions for temperature, concentration, velocity and their gradients as follows:

CASE 1:

$$\theta = e^{-d_1 y} + E\begin{bmatrix} m_{11}e^{-d_1 y} - m_5 e^{-2d_3 y} - m_6 e^{-2d_1 y} - m_7 e^{-2d_2 y} + m_8 e^{-d_4 y} \\ -m_9 e^{-d_5 y} + m_{10} e^{-d_6 y} \end{bmatrix} \quad (23)$$

$$\mathbb{C} = m_2 e^{-d_2 y} - m_1 e^{-d_1 y} + E[m_{19}e^{-d_2 y} - m_{12}e^{-d_1 y} + m_{13}e^{-2d_3 y} + m_{14}e^{-2d_1 y} + m_{15}e^{-2d_2 y} - m_{16}e^{-d_4 y} + m_{17}e^{-d_5 y} - m_{18}e^{-d_6 y}] \quad (24)$$

$$\mathbb{U} = (m_4 + m_3)e^{-d_3 y} - m_4 e^{-d_1 y} - m_3 e^{-d_2 y} + E\begin{bmatrix} m_{42}e^{-d_3 y} + m_{35}e^{-d_1 y} + m_{36}e^{-2d_3 y} + m_{37}e^{-2d_1 y} + m_{38}e^{-2d_2 y} \\ m_{42}e^{-d_3 y} + m_{35}e^{-d_1 y} + m_{36}e^{-2d_3 y} + m_{37}e^{-2d_1 y} + m_{38}e^{-2d_2 y} \end{bmatrix} \quad (25)$$

CASE 2:

$$\theta = e^{-d_1 y} + E\begin{bmatrix} m_{47}e^{-d_1 y} - m_{44}e^{-2d_3 y} - m_6 e^{-2d_1 y} - m_7 e^{-2d_2 y} + m_{45}e^{-d_4 y} \\ -m_9 e^{-d_5 y} + m_{46}e^{-d_6 y} \end{bmatrix} \quad (26)$$

$$\mathbb{C} = m_2 e^{-d_2 y} - m_1 e^{-d_1 y} + E\begin{bmatrix} m_{52}e^{-d_2 y} - m_{48}e^{-d_1 y} + m_{49}e^{-2d_3 y} + m_{14}e^{-2d_1 y} \\ m_{15}e^{-2d_2 y} - m_{50}e^{-d_4 y} + m_{17}e^{-d_5 y} - m_{51}e^{-d_6 y} \end{bmatrix} \quad (27)$$

$$\mathbb{U} = m_{43}e^{-d_3 y} - m_4 e^{-d_1 y} - m_3 e^{-d_2 y} + E\begin{bmatrix} m_{66}e^{-d_3 y} + m_{62}e^{-d_1 y} + m_{63}e^{-2d_3 y} + m_{37}e^{-2d_1 y} + m_{38}e^{-2d_2 y} \\ +m_{64}e^{-d_4 y} + m_{40}e^{-d_5 y} + m_{65}e^{-d_6 y} - m_{57}e^{-d_2 y} \end{bmatrix} \quad (28)$$

The Rate of Heat Transfer

In dimensionless form, the surface heat transfer rate in terms of Nusselt number from the gradient of temperature is

$$Nu = -\left[\frac{\partial \theta}{\partial y}\right]_{y=0} \tag{29}$$

CASE 1:

From equations (23) and (29), we get

$$N_u = d_1 + E[m_{11}d_1 - 2m_5d_3 - 2d_1m_6 - 2d_2m_7 + d_4m_8 - m_9d_5 + m_{10}d_6] \tag{30}$$

CASE 2:

From equations (26) and (29), we get

$$N_u = d_1 + E[m_{47}d_1 - 2m_{44}d_3 - 2d_1m_6 - 2d_2m_7 + d_4m_{45} - m_9d_5 + m_{46}d_6] \tag{31}$$

The Rate of Mass Transfer:

In dimensionless form, the surface mass transfer rate in terms of sherwood number from the gradient of concentration is

$$Sh = -\left[\frac{\partial C}{\partial y}\right]_{y=0} \tag{32}$$

CASE 1:

From equations (24) and (32), we get

$$S_h = m_2d_2 - m_1d_1 + E\begin{bmatrix} m_{19}d_2 - m_{12}d_1 + 2d_3m_{13} + 2d_1m_{14} + 2d_2m_{15} \\ -m_{15}d_4 + m_{17}d_5 - m_{18}d_6 \end{bmatrix} \tag{33}$$

CASE 2:

From equations (27) and (32), we get

$$S_h = m_2d_2 - m_1d_1 + E\begin{bmatrix} m_{52}d_2 - m_{48}d_1 + 2d_3m_{49} + 2d_1m_{14} + 2d_2m_{15} \\ -m_{50}d_4 + m_{17}d_5 - m_{51}d_6 \end{bmatrix} \tag{34}$$

Shear stress

The shear stress in terms of the skin-friction coefficient from the gradient of velocity in dimensionless form is

$$\tau = -\left[\frac{\partial U}{\partial y}\right]_{y=0} \tag{35}$$

CASE 1:

From equations (25) and (35), we get

$$\tau = d_3(m_3 + m_4) - d_1m_4 - d_2m_3 + E\begin{bmatrix} d_3m_{42} + d_1m_{35} + 2d_3m_{36} \\ +2d_1m_{37} + 2d_2m_{38} + d_4m_{39} + d_5m_{40} + d_6m_{41} - d_2m_{27} \end{bmatrix} \tag{36}$$

CASE 2:

From equations (28) and (35), we get

$$\tau = d_3m_{43} - d_1m_4 - d_2m_3 + E\begin{bmatrix} d_3m_{66} + d_1m_{62} + 2d_3m_{63} \\ +2d_1m_{37} + 2d_2m_{38} + d_4m_{64} + d_5m_{40} + d_6m_{65} - d_2m_{57} \end{bmatrix} \tag{37}$$

RESULTS AND DISCUSSIONS

In view of identifying theeffects of various parameters, the exact solutions for the fields of temperature, concentration, velocity and their gradients i.e., rate of heat and mass transfers, shear stress are obtained. The results are shown graphically in figures (1)-(20) and effects of their gradients are discussed through tables with the viz., Prandtl number (P_r), Schmidt number (S_c), parameters of chemical reaction parameter (K_0), heat absorption (Q), permeability of porous medium (K) and radiation (F), soret number (S_0), thermal grashoff number (G_r), mass grashoff number (G_m) and magnetic parameter (M) in the case of hydrogen, ammonia and water vapor.

The results of concentration for different values of parameters involved are discussed for hydrogen, ammonia and water vapor with grashoff numbers ($G_r > 0$, $G_m > 0$), Eckert number (<<1) and are shown in figures (1)-(4) and these figures are considered forU_p = 0.From figure (1) it has been observed that the concentration increases with the decrease in S_c,K_0 . Also from figure (3), it is noticed that the concentration rises with the rise in$S_0$and from figure (2), it is observed that the concentration increases near the plate and then decreases with a point of separation moving away from the plate. For

U_p = 0.5, the effects of concentration for S_c , F are shown in figures (5) and (6) which are in good agreement with the effects of S_c , F at U_p = 0

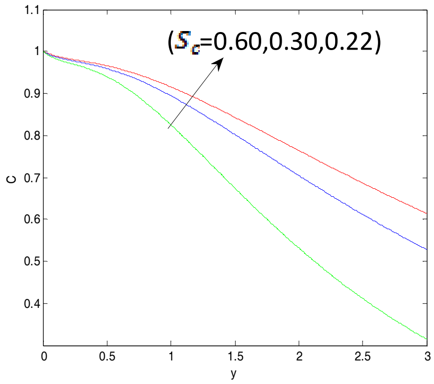

Fig.1.Concentration effects for different values of S_c, U_p=0,P_r=0.68, K_0=0.02,F=0.5,Q=0.5,S_0=1,M_1=2

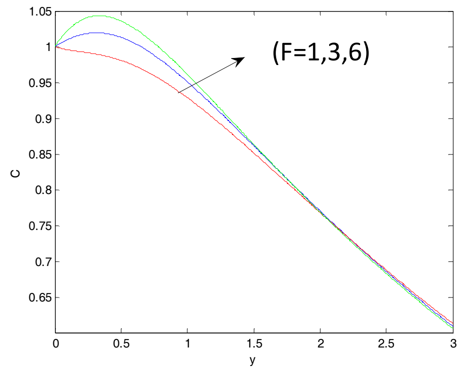

Fig.2.Effects of concentration for several values of F, U_p =0, P_r=0.68,S_c=0.22, K_0=0.02,Q=0.5,S_0=1,M_1=2

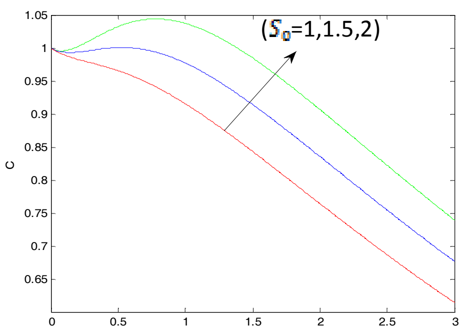

Fig.3.Effectsof concentration for several valuesof S_0, U_p =0,P_r=0.68, S_c=0.22,K_0=0.02,F=0.5,Q=0.5,M_1=2

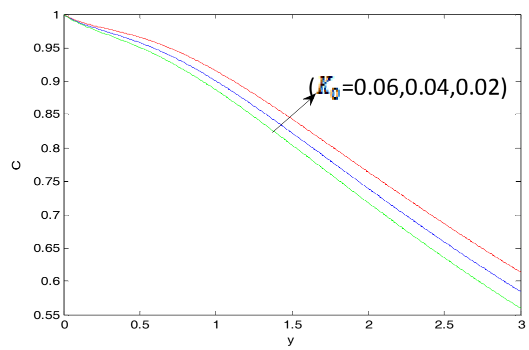

Fig.4. Concentration effects for various valuesofK_0,U_p =0, P_r=0.68,S_c=0.22, F=0.5,Q=0.5,S_0=1,M_1=2

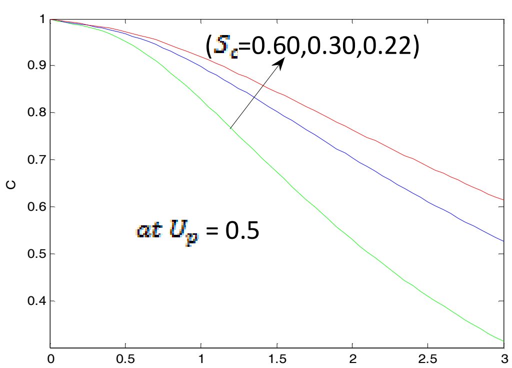

Fig.5. Concentration effects for different values ofS_c,U_p=0.5,P_r=0.68,K_0=0.02,F=0.5, Q=0.5,S_0=1, M_1=2

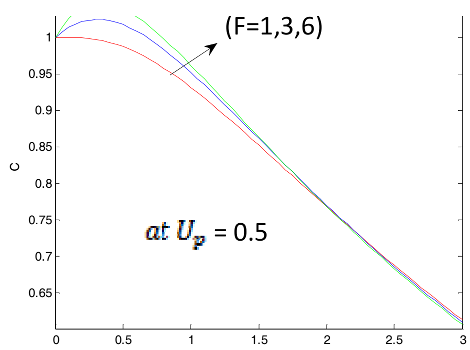

Fig.6.Effects of concentration for several values of F, U_p=0.5, P_r=0.68, S_c=0.22,K_0=0.02, Q=0.5, S_0=1,M_1=2

The effects of temperature for various values of parametersinvolved are analyzed for hydrogen, ammonia and water vapor with Grashoff numbers ($G_r, G_m > 0$),Eckert number (<<1) and are shown in figures from (7)-(11) and these are presented forU_p=0. From figure (7) it has been noticed that the temperature rises with the fallof P_r, F, Q, $M_1$and is shown in figures (7), (8), (9), (11).From figure (10), it is observed that the temperature rises with the rise in

S_0.For U_p = 0.5, the effects of temperature for P_r , F, Q are shown in figures (12)-(14), which are in good agreement with the effects of P_r , F, Q at U_p = 0

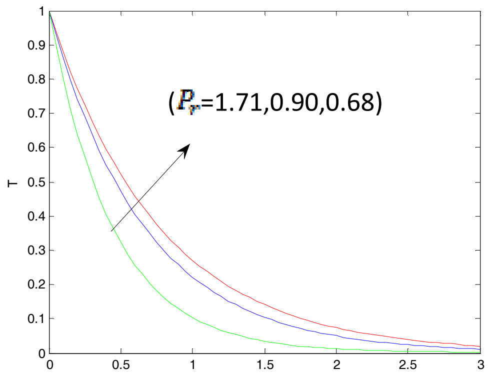

Fig.7.Effects of temperature for various values of P_r,U_p =0,S_c=0.22,K_0=0.02, F=0.5,Q=0.5,S_0=1, M_1=2

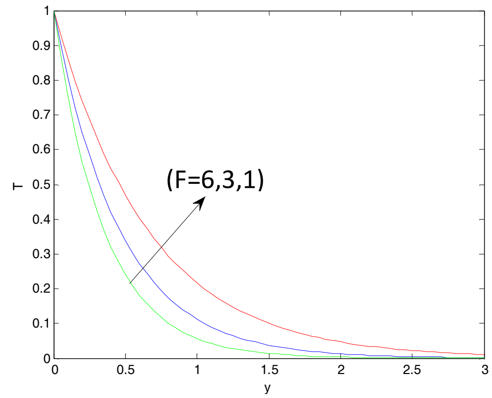

Fig.8.Temperature effects for several values of$F$,U_p =0, P_r=0.68,K_0=0.02, S_c=0.22, Q=0.5, S_0=1, M_1=1

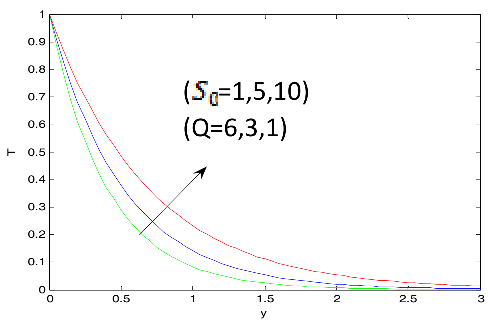

Fig.9.Temperature effects for several values of Q,U_p =0,P_r=0.68,S_c=0.22, K_0=0.02, F=0.5,S_0=1,M_1=1

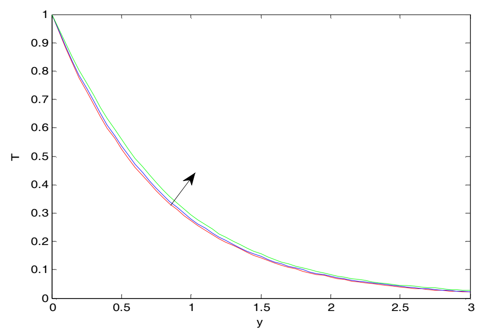

Fig.10.Effectsof temperature for different values ofS_0,U_p =0, P_r=0.68, S_c=0.22, K_0=0.02, F=0.5, Q=0.5, M_1=1

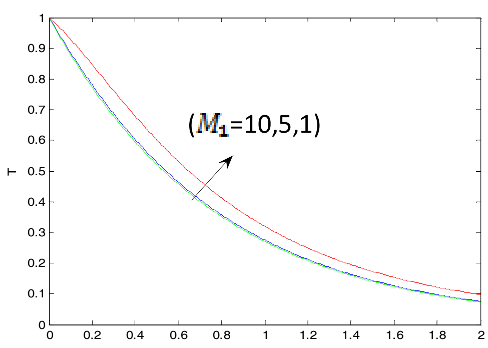

Fig.11. Effect of temperature for several values of M_1,U_p =0, P_r=0.68,S_c=0.22, K_0=0.02, F=0.5, Q=0.5, S_0=1

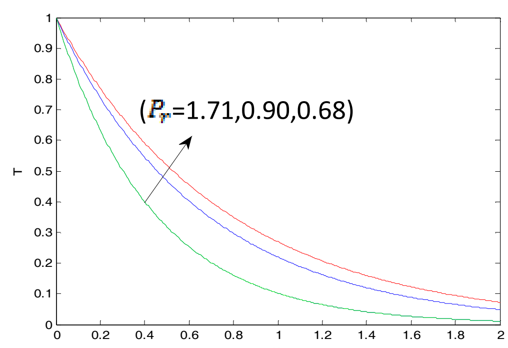

Fig.12.Effects of temperature for various values of P_r,U_p =0.5,S_c=0.22, K_0=0.02, F=0.5, Q=0.5, S_0=1,M_1=2

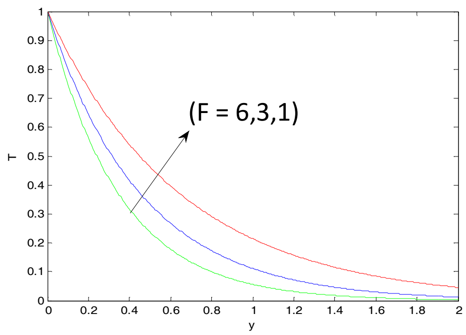

Fig.13.Temperature effects for several values of F, U_p =0.5, P_r=0.68, K_0=0.02, S_c=0.22, Q=0.5, S_0=1, M_1=1

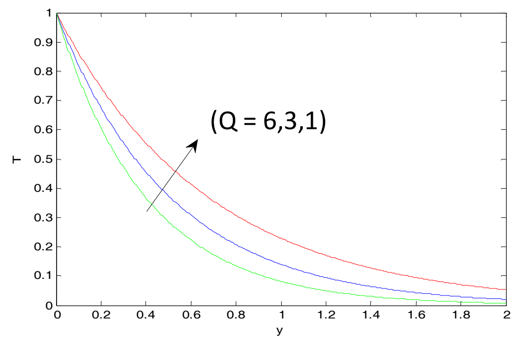

Fig.14.Temperature effects for several values of Q, U_p =0.5, P_r=0.68, S_c=0.22, K_0=0.02, F=0.5, S_0=1, M_1=1

The effects of velocity for various values of parameters involved are analyzed for hydrogen, ammonia and water vapor with Grashoff numbers ($G_r, G_m > 0$), Eckert number (<<1) and are shown in figures from (15)-(20)and these are presented for U_p = 0. The velocity increases with the decrease in S_c, K_0, F, Q and M_1 which is shown in figures (15) - (18) and (20).From figure (19), it is observed that the velocity rises with the rise in S_0.For U_p = 0.5, the velocity results for S_c , F are shown in figures (21)-(22) which are in good agreement with the effects of S_c , F at U_p = 0

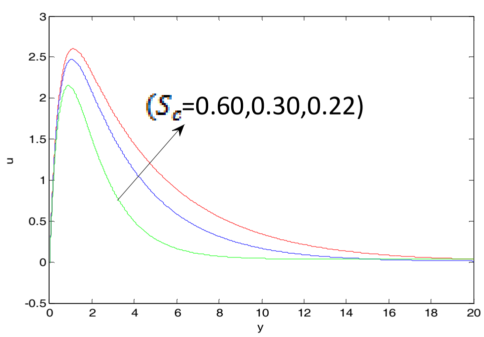

Fig.15.Consequences of velocity for various values of S_c, U_p =0, P_r=0.68, K_0=0.02, F=1, Q=1, S_0=2, M_1=2

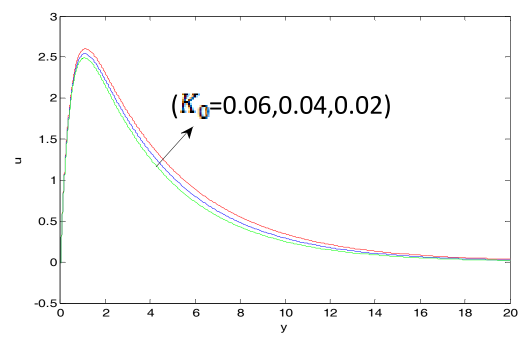

Fig.16.Velocity effects for several values of K_0, U_p =0, P_r=0.68, S_c=0.22, F=1, Q=1, S_0=2, M_1=2

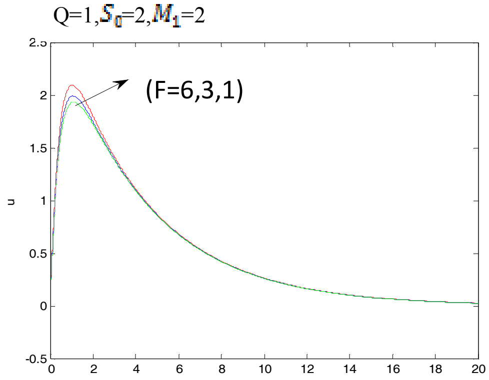

Fig.17.Effects of velocity for different values of F, U_p =0, P_r=0.68, S_c=0.22, K_0=0.02, Q=1, S_0=2, M_1=2

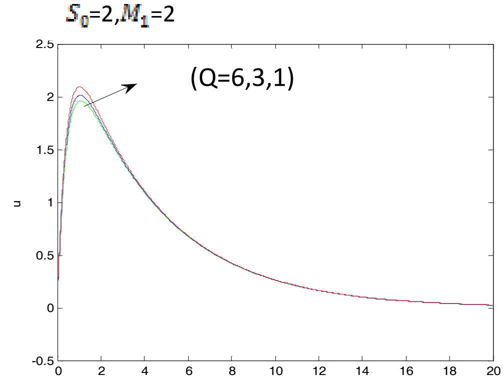

Fig.18.Velocity consequences for various values of Q, U_p =0, P_r=0.68, S_c=0.22, K_0=0.02, F=1, S_0=2, M_1=2

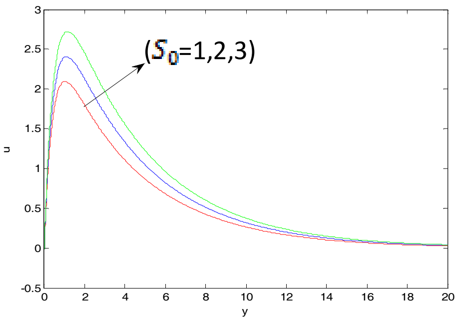

Fig.19.Velocity leads for different values of S_0,U_p =0,P_r=0.68,S_c=0.22,K_0=0.02, F=1, Q=1,M_1=2

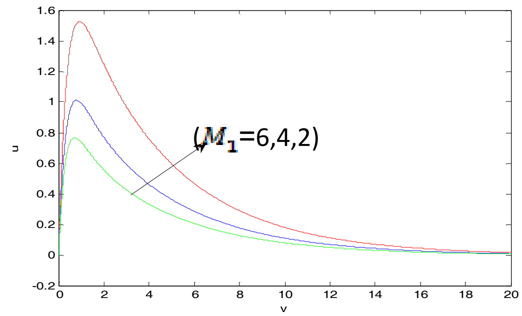

Fig.20.Effect of velocity for various values ofM_1, U_p =0, P_r=0.68,S_c=0.22,K_0=0.02, F=1, Q=1, S_0=2.

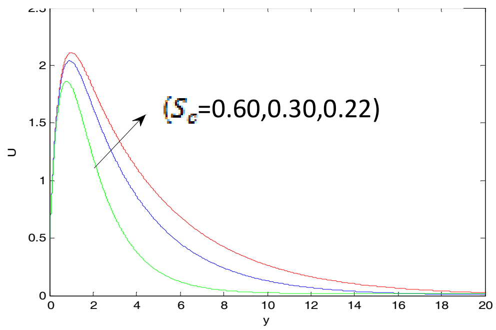

Fig.21.Consequences of velocity for various values ofS_c,U_p =0.5, P_r=0.68, K_0=0.02, F=1, Q=1, S_0=2, M_1=2

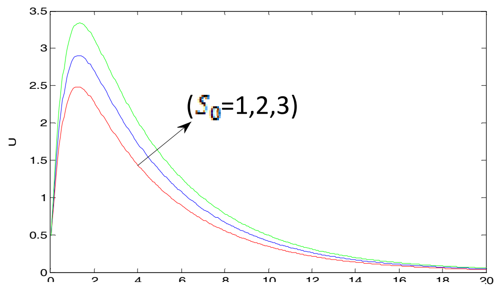

Fig.22.Velocity leads for different values of S_0,U_p =0.5,P_r=0.68,S_c=0.22, K_0=0.02, F=1, Q=1, M_1=2

The effects of mass and heat transfer rates, shear stress in terms of Sherwood number, nusselt number and skin friction are discussed for hydrogen, ammonia and water vapor at u=0 and u_p =0.5with Grashoff numbers ($G_r, G_m > 0$), Eckert number (<<1) and are shown in the following tales.

Table 1 shows the results of Skin friction for various values of P_r ,S_c, K_0, F, and Q. From this table, it is identified that the skin friction in both the cases increases with the increase in P_r ,S_c , K_0, F and Q.

Table 2 shows the effects of Sherwood number for several values of P_r ,S_c, K_0, F, Q, S_0andM_1. It is noticed that, Sherwood number decreases with the increase in P_r ,S_c ,F, Q, $S_0$and$M_1$and Sherwood number increases with the increase in K_0 in both the cases.

Table 3 shows the Nusselt number for different values ofP_r ,S_c, K_0, F, Q, S_0andM_1. AsP_r,K_0,S_c,F,

Q and M_1rises, Nusselt number also rises in both the cases and it falls with the rise in S_0

Table 1

Pr	Sc	Ko	F	Q	M1	Skin Friction at u=0	Skin friction at u_p =0.5
0.68	0.22	0.02	1	1	2	-6.453694575	-6.41119388
0.9	0.22	0.02	1	1	2	-6.337753166	-6.194715608
1.71	0.22	0.02	1	1	2	-6.029398846	-6.015815959
0.68	0.3	0.02	1	1	2	-6.362018197	-6.38410691
0.68	0.6	0.02	1	1	2	-6.101347385	-6.044748878
0.68	0.22	0.04	1	1	2	-6.389647558	-6.349469656
0.68	0.22	0.06	1	1	2	-6.333526225	-6.294701896
0.68	0.22	0.02	3	1	2	-6.171009523	-6.372552984
0.68	0.22	0.02	5	1	2	-6.018390537	-6.107167391
0.68	0.22	0.02	1	3	2	-6.318390537	-6.273966677
0.68	0.22	0.02	1	5	2	-6.23968607	-6.171413917

Table 2

Pr	Sc	Ko	F	Q	So	M1	Sherwood Number at u=0	Sherwood Number at u_p =0.5
0.68	0.22	0.02	1	1	1	2	-0.127229634	-0.126667158
0.9	0.22	0.02	1	1	1	2	-0.17565069	-0.174975787
1.71	0.22	0.02	1	1	1	2	-0.353925333	-0.352968591
0.68	0.3	0.02	1	1	1	2	-0.17972482	-0.178956128
0.68	0.6	0.02	1	1	1	2	-0.377360631	-0.375784613
0.68	0.22	0.04	1	1	1	2	-0.107674802	-0.107128032
0.68	0.22	0.06	1	1	1	2	-0.090145994	-0.089612579
0.68	0.22	0.02	3	1	1	2	-0.261011581	-0.260622208
0.68	0.22	0.02	5	1	1	2	-0.362015953	-0.361703511
0.68	0.22	0.02	1	3	1	2	-0.223215818	-0.222788206
0.68	0.22	0.02	1	5	1	2	-0.2998937	-0.29953767
0.68	0.22	0.02	1	1	3	2	-0.858736426	-0.855471792
0.68	0.22	0.02	1	1	5	2	-1.59048454	-1.581069896
0.68	0.22	0.02	1	1	1	4	-0.127174037	-0.126936846
0.68	0.22	0.02	1	1	1	6	-0.127157391	-0.127034586

Table 3

Pr	Sc	Ko	F	Q	M1	Nusselt Number at u=0	Nusselt Number at u_p=0.5
0.68	0.22	0.02	1	1	2	1.680442604	1.675283094
0.9	0.22	0.02	1	1	2	1.900561303	1.894174203
1.71	0.22	0.02	1	1	2	2.710953282	2.700982759
0.68	0.3	0.02	1	1	2	1.680425137	1.675245973
0.68	0.6	0.02	1	1	2	1.680378557	1.672962344
0.68	0.22	0.04	1	1	2	1.680431102	1.674032231
0.68	0.22	0.06	1	1	2	1.68042119	1.672843351
0.68	0.22	0.02	3	1	2	2.288595214	2.284545599
0.68	0.22	0.02	5	1	2	2.747730496	2.744231113
0.68	0.22	0.02	1	3	2	2.116784409	2.112476547
0.68	0.22	0.02	1	5	2	2.465342622	2.461525928
0.68	0.22	0.02	1	1	4	1.680189878	1.674860793
0.68	0.22	0.02	1	1	6	1.680114209	1.674273541

CONCLUSIONS

From above discussions it has been concluded that the concentration increases with the decrease in S_c,K_0 and it also rises with the rise in S_0.The concentration increases near the plate and then decreases with a point of separation moving away from the plate. The temperature rises with the fall of P_r, F, Q, M_1 and it rises with the rise in S_0.The velocity increases with the decrease in S_c,K_0,F, Q and M_1 and it rises with the rise in S_0.The skin friction in both the cases increases with the increase in P_r ,S_c , K_0 ,F and Q.

The Sherwood number decreases with the increase in P_r ,S_c ,F, Q, $S_0$and$M_1$and it increases with the increase in K_0 in both the cases.. AsP_r,K_0,S_c,F, Q andM_1rise, Nusselt number also rises in both the cases and it falls with the rise in S_0.

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APPENDIX I

$$b = F + QP_r, d_1 = \frac{P_r + \sqrt{P_r^2 + 4b}}{2}, \quad d_2 = \frac{S_c + \sqrt{S_c^2 + 4k_0 S_c}}{2}, \quad d_3 = \frac{1 + \sqrt{1 + 4M_1}}{2}, \quad d_4 = d_1 + d_3,$$

$$d_5 = d_1 + d_2, d_6 = d_2 + d_3, M_1 = M + \frac{1}{K}$$

$$m_1 = \frac{S_0 S_c d_1^2}{d_1^2 - S_c d_1 - k_0 S_c}, \quad m_2 = m_1 + 1, \quad m_3 = \frac{G_m m_2}{d_2^2 - d_2 - M_1}, \quad m_4 = \frac{G_r}{d_1^2 - d_1 - M_1} - \frac{G_m m_1}{d_1^2 - d_1 - M_1},$$

$$m_5 = \frac{P_r d_3^2 (m_3 + m_4)^2}{4d_3^2 - 2P_r d_3 - b}, \quad m_6 = \frac{P_r d_1^2 m_4^2}{4d_1^2 - 2P_r d_1 - b}, m_7 = \frac{P_r d_2^2 m_3^2}{4d_2^2 - 2P_r d_2 - b}, \quad m_8 = \frac{2P_r d_1 d_3 m_4 (m_4 + m_3)}{d_4^2 - P_r d_4 - b},$$

$$m_9 = \frac{2P_r d_1 d_2 m_4 m_3}{d_5^2 - P_r d_5 - b}, \quad m_{10} = \frac{2P_r d_2 d_3 m_3 (m_4 + m_3)}{d_6^2 - P_r d_6 - b}, m_{11} = m_5 + m_6 + m_7 - m_8 + m_9 - m_{10},$$

$$m_{12} = \frac{S_0 S_c m_{11} d_1^2}{d_1^2 - S_c d_1 - k_0 S_c}, \quad m_{13} = \frac{4S_0 S_c d_3^2 m_5}{4d_3^2 - 2S_c d_3 - k_0 S_c}, \quad m_{14} = \frac{4S_0 S_c d_1^2 m_6}{4d_1^2 - 2S_c d_1 - k_0 S_c}, \quad m_{15} = \frac{4S_0 S_c d_2^2 m_7}{4d_2^2 - 2S_c d_2 - k_0 S_c},$$

$$m_{16} = \frac{S_0 S_c m_8 d_4^2}{d_4^2 - S_c d_4 - k_0 S_c}, \quad m_{17} = \frac{S_0 S_c m_9 d_5^2}{d_5^2 - S_c d_5 - k_0 S_c}, \quad m_{18} = \frac{S_0 S_c m_{10} d_6^2}{d_5^2 - S_c d_6 - k_0 S_c}, m_{21} = \frac{G_r m_5}{4d_3^2 - 2d_3 - M_1},$$

$$m_{19} = m_{12} - m_{13} - m_{14} - m_{15} + m_{16} - m_{17} + m_{18}, \; m_{20} = \frac{G_r m_{11}}{d_1^2 - d_1 - M_1} m_{22} = \frac{G_r m_6}{4d_1^2 - 2d_1 - M_1},$$

$$m_{23} = \frac{G_r m_7}{4d_2^2 - 2d_2 - M_1}, \quad m_{24} = \frac{G_r m_8}{d_4^2 - d_4 - M_1}, \quad m_{25} = \frac{G_r m_9}{d_5^2 - d_5 - M_1}, \quad m_{26} = \frac{G_r m_{10}}{d_6^2 - d_6 - M_1}$$

$$, m_{27} = \frac{G_m m_{19}}{d_2^2 - d_2 - M_1}, \quad m_{28} = \frac{G_m m_{12}}{d_1^2 - d_1 - M_1}, \quad m_{29} = \frac{G_m m_{13}}{4d_3^2 - 2d_3 - M_1}, \quad m_{30} = \frac{G_m m_{14}}{4d_1^2 - 2d_1 - M_1},$$

$$m_{31} = \frac{G_m m_{15}}{4d_2^2 - 2d_2 - M_1},$$

$$m_{32} = \frac{G_m m_{16}}{d_4^2 - d_4 - M_1}, \quad m_{33} = \frac{G_m m_{17}}{d_5^2 - d_5 - M_1}, \quad m_{34} = \frac{G_m m_{18}}{d_6^2 - d_6 - M_1},$$

$$m_{35} = m_{28} - m_{20}, m_{41} = -m_{26} + m_{34}$$

$$m_{36} = -m_{29} + m_{21}, m_{37} = -m_{30} + m_{22}, \quad m_{38} = -m_{31} + m_{23}, m_{39} = -m_{24} + m_{32},$$

$$m_{40} = -m_{33} + m_{25}, \quad m_{42} = -m_{35} - m_{36} - m_{37} - m_{38} - m_{39} - m_{40} - m_{41} + m_{27},$$

$$m_{43} = U_p + m_4 + m_3, m_{44} = \frac{P_r d_3^2 m_{43}^2}{4d_3^2 - 2P_r d_3 - b}, \quad m_{45} = \frac{2P_r d_1 d_3 m_4 m_{43}}{d_4^2 - P_r d_4 - b},$$

$$m_{46} = \frac{2P_r d_2 d_3 m_3 m_{43}}{d_6^2 - P_r d_6 - b}, m_{47} = m_{44} + m_6 + m_7 - m_{45} + m_9 - m_{46} m_{48} = \frac{S_0 S_c m_{47} d_1^2}{d_1^2 - S_c d_1 - k_0 S_c},$$

$$m_{49} = \frac{4S_0 S_c d_3^2 m_{44}}{4d_3^2 - 2S_c d_3 - k_0 S_c}, m_{50} = \frac{S_0 S_c m_{45} d_4^2}{d_4^2 - S_c d_4 - k_0 S_c}, \quad m_{51} = \frac{S_0 S_c m_{46} d_3^2}{d_6^2 - S_c d_6 - k_0 S_c}$$

$$m_{52} = m_{48} - m_{49} - m_{14} - m_{15} + m_{50} - m_{17} + m_{51}, m_{53} = \frac{G_r m_{47}}{d_1^2 - d_1 - M_1}, m_{54} = \frac{G_r m_{44}}{4d_3^2 - 2d_3 - M_1}$$

$$m_{55} = \frac{G_r m_{45}}{d_4^2 - d_4 - M_1}, m_{56} = \frac{G_r m_{46}}{d_6^2 - d_6 - M_1}, \quad m_{57} = \frac{G_m m_{52}}{d_2^2 - d_2 - M_1}, \; m_{58} = \frac{G_m m_{48}}{d_1^2 - d_1 - M_1},$$

$$m_{59} = \frac{G_m m_{49}}{4d_3^2 - 2d_3 - M_1}$$

$m_{60} = \frac{G_m m_{50}}{d_4^2 - d_4 - M_1}$, $m_{61} = \frac{G_m m_{51}}{d_6^2 - d_6 - M_1}$, $m_{63} = -m_{59} + m_{54}$, $m_{64} = -m_{55} + m_{60}$,
$m_{62} = m_{58} - m_{53}, m_{65} = -m_{56} + m_{61},$
$m_{66} = -m_{62} - m_{63} - m_{37} - m_{38} - m_{64} - m_{40} - m_{65} + \ m_{57}$

APPENDIX 11
Nomenclature:

C , θ Non dimensional fluid concentration and temperature

$\tilde{C}$, $\tilde{T}$dimensional concentration and temperature

C_w , T_w fluid concentration and temperature near the wall

$\widetilde{C_\infty}$, $\widetilde{T_\infty}$ fluid concentration and temperature far away from the wall

$\mathcal{D}$mass diffusivity

C_pSpecific heat at constant pressure

E Eckert number

$e_{b\lambda}$ Planck function

F radiation parameter

G_r , G_m thermal and mass grashoff numbers

gAcceleration due to gravity

k_0Non dimensional chemical reaction parameter

KNon dimensional coefficient of permeability of porous medium

K_cRate of chemical reaction

$K_{\lambda w}$Absorption coefficient

$\mathcal{K}_p$Permeability of porous medium

τSkin friction coefficient

Nu Nusselt number

Sh Sherwood number

M -Magnetic parameter

P_rPrandtl number

q_rRadiative flux

S_cSchmidt number

$\mathcal{V}_0$Suction velocity

$\tilde{\mathcal{U}}$,$\tilde{\mathcal{V}}$ velocity components U non dimensional velocity

QHeat absorption parameter

S_0Soret number

κ Thermal conductivity

ν Kinematic viscosity

σ Electric conductivity

μ Dynamic viscosity

β_T ,β_c coefficient of thermal and concentration expansions

ρDensity of the fluid.