Effect of Chemical Reaction on MHD Casson Fluid flow past an Inclined Surface with Radiation

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Abstract: **MHD casson fluid of viscous, incompressible, electrically-conducting fluid past an inclined moving plate in the presence of a uniform transverse magnetic field and thermal and concentration buoyancy effects is considered.**

The governing partial differential equations are reduced to a system of non-linear ordinary differential equations which are solved analytically using perturbation technique. The numerical results are presented graphically for different values of the parameters such as Chemical reaction parameter, Radiation parameter, Heat parameter, Casson parameter, Schmidt number, Grashof number, Prandtl number, Hartmann Parameter, and modified Grashof numbers etc are discussed. Finally the numerical values of skin-friction, Nusselt number and Sherwood number are shown in tabular form.

Key Words: **Casson fluid, MHD, Chemical reaction, inclined surface, radiation, heatsource/sink.**

1. INTRODUCTION

The non-Newtonian fluid flow is important for their numerous engineering applications. This article has direct significant application in related to non-Newtonian fluids like as Cassonfluids(Human Blood, Honey etc.), nanofluids and Power law fluids etc. In industrial environment non-Newtonian flow fluids plays a vital role. In recent years, due to the growing applications of non-Newtonian fluids, various researchers have done different works in this field. Eldate.N.T.M.[1], Mustafa.M et al.,[2], Mukhophadhyay [3] and Kenneth walters [4] have studied the behaviour of non-Newtoian fluids between two rotating cylinder and stagnation point over a strectching sheet. Shehzad et al discussedon Effects of mass transfer on MHD flow of a Casson fluid with chemical reaction and suction.Mukhophadhyay[5] presented on Casson fluid flow and heat transfer over a nonlinearly stretching surface.Dash et al., [6]reported on Casson fluid flow in a pipe filled with a homogeneous porous medium.M.J.Subhakar et al.,[7] reported on Effect of MHD Casson Fluid flow over a vertical Plate with Heat Source .A. J. Chamkha[8] has studied on Transient hydromagnetic three-dimensional natural convection from an inclined stretching permeable surface. On free convection-radiation interaction from an isothermal plate inclined at a small angle to the horizontal investigated by M.A. Hossain et al., [9].Unsteady MHD Convective Heat And Mass Transfer Past An Inclined Moving Surface With Heat Absorption explained by J.L.Ramprasad et al.[10]. It is concluded an increase in the prandtl number and heat absorption coefficient lead to decrease in thermal boundary layer.Chemical reaction and soret effects on cassonMHD fluid flow over a vertical plate discussed by charankumaret al.[11]. It is observed that the rise of the casson fluid parameter, the temperature is decreases but the velocity found to be increase in this case. Rama SubbareddyGorla., et al.[12] have studied on Mixed Convection in Non-Newtonian Fluids along a Vertical Plate in Porous Media with Constant Surface Heat Flux.KerehalliVinayaka Prasad., et al. [13] have developed on Non-Newtonian Power-Law Fluid Flow and Heat Transfer over a Non-Linearly Stretching Surface.

RobensonCherizol. et al., [15] and Schowalter [16] discussed on Review of Non-Newtonian Mathematical Models for Rheological Characteristics of Viscoelastic Composites.Acrivosa., et al., [17] have investigated on Momentum and Heat Transfer in Laminar Boundary Layer Flows of Non-Newtonian Fluids Past External Surfaces. Chen HT., et al., [18] have explained on Natural convection of a non-Newtonian fluid about a horizontal cylinder and sphere in a porous medium. Nakayama A. et al., [19] discussed on Buoyancy induced flow of non-Newtonian fluids over a non-isothermal body of arbitrary shape in a fluid-saturated porous medium. Yang .Y.T. et al.,[20] reported on Free convection heat transfer of non-Newtonian fluids over axis symmetric and two-dimensional bodies of arbitrary shape embedded in a fluid-saturated porous medium.

In this work it is examined Chemical reaction effect on casson MHD fluid flow over an inclined moving plate with heat source/sink. This Problem is solved numerically using the perturbation technique for the velocity, the temperature and the concentration species. The skin friction, Nusselt number and Sherwood number are also obtained and are shown in tabular form. The effects of various physical parameters like as Chemical reaction parameter, Radiation parameter, Heat parameter, Casson parameter, Schmidt number, Grashof number, Prandtl number, Hartmann Parameter, and modified Grashof number has been discussed in detailed. The results are made in this article are good agreement with previous work[11],in the absence of inclination.

2. FORMULATION OF THE PROBLEM

MHD Casson fluid of incompressible, viscous, electrically-conducting fluid over an inclined surface moving with constant velocity with radiation and chemical reaction in the presence of Soret effect is considered.The rheological equation of state for an isotropic and incompressible flow of Casson fluid [1,2] is

$$\tau_{ij} = \begin{cases} \left(\mu_B + p_y / \sqrt{2\pi}\right) 2e_{ij}, \pi > \pi_c \\ \left(\mu_B + p_y / \sqrt{2\pi_c}\right) 2e_{ij}, \pi < \pi_c \end{cases} \qquad (A)$$

Where μ_B is plastic dynamic viscosity, p_y is yield stress, π_c is critical value of π and π is the product of the component of deformation rate with itself, namely, $\pi = e_{ijij}$, e_{ij} is the (i,j)th component of deformation rate.

The x - axis is taken along the plate in the vertical upward direction and the y - axis is taken normal to the plate. The surface temperature of the plate oscillates with small amplitude about a non-uniform mean temperature. The fluid is assumed to have constant properties except for the influence of the density variations with temperature and concentration which are considered only in the body force term.The temperature of the plate oscillates with little amplitude about a non-uniform temperature.

- The flow is Unsteady and laminar.
- The plate is sufficiently long enough, so all the physical quantities are functions of y and t only.
- It is assumed that there exist a homogeneous chemical reaction of first order with constant rate K_r between the diffusing species and the fluid.
- A uniform magnetic field is applied in the direction perpendicular to the plate.
- The viscous dissipation and the Joule heating effects are assumed to be negligible in the energy equation.
- The transverse applied magnetic field and magnetic Reynolds number are assumed to be very small, so that the induced magnetic field is negligible.
- Also it is assumed that there is no applied voltage, so that the electric field is absent.
- The temperature in the fluid flowing is governed by the energy concentration equation involving radiative heat temperature.

By usual Boussinesq's approximation, the flow is governed by the following equations

$$\frac{\partial u'}{\partial t'} = \left(1 + \frac{1}{\beta}\right)\frac{\partial^2 u'}{\partial y'^2} + g\, cos\phi\, \beta^* \left(C' - C'_\infty\right)$$

$$-\frac{\sigma}{\rho} B_0^2 u' + g\, cos\phi\, \beta\left(T' - T'_\infty\right) \qquad (1)$$

$$\frac{\partial T'}{\partial t'} = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{1}{\rho C_p}\frac{\partial q'_r}{\partial y'} + \frac{Q_0}{\rho C_p}(T' - T'_\infty) \qquad (2)$$

$$\frac{\partial C'}{\partial t'} = S_0 \frac{\partial^2 T'}{\partial y'^2} + D\frac{\partial^2 C'}{\partial y'^2} - K'_r\left(C' - C'_\infty\right) \qquad (3)$$

Equations (1), (2) and (3)refer Momentum equation, Energy Equation and Species Equation respectively. Where u is the velocity of the fluid, β is Casson parameter, Q_0 is the heat source/sink parameter, D is the molecular diffusivity, k is thermal conductivity, C is mass concentration, t is time, υ is the kinematics viscosity, g is the gravitational constant, β *and* β^* are the thermal expansions of fluid and concentration, T is temperature of fluid , ρ is density, $C_p$is the specific heat capacity at constant pressure, y is distance, q_r is the radiative flux, β_0 is the magnetic field, kr_0 is the chemical reaction rate constant. R.H.S. of equation (1), second term is thermal concentration effect, third term is magnetic effect, fourth term is thermal buoyancy effect. R.H.S. of equation (2) second term is thermal radiation flux and third term is thermal radiation. R.H.S. of equation (3), second term is chemical reaction and third term soret (Thermo Diffusion) effect. Under the above assumptions the physical variables are functions of y and t.

The boundary conditions are:

$$u = U\ ; T' = T'_w + \varepsilon e^{i\omega t}\, (T'_w - T'_\infty)\ ;$$

$$C' = C'_w + \varepsilon e^{i\omega t}\, (C'_w - C'_\infty)\ ; \text{ at } y = 0 \qquad (4)$$

$$u' \to 0\ ; T' \to 0\ ; C' \to 0\ ; \text{ as } y \to \infty$$

Introducing the dimensionless quantities

$$u = \frac{u'}{U}\ ; \quad y = \frac{y'U}{\upsilon}\ ; \quad t = \frac{t'U^2}{\upsilon}\ ;$$

$$Gc = \frac{g\beta^* \upsilon (C'_w - C'_\infty)}{U^3}\ ; \quad Q = \frac{Q_0 \upsilon}{\rho C_p U^2}\ ;$$

$$\theta = \frac{T'-T'_\infty}{T'_w-T'_\infty} \;;\; C = \frac{C'_w-C'_\infty}{T'_w-T'_\infty} \;;\; M = \frac{\sigma\beta_0^2\upsilon}{\rho U^2} \;;$$

$$R = \frac{16a\sigma^*\upsilon^2 T'_\infty}{U^2\rho C_p} \;;\; \mu = \upsilon\rho \;;\; \Pr = \frac{\mu C_p}{k} \;;$$

$$Sc = \frac{\upsilon}{D}; Kr = \frac{Kr_0\upsilon}{U^2} \tag{5}$$

The thermal radiation flux gradient may be expressed as follows

$$-\frac{\partial q_r}{\partial y'} = 4a\sigma^*(T'_\infty - T'^4) \tag{6}$$

Considering the temperature difference by assumption within the flow are sufficiently small such that T'^4 may be expressed as a linear function of the temperature. This is attained by expanding in T'^4 taylor's series about T'_∞ and ignoring higher orders terms.

$$T'^4 = 4T'^3_\infty T' - 3T'^4_\infty \tag{7}$$

Substituting the dimensionless variables (5) into (1) to (3) and using equations (6) and (7), reduce to the following dimensionless form.

$$\frac{\partial u}{\partial t} = \left(1+\frac{1}{\beta}\right)\frac{\partial^2 u}{\partial y^2} - Mu + G_1\theta + G_2 C \tag{8}$$

$$\frac{\partial\theta}{\partial t} = \frac{1}{\Pr}\frac{\partial^2\theta}{\partial y^2} - (R-Q)\theta \tag{9}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - Kr\,C + Sr\frac{\partial^2\theta}{\partial y^2} \tag{10}$$

Where $G_1 = G_r \cos\phi$,

$G_2 = G_c \cos\phi$

The corresponding boundary conditions of (4) in dimensionless form are

$u = 1;\ \theta = 1 + \varepsilon e^{i\omega t};\ C = 1 + \varepsilon e^{i\omega t}$
at y = 0 (11)

$u \to 0;\ \theta \to 0;\ C \to 0$
as $y \to \infty$ (12)

3. METHOD OF SOLUTION

Equation (8) represent a set of partial differential equations that cannot be solved in closed form. However, it can be reduced to a set of ordinary differential equations in dimensionless form that can be solved analytically. This can be done by representing the velocity, temperature and concentration as

$$u = u_0 + \varepsilon e^{i\omega t}u_1 + O(\varepsilon^2) + \ldots\ldots\ldots\ldots\ldots, \tag{13}$$

$$\theta = \theta_0 + \varepsilon e^{i\omega t}\theta_1 + O(\varepsilon^2) + \ldots\ldots\ldots\ldots\ldots, \tag{14}$$

$$C = C_0 + \varepsilon e^{i\omega t}C_1 + O(\varepsilon^2) + \ldots\ldots\ldots\ldots\ldots, \tag{15}$$

Where $u_0(y)$, $u_1(y)$, $\theta_0(y)$, $\theta_1(y)$, $C_0(y)$ and $C_1(y)$ have to be determined.

$$\left(1+\frac{1}{\beta}\right)u''_0 - M\,u_0 = -G_1\theta_0 - G_2 C_0 \tag{16}$$

$$A_4 u''_1 - (M + i\omega)u_1 = -G_1\theta_1 - G_2 C_1 \tag{17}$$

$$\frac{1}{\Pr}\theta''_0 = (R-Q)\theta_0 \tag{18}$$

$$\frac{1}{\Pr}\theta''_1 = (R-Q+i\,\omega)\theta_1 \tag{19}$$

$$C''_0 - ScKrC_0 = -ScSr\theta''_0 \tag{20}$$

$$C''_1 - Sc\,(Kr + i\,\omega)\,C_1 = -Sc\,Sr\,\theta''_1 \tag{21}$$

All primes denote differentiation with respect to y.
The boundary conditions are

$$u_0 = 1,\ \theta_0 = 1,\ C_0 = 1,\ \text{at } y = 0 \tag{22}$$

$$u_1 = 0\,,\ \theta_1 = 1,\ \ \theta_1 = 1 \quad \text{at } y = 0 \tag{23}$$

$$u_0 \to 0\,,\ \theta_0 \to 0,\ C_0 \to 0 \ \text{ as } \ y \to \infty \tag{24}$$

$$u_1 \to 0,\ \theta_1 \to 0,\ C_1 \to 0 \ \text{ as } \ y \to \infty \tag{25}$$

Solving the system (11) subject to the boundary conditions (12),
we obtain

$$u_0 = B_1 e^{-\sqrt{A_5}y} + \left(\frac{A_6}{A_1 - A_5}\right) e^{-\sqrt{A_1}\,y} +$$

$$\left(\frac{A_7}{Sc\,Kr - A_5}\right) e^{-\sqrt{Sc\,Kr}\,y} \tag{26}$$

$$u_1 = B_2 e^{-\sqrt{A_8}y} + \left(\frac{A_6}{A_2 - A_8}\right) e^{-\sqrt{A_1}\,y}$$

$$+\left(\frac{A_7 g_2}{A_3 - A_8}\right) e^{-\sqrt{A_3}\,y} + \left(\frac{A_7 g_1}{A_2 - A_8}\right) e^{-\sqrt{A_2}\,y} \tag{27}$$

$$\theta_0 = e^{-\sqrt{A_1}\,y} \tag{28}$$

$$\theta_1 = e^{-\sqrt{A_2}\,y} \tag{29}$$

$$C_0 = e^{-\sqrt{Sc\,Kr}\,y} \tag{30}$$

$$C_1 = g_2 e^{-\sqrt{A_3}\,y} + g_1 e^{-\sqrt{A_2}\,y} \tag{31}$$

In view of above solutions, the velocity, the temperature and concentration distributions in the boundary layer become

$$u(y,t) = \begin{pmatrix} B_1 e^{-\sqrt{A_5}\,y} + \left(\frac{A_6}{A_1 - A_5}\right) e^{-\sqrt{A_1}\,y} \\ + \left(\frac{A_7}{Sc\,Kr - A_5}\right) e^{-\sqrt{Sc\,Kr}\,y} \end{pmatrix}$$

$$+\varepsilon e^{i\omega t} \begin{pmatrix} B_2 e^{-\sqrt{A_8}\,y} + \left(\frac{A_6}{A_2 - A_8}\right) e^{-\sqrt{A_2}\,y} \\ + \left(\frac{A_7 g_2}{A_3 - A_8}\right) e^{-\sqrt{A_3}\,y} + \left(\frac{A_7 g_1}{A_2 - A_8}\right) e^{-\sqrt{A_2}\,y} \end{pmatrix} \tag{32}$$

$$\theta(y,t) = \left(e^{-\sqrt{A_1}\,y}\right) + \varepsilon e^{i\omega t}\left(e^{-\sqrt{A_2}\,y}\right) \tag{33}$$

$$C(y,t) = \left(e^{-\sqrt{Sc\,Kr}\,y}\right) +$$

$$\varepsilon e^{i\omega t}\left(g_1\, e^{-\sqrt{A_2}\,y} + g_2\, e^{-\sqrt{A_3}\,y}\right) \tag{34}$$

$$C_f = \begin{pmatrix} B_1\sqrt{A_5} + \left(\frac{A_6}{A_1 - A_5}\right)\sqrt{A_1} \\ + \left(\frac{A_7}{Sc\,Kr - A_5}\right)\sqrt{Sc\,Kr} \end{pmatrix}$$

$$+\varepsilon e^{i\omega t} \begin{pmatrix} B_2\sqrt{A_8} + \left(\frac{A_6}{A_2 - A_8}\right)\sqrt{A_2} \\ + \left(\frac{A_7 g_2}{A_3 - A_8}\right)\sqrt{A_3} + \left(\frac{A_7 g_1}{A_2 - A_8}\right)\sqrt{A_2} \end{pmatrix} \tag{35}$$

$$Nu = \sqrt{A_1} + \varepsilon e^{i\omega t}\sqrt{A_2} \tag{36}$$

$$Sh = \sqrt{Sc\,Kr} + \varepsilon e^{i\omega t}\left(g_1\sqrt{A_2} + g_2\sqrt{A_3}\right) \tag{37}$$

4. RESULTS AND DISCUSSION

Casson MHD flow over an inclined moving plate with chemical reaction parameter has been formulatedand analysed analytically.The effect of chemical reaction parameter on the concentration field is illustrated in Fig.1. As the chemical reaction parameter increases the concentration is found to be decreasing. Fig. 2. shows the variation of the thermal boundary-layer with the perturbation parameter (ε). It is observed that the thermal boundary layer thickness increases with an increase in the perturbation parameter.Fig. 3.depicts the effect of the heat source/sink parameter (Q) on the temperature. It is noticed that as the heat source/sink parameter increases, the temperature increases. The effect of the heat source/sink parameter (Q) on the velocity boundary-layer depicted in Fig.4. It is noticed that as the heat source/sink parameter increases, the velocity boundary-layer increases.The effect of Casson parameter (β) in velocity is shown in Fig. 5. It is observe that velocity increases near the plate and decreases far away the plate with raising the cassson parameter.The effect of inclination of the plate on velocity is shown in Fig.6. From Fig.6, we observe that fluid velocity is decreased in increasing angle ϕ.

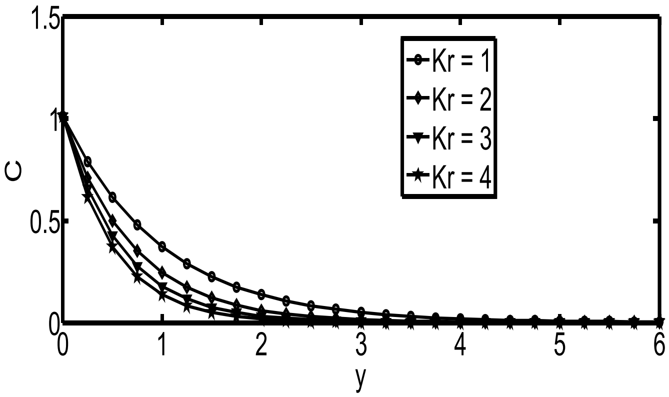

Fig.1: Variation of the concentration profiles with Chemical reaction parameter (Kr) for Sc = 1.0, Sr = 1, t = 0.1, ε = 0.01, ω = 1.0, R = 0.2, Pr = 2, Q = 0.1

The fluid has higher velocity when the plate is vertical i.e. ϕ = 0, than when inclined because of the fact that the buoyancy effect decreases due to gravity components g cosϕ, as the plate is inclined

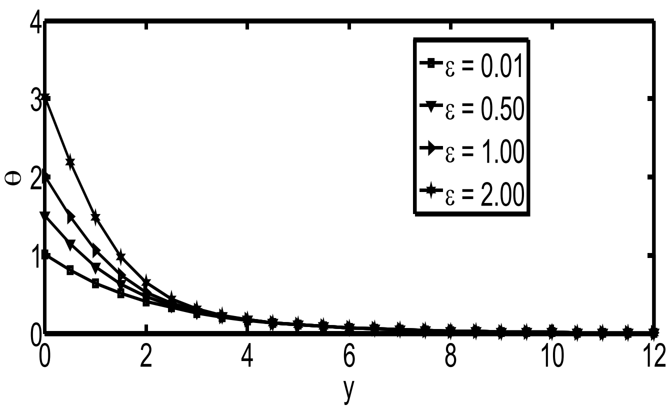

Fig.2: Variation of the temperature profiles with perturbation parameter (ε) for Kr = 0.5, β = 2, t = 0.1, ω = 0.1, R = 0.2, Pr = 2, Q = 0.1

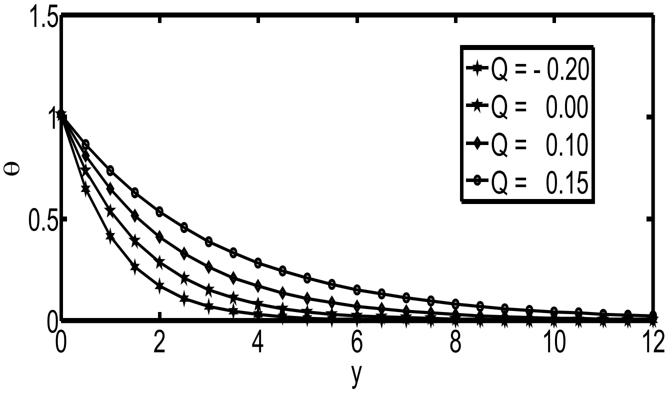

Fig.3: Variation of the temperature profiles with heat source/sink parameter (Q) for Kr = 0.5, β = 2, t = 0.1,ε = 0.01, ω = 0.1, R = 0.2, Pr = 2, Q = 0.1

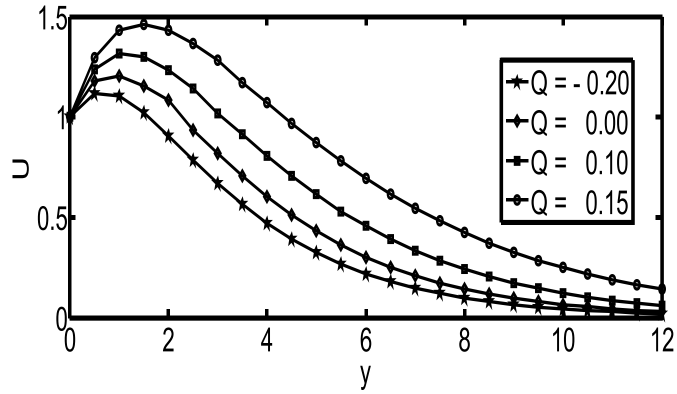

Fig.4: Variation of the velocity profiles with heat source/sink parameter (Q) for Kr = 0.5, β = 2, t = 0.1,ε = 0.01, ω = 0.1, R = 0.2, Pr = 2, Sr = 1, Sc = 2, ϕ = π/6, M = 0.5, Gc = 2, Gr = 2

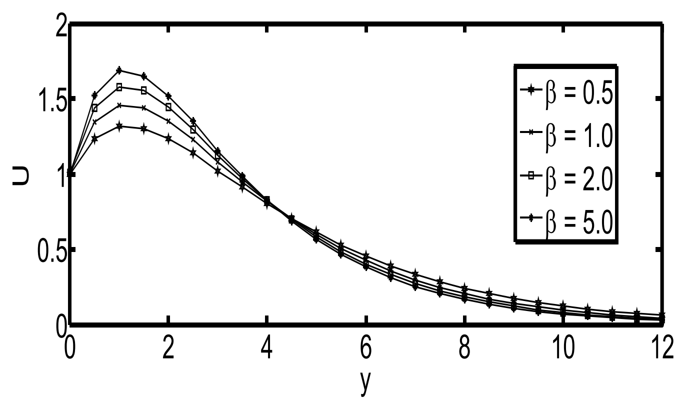

Fig.5: Variation of the velocity profiles with casson parameter (β) for Kr = 0.5, t = 0.1,ε = 0.01, ω = 0.1, R = 0.2, Pr = 2, Q = 0.1, Sr = 1, Sc = 2, ϕ = π/6, M = 0.5, Gc= 2, Gr = 2

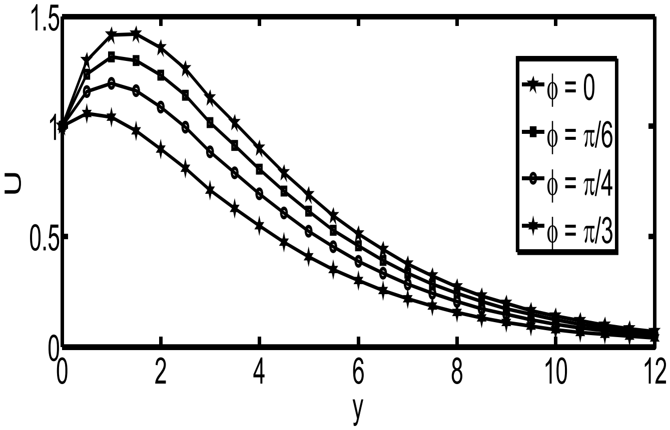

Fig.6: Variation of the velocity profiles with inclination angle (ϕ) for Kr = 0.5, β = 2, t = 0.1, ε = 0.01, ω = 0.1, R = 0.2, Pr = 2, Q = 0.1, Sr = 1, Sc = 2, M = 0.5, Gc = 2, Gr = 2

Table. 1: Influence of Sherwood number

Sc	Kr	Sh
1	0.5	0.7014
2	0.5	0.9897
3	0.5	1.2129
4	0.5	1.4037
1	**1**	0.9998
1	**2**	1.4221
1	**3**	1.7466
1	**4**	2.0207

From Table1, it is observed that the Sherwood number at an inclined plate increases with an increase in the chemical reaction parameter or Schmidt number. From Table2, it is found that the Nusselt number at an inclined plate increases with an increase in the Prandtlnumber or Thermal radiation conduction whereas Nusselt number at an inclined plate decreases with an increase in the heat source/sink parameter. It is noticed that, the skin-friction coefficient at an inclined plate increases with an increase in the themalGrashof number or solutalGrashof number or Casson parameter whereas the skin-friction coefficient at an inclined plate decreases with an increase in the Schmidt number or thermal radiation induction or inclined angle or Hartmann number.

Table. 2: Influence of Nusselt Number

Pr	R	Q	Nu
1	0.2	0.1	0.3197
2	0.2	0.1	0.4521
3	0.2	0.1	0.5537
4	0.2	0.1	0.6394
2	**0.5**	0.1	0.9034
2	**0.8**	0.1	1.1951
2	**1**	0.1	1.3551
2	0.2	**-0.2**	0.9034
2	0.2	**0**	0.6389
2	0.2	**0.15**	0.3202

Table. 3: Influence of Skin-friction Number

Pr	R	Q	Nu
1	0.2	0.1	0.3197
2	0.2	0.1	0.4521
3	0.2	0.1	0.5537
4	0.2	0.1	0.6394
2	**0.5**	0.1	0.9034
2	**0.8**	0.1	1.1951
2	**1**	0.1	1.3551
2	0.2	**-0.2**	0.9034
2	0.2	**0**	0.6389
2	0.2	**0.15**	0.3202

Sc	Gr	Gc	β	R	ϕ	M	Cf
2	2	2	0.5	0.2	π/6	0.5	0.6869
4	2	2	0.5	0.2	π/6	0.5	0.5928
6	2	2	0.5	0.2	π/6	0.5	0.5453
8	2	2	0.5	0.2	π/6	0.5	0.515
2	**5**	2	0.5	0.2	π/6	0.5	1.7082
2	**7**	2	0.5	0.2	π/6	0.5	2.3891
2	**10**	2	0.5	0.2	π/6	0.5	3.4104
2	2	**5**	0.5	0.2	π/6	0.5	1.3082
2	2	**7**	0.5	0.2	π/6	0.5	1.7225
2	2	**10**	0.5	0.2	π/6	0.5	2.3439
2	2	2	**1**	0.2	π/6	0.5	1.0058
2	2	2	**2**	0.2	π/6	0.5	1.2995
2	2	2	**5**	0.2	π/6	0.5	1.5736
2	2	2	0.5	**0.4**	π/6	0.5	0.2122
2	2	2	0.5	**0.6**	π/6	0.5	0.1638
2	2	2	0.5	**0.8**	π/6	0.5	0.1367
2	2	2	0.5	0.2	**0**	0.5	0.2025
2	2	2	0.5	0.2	**π/4**	0.5	0.0586
2	2	2	0.5	0.2	**π/3**	0.5	-0.0431
2	2	2	0.5	0.2	π/6	**0.1**	0.3524
2	2	2	0.5	0.2	π/6	**0.15**	0.3121
2	2	2	0.5	0.2	π/6	**0.2**	0.2786
2	2	2	0.5	0.2	π/6	**0.25**	0.2493

5. CONCLUSIONS

Casson MHD flow over an inclined moving plate with chemical reaction parameter and soret parameter have been formulated.The results are made in this article are good agreement with previous work [11], in the absence of inclination.As the chemical reaction parameter increases the concentration is found to be decreasing. It is observed that the thermal boundary layer thickness increases with an increase in the perturbation parameter(ε).It is noticed that as the heat source/sink parameter increases, the temperature increases.It is noticed that as the heat source/sink parameter increases, the velocity boundary-layer increases.It is observed that velocity increases near the plate and decreases far away the plate with raising the casson parameter.Fluid velocity is decreased in increasing angle ϕ was examined.

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