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HEAT AND MASS TRANSFER ON BOUNDARY LAYER FLOW OF A CASSON FLUID OVER A MOVING VERTICAL POROUS PLATE WITH HEAT GENERATION AND CHEMICAL REACTION IN THE PRESENCE OF SORET EFFECT

S. Ramalingeswara Rao[1], G. Vidyasagar[1] , G.V.S.R.Deekshitulu[2]
[1]Assistant Professor, Department of EM&H, SRKR Engineering College, Bhimavaram, West Godavari(DT), A.P. India.
[2]Professor, Department of Mathematics, J.N.T.U. Kakinada, Kakinada, A.P., India.
Email: [1]ramu.eswar30@gmail.com, [1]vidyasagarsvu@gmail.com, [3]dixitgvsr@gmail.com

Abstract – ***This paper is focused on the study of effect of heat and mass transfer on chemically reacting boundary layer flow of a Casson fluid over a porous stretching sheet in the differential equations are transformed by introducing similarity variable and solved numerically by using Range Kutta method of fourth order along with shooting method. The velocity, temperature and concentration distributions for different parameters graphically.***

Keywords*:* Mass Transfer, MHD, Casson Parameter, suction, heat generation, chemical reaction, radiation effect and Soret effect

I. INTRODUCTION

The combined effects of heat and mass transfer with chemical reaction have attracted many researchers due to its wide range of applications in Engineering and Science. Heat and mass transfers occur simultaneously in the processes of drying and evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler. The study of magnetohydrodynamic (MHD) flow of an electrically conducting fluid is of considerable interest due to its application in many engineering problems such as MHD generators, plasma studies, nuclear reactors, and geothermal energy extractions. The study of boundary layer flow over a stretching sheet has finds applications in chemical engineering, particularly in manufacture artificial film, artificial fibers, polymer extrusion, drawing of plastic films and wires, glass fiber and paper production. Das et al. (1994) studied the first order chemical reaction effect on the flow past an impulsively started infinite vertical plate with constant heat flux and mass transfer. Anjalidevi and Kandaswamy (1999) considered the heat and mass transfer on steady laminar flow along a semi-infinite horizontal plate in the presence of chemical reaction. The Soret and Dufour effects on heat and mass transfer about vertical surfaces in porous media have been studied by Postelnicu (2004). Radiation on boundary layer flow over a moving vertical porous plate was analyzed by Makinde (2005). Muthucumaraswamy et al. (2006) have studied the effect of chemical reaction isothermal vertical plate with radiation. Hossian and Mandal (1985) investigated mass transfer effects on unsteady hydromagnetic free convection flow past an accelerated vertical porous plate. Jha (1991) studied the effect of magnetic field on mass transfer flow past a uniformly accelerated vertical plate through a porous medium. Elbashbeshy (1997) analyzed the heat and mass transfer along a vertical plate in the presence of magnetic field. The combined heat and mass transfer convection flow from a vertical surface with Ohmic heating and viscous dissipation was analyzed by Chen (2004). Crane (1970) was the first researcher who investigated the boundary layer flow over a stretching surface.

After the study of fluid flow over a stretching sheet has received wide attention among researchers. Rajagopal et al. (1984) discussed the flow of second order fluid over a stretched sheet. Anderson et al. (1992) consider magnetic field on the flow of a viscoelastic fluid past a stretching sheet. Abel et al. (2005) analyzed MHD boundary layer flow over continuously moving stretching surface embedded in a porous medium by considering the Buoyancy force and effects. Mukhopadyaya et al. (2008) discussed the free convective boundary layer flow with variable viscosity over a stretching surface with thermal radiation. Pal (2009) investigated the mixed convection flow of an incompressible fluid over a stretching sheet in the presence of radiation. Ahmed (2009) analyzed the free convective heat and mass transfer of a viscous incompressible fluid over a stretching sheet in the presence of suction with Soret and Dufour effects.

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Heat and mass transfer in non-Newtonian fluids have applications in engineering such as catalytic reactors, the filtration and blood plasmapheresis devices. Casson fluid is the most popular non-Newtonian fluid used to model blood. It is defined as a shear thinning liquid which has a infinite viscosity at zero rate of shear, possessing a yield stress below which no flow occurs and zero viscosity at infinite rate of shear. It is reduced to Newtonian fluid at very high wall shear stress i.e. when the wall stress is much greater than yield stress. Merill et al. (1965) and McDonald (1974) conducted experiments on the behavior of blood as a Casson fluid. Eldabe (1995) considered the heat transfer of Casson fluid flow between two rotating cylinders. The flow of Casson fluid in a tube was studied by and Nagarani et al. (2004). Mass transfer in a Casson flowing through an annular geometry was examined by Nagarani et al. (2009). Dash et al. (2000) examined by Shear-augmented dispersion of a solute in a Casson fluid flowing in a conduit. Attia (2010) analyzed the transient Couette flow of a Casson fluid between parallel plates with magnetic field and heat transfer. The unsteady boundary layer flow of a Casson fluid over a moving flat plate was studied by Mustafa et al. (2011). Hayat et al. (2012) studied the mixed convection stagnation point flow of a Casson fluid. Shehzad (2013) discussed the effects of mass transfer on the MHD boundary layer flow of a Casson fluid with chemical reaction. Sarojamma et al. (2014) studied heat and mass transfer on MHD boundary layer flow of a chemically reacting Non-Newtonian flow over a Stretching sheet with suction. Vidyasagar and Ramana (2017) analyzed radiation effects on MHD boundary layer flow over a moving vertical porous plate with heat generation in the presence of chemically reacting Non Newtonian fluid and soret effect.

In view of the above studies, we consider the MHD boundary layer flow of a Casson fluid over a stretching sheet with heat and mass transfer and chemical reaction

NOMENCLATURE:

u, v : Velocity components along the x and y axes

T : Fluid temperature inside the boundary layer

T_∞ : Ambient temperature for away from the plate

T_w : Uniform constant temperature at the wall

C : Species concentration inside the boundary layer

C_∞ : Species concentration of the ambient fluid

g : Acceleration due to gravity

$K^{*'}$: Permeability of the porous medium

B_0 : Uniform magnetic field

Nagarani et al. (2004). Mass transfer in a Casson flowing through an annular geometry was examined by Nagarani et al. (2009). Dash et al. (2000) examined by Shear-augmented dispersion of a solute in a Casson fluid flowing in a conduit. Attia (2010) analyzed the transient Couette flow of a Casson fluid between parallel plates with magnetic field and heat transfer. The unsteady boundary layer flow of a Casson fluid over a moving flat plate was studied by Mustafa et al. (2011). Hayat et al. (2012) studied the mixed convection stagnation point flow of a Casson fluid. Shehzad (2013) discussed the effects of mass transfer on the MHD boundary layer flow of a Casson fluid with chemical reaction. Sarojamma et al. (2014) studied heat and mass transfer on MHD boundary layer flow of a chemically reacting Non-Newtonian flow over a Stretching sheet with suction. Vidyasagar and Ramana (2017) analyzed radiation effects on MHD boundary layer flow over a moving vertical porous plate with heat generation in the presence of chemically reacting Non Newtonian fluid and soret effect.

In view of the above studies, we consider the MHD boundary layer flow of a Casson fluid over a stretching sheet with heat and mass transfer and chemical reaction

Pr : Prandtl number

M : Magnetic parameter

Gr : Grashof number

Gc : Modified Grashof number

Sc : Schmidt number

D : Molecular diffusivity of the species concentration

K : Permeability parameter

k1 : Chemical Reaction

Ch : Chemical Parameter

Q0 : Heat Parameter

B : Heat Generation

D1 : Soret Parameter

Ra : Radiation Parameter

GREEK SYMBOLS:

θ : Dimensionless temperature

ρ : Fluid density

υ : Kinematics viscosity

σ : Electrical conductivity

β , β^*: Thermal and concentration expansion coefficients

MATHEMATICAL FORMULATION:

Consider the steady, incompressible flow of a Casson fluid over a porous stretching surface at y = 0. Choose the coordinate system such that x-axis is parallel to the surface and y-axis normal to the surface. The fluid occupies half space y > 0. A uniform magnetic field B0 is applied in the y direction. The transverse applied magnetic field and magnetic Reynolds number are assumed to be very small, so that the induced magnetic field and Hall effects becomes negligible. We also considered the heat and mass transfer processes in the presence of chemical reaction and heat generation. The rheological equation of state for an isotropic and incompressible flow of a Casson fluid can be written as (Nakamura and Sawada (1988), Mustafa et al. (2012)).

$$\tau_{ij} = \begin{matrix} 2(\mu_B + P_y/\sqrt{2\pi})e_{ij}, \pi > \pi_c \\ 2(\mu_B + P_y/\sqrt{2\pi_c})e_{ij}, \pi < \pi_c \end{matrix}$$

Where μ_B is the plastic dynamic viscosity of the non-Newtonian fluid, Py is the yield stress of the fluid, e ij denotes the (i, j) - th component of the deformation rate, π = e ij, e ij is the product of the component of deformation rate with itself, πc is the critical value of π based on the non-Newtonian model.

The continuity, momentum and energy equations are
Continuity Equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (1)$$

Momentum Equation:

α : Thermal diffusivity

F_w : Suction parameter

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \gamma(1+\frac{1}{\beta})\frac{\partial^2 u}{\partial y^2} - \sigma \frac{B_0^2}{\rho}u - \frac{\gamma}{K^*}u + g\beta(T - T_\infty) + g\ \beta^*(C - C_\infty) \qquad (2)$$

Energy Equation:

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y} + \frac{Q_0}{\rho C_P}(T - T_\infty) + \frac{\sigma B_0^2}{\rho}u^2 \qquad (3)$$

Concentration Equation:

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial y^2} - k_1(C - C_\infty) + D_1\frac{\partial^2 T}{\partial y^2} \qquad (4)$$

$$\frac{\partial q_r}{\partial y} = 4\alpha^2(T - T_\infty)$$

Where u and v are the velocity components in x and y directions, γ is the kinematic viscosity, $\beta = \mu_B\sqrt{2\pi_c}/P_Y$ is the Casson fluid parameter, σ is the electric Conductivity of the fluid, ρ is the density of the fluid, T is the temperature of the fluid, C is the Concentration field, α is the thermal diffusivity, D is the mass diffusivity, k is the reaction rate.

The Boundary Conditions for the Velocity, Temperature and Concentration fields are

u=u , v=-V $_0, T = T_w, C = C_W$ when y=0

u →0, T→ T $_\infty$,C →C as y → ∞

(5)

We define the following non dimensional variables

$$\eta = \sqrt{\frac{c}{\gamma}}y,\ f(\eta) = \frac{\psi}{x\sqrt{c\gamma}},\ \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty},\ \phi(\eta) = \frac{C - C_\infty}{C_W - C_\infty},\ B = \frac{Q_0}{C\rho C_P} \qquad (6)$$

Where is the stream function with

$$u = \frac{\partial\psi}{\partial y},\ v = -\frac{\partial\psi}{\partial x}$$

η is the similarity variable substituting the non-dimensional variables

In view of the Equations (2) to (4) take the form

$$(1+\frac{1}{\beta})f''' + ff'' - (f')^2 - (M+K)f' = -(Gr\theta + Gc\phi) \qquad (7)$$

$$\frac{1}{\Pr}\theta'' + f\theta' - (Ra - B)\theta + M^2u^2 = 0 \qquad (8)$$

$$\phi'' - Scf\theta' - ScK_1\phi + \theta'' SrSc = 0 \qquad (9)$$

where the primes denote the differentiation with respect to η, M is the magnetic parameter, K is the permeability parameter, Gr is the temperature Grashof number, Gc is the Modified Grashof number, $\Pr$ is the Prandtl number, Ra is the Radiation parameter, B is the Heat Generation, Ch is the Chemical Parameter, Sr is the Soret effect and is the Schmidt number.

The Corresponding non –dimensional boundary conditions are

$f' = 1,\ f = S, \theta = 1, \phi = 1$, when η =0

$f'(\infty) \to 0,\ \theta(\infty) \to 0,\ \phi(\infty) \to 0 \quad as\ y \to \infty$

(10)

SOLUTION OF THE PROBLEM

The governing boundary layer equations (7) to (9) subject to boundary conditions (10) are solved numerically by using shooting method. First of all, higher order non-linear differential equations (7) to (9) are converted into simultaneous non linear differential equations of first order and they are further transformed into initial value problem by applying the Range Kutta method of 4th order along with shooting technique. From the process of numerical computation are respectively proportional to $f''(0)$, $-\theta'(0)$ and $-\phi'(0)$ are also sorted out and their numerical values are presented in a tabular form.

RESULTS AND DISCUSSION

In order to get a physical insight into the problem, a representative set of numerical results is shown graphically in Figs.1-27, to illustrate the influence of physical parameters viz., the effect of the Casson parameter (β), Magnetic field (M), Porous parameter (K), Grashof Number

(Gr), Modified Grashof number (Gc), Suction parameter (S), Prandtl Number (Pr), Radiation parameter (Ra), Heat Generation (B), Schmidt's Number (Sc), Chemical Reaction (Ch) and Soret effect (Sr) on the flow variables certain important results have been presented graphically.

Fig 1 presents the effect of Casson parameter (β) on velocity. It is observed that the velocity increases asymptotically from its highest value on the surfaces to zero as $\eta \rightarrow \infty$. The presence of yield stress reduces the velocity. Increasing values of β increases the velocity further and thus there is a decrease in the thickness of the boundary layer.

Fig.2 shows the variation of chemical reaction (Ch) on velocity. The effect of chemical reaction increases with the increases on velocity. Fig 3 illustrates the effect of Grashof number (Gr) on velocity. We observe that the velocity decreases with the increase of Grashof number (Gr). Fig 4 illustrates the effect of magnetic field (M) on velocity. We observe that the velocity decreases with the increase of magnetic field (M). Fig 5 illustrates the effect ofmodified Grashof number (Gc) on velocity. We observe that the velocity decreases with the increase of modified Grashof number (Gc). Fig 6 shows the temperature for different values of heat generation (B). It is observed that the temperature increases with the increase of heat generation (B). Fig 7 illustrates the effect of porous parameter (K) on velocity. We observe that the velocity decreases with the increase of porous parameter (K). Fig 8 shows the temperature for different values of chemical reaction parameter (Ch). It is seen that the temperature decreases with the increase of chemical reaction parameter (Ch). Fig 9 shows the temperature for different values of modified Grashof number (Gc). It is seen that the temperature decreases with the increase of modified Grashof number (Gc). Fig 10 shows the temperature for different values of Prandtl number (Pr). It is seen that the temperature decreases with the increase of Prandtl number (Pr). From fig 11 shows the temperature for different values of Grashof number (Gr). It is seen that the temperature increases with the increase of Grashof number (Gr). Fig 12 shows the temperature for different values of radiation parameter (Ra). It is seen that the temperature decreases with the increase of radiation parameter (Ra). From Fig 13 shows the temperature

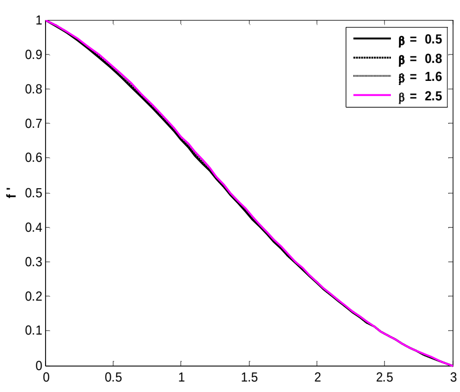

Fig 1: The Velocity Profile for different values for Casson Parameter (β)

for different values of porous parameter (K). It is seen that the temperature decreases with the increase of porous parameter (K). Fig 14 shows the concentration for different values of chemical reaction (Ch). It is seen that the concentration decreases with the increase of chemical reaction (Ch). Fig 15 shows the concentration for different values of modified Grashof number (Gc). It is seen that the temperature decreases with the increase of modified Grashof number (Gc). Fig 16 shows the concentration for different values of magnetic parameter (M). It is seen that the concentration increases with the increase of magnetic parameter (M). Fig 17 shows the concentration for different values of Grashof number (Gr). It is seen that the concentration increases with the increase of Grashof number (Gr). Fig 18 shows the concentration for different values of Schmitt number (Sc). It is seen that the concentration decreases with the increase of Schmitt number (Sc). Fig 19 shows the concentration for different values of porous parameter (K). It is seen that the concentration increases with the increase of porous parameter (K). Fig 20 shows the concentration for different values of Soret number (Sr). It is seen that the concentration decreases with the increase of Soret number (Sr).

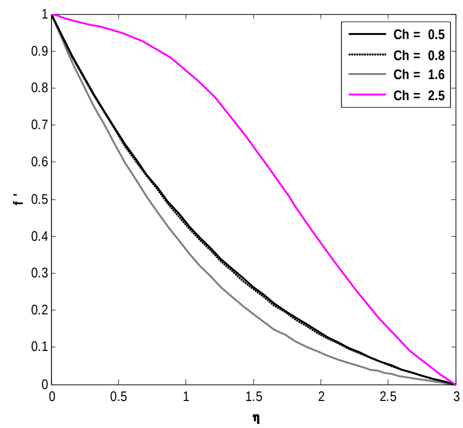

Fig 2: The velocity profile for the different values for chemical reaction (Ch)

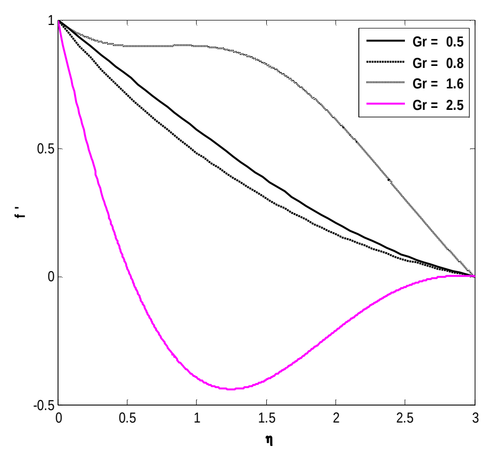

Fig 3: The velocity profile for the different values for Grashof number (Gr)

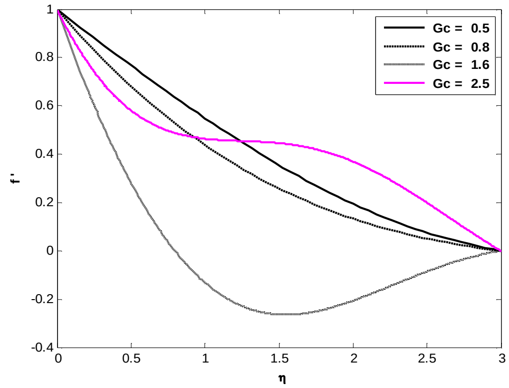

Fig 5: The velocity profile for the different values for modified Grashof number (Gc)

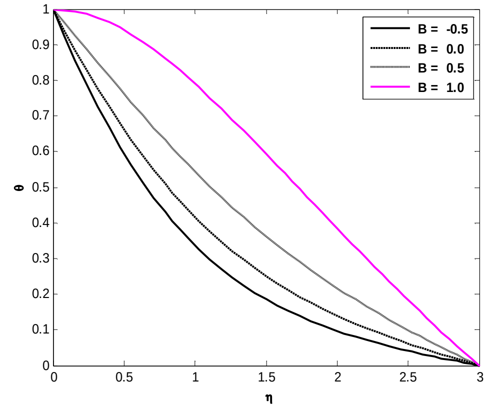

Fig 6: The temperature profile for the different values for heat generation (B)

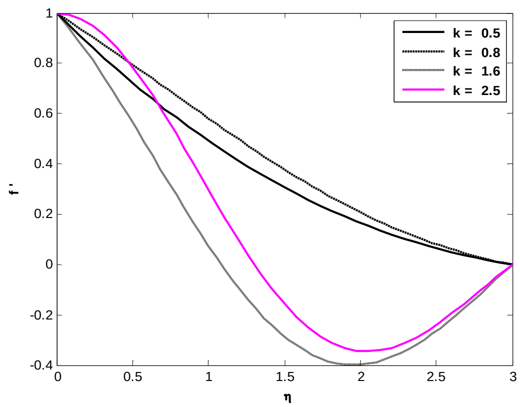

Fig 7: The velocity profile for the different values for porous parameter (K)

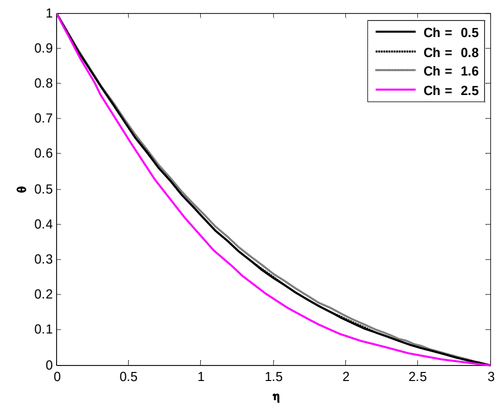

Fig 8: The temperature profile for the different values for Chemical Reaction (Ch)

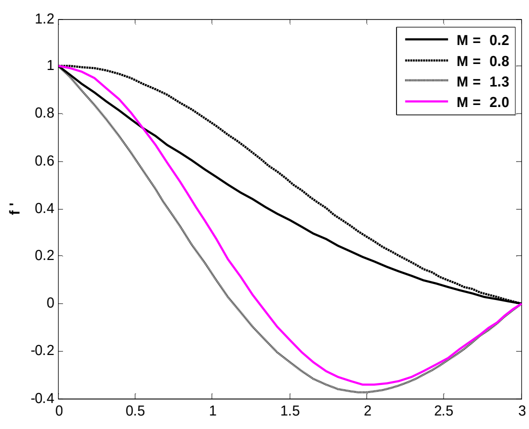

Fig 4: The velocity profile for the different values for magnetic field (M)

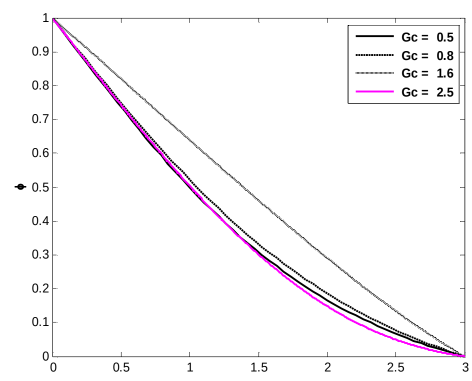

Fig 9: The temperature profile for the different values for modified Grashof number (Gc)

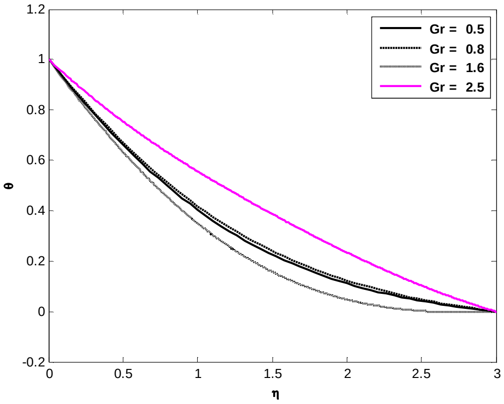

Fig 11: The temperature profile for the different values for Grashof number (Gr)

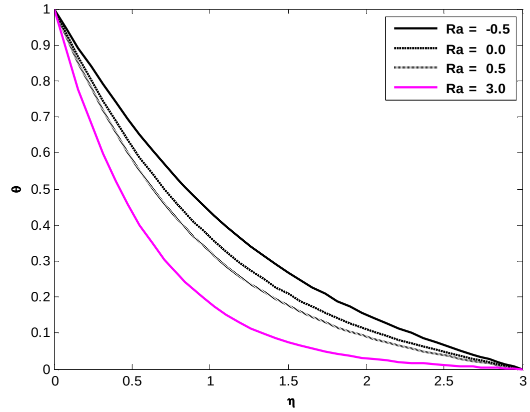

Fig 12: The temperature profile for the different values for radiation parameter (Ra)

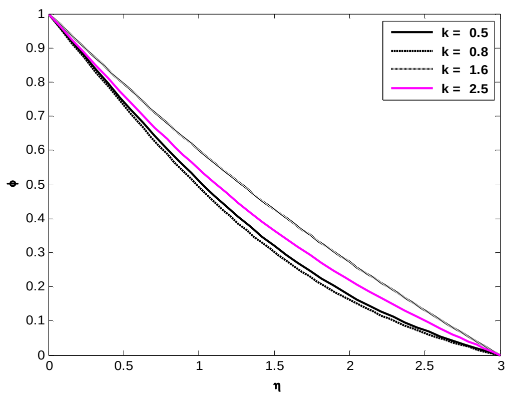

Fig 13: The temperature profile for the different values for porous parameter (K)

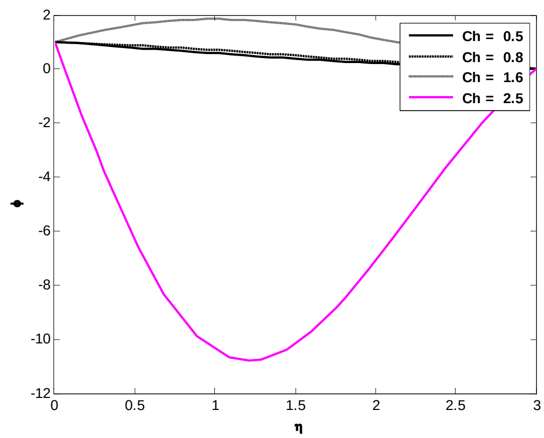

Fig 14: The Concentration profile for the different values for Chemical reaction (Ch)

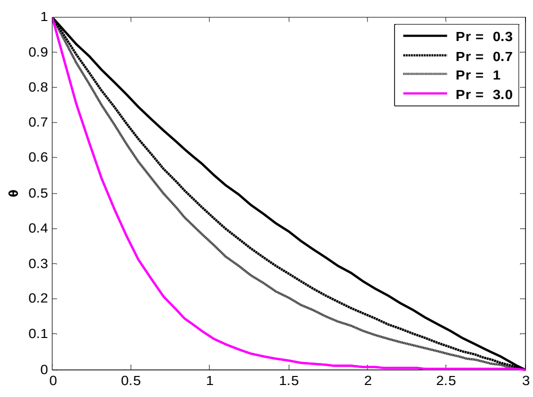

Fig 10: The temperature profile for the different values for Prandtl number (Pr)

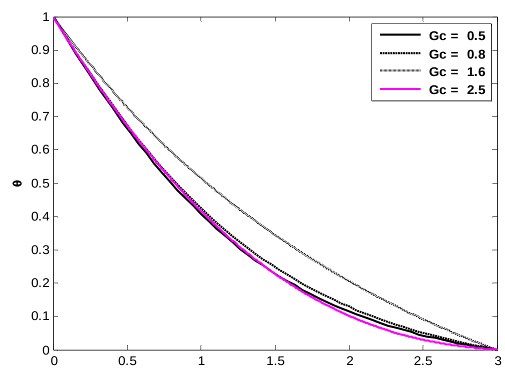

Fig 15: The Concentration profile for the different values for modified Grashof number (Gc)

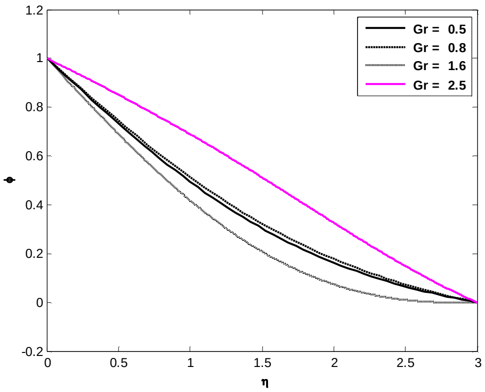

Fig 17: The Concentration profile for the different values for Grashof number (Gr)

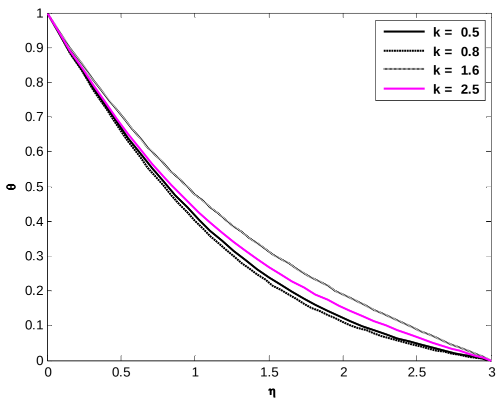

Fig 19: The Concentration profile for the different values for porous parameter (K)

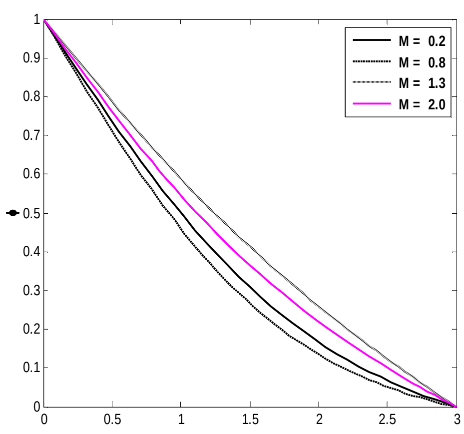

Fig 16: The Concentration profile for the different values for magnetic parameter (M)

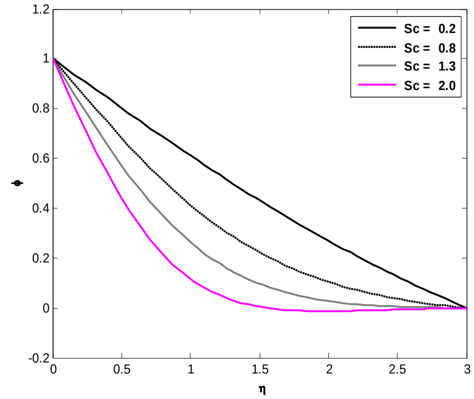

Fig 18: The Concentration profile for the different values for Schmitt number (Sc)

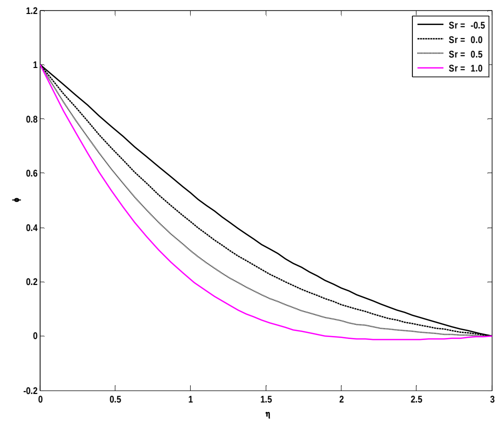

Fig 20: The Concentration profile for the different values for Soret effect (Sr)

CONCLUSIONS:

This paper gives the effect of Heat and mass transfer on MHD boundary layer flow for a Casson fluid over a stretching sheet in presence of heat generation and chemical reaction. The governing equations are solved by shooting technique. It is observed that velocity is decreasing function of Casson parameter β, Magnetic parameter M, Suction parameter S. The thermal boundary layer thickness decreases with an increase in Prandtl number Pr.

- From Fig (3), we observed that the velocity decreases with the increase of Grashof number (Gr).
- From Fig (4), we observed that the velocity decreases with the increase of modified Grashof number (Gc).
- From Fig (7), it is observed that the temperature increases with the increase of heat generation (B).
- From Fig (8), we observe that the temperature increases with the increase of Casson parameter (β).
- From Fig (9), it is seen that the temperature decreases with the increase of Chemical parameter (Ch).

- From Fig (10), it is seen that the temperature decreases with the increase of modified Grashof number (Gc).
- From Fig (18), it is seen that the concentration increases with the increase of Grashof number (Gr).
- From Fig (22), it is seen that the concentration decreases with the increase of Soret number (Sr).

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