Thermal Radiation and Nth order chemical reaction effects on Magnetohydrodynamic Casson fluid flow over a permeable stretching sheet

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Abstract - This work consists of a boundary layer analysis of two dimensional Magnetohydrodynamics (MHD) flow of a Casson fluid over a permeable stretching sheet in the occurrence of thermal radiation and *n*th order chemical reaction. The flow governing equations are modelled via boundary layer approximations. Conservation laws of mass, momentum, energy and concentration of nonlinear partial differential equations are lessened to a set of nonlinear ordinary differential equations using similitude transformation. The boundary layer equations are elucidated numerically, by MATLAB bvp4c solver. The variation of several pertinent parameters on flow convective characteristic phenomena are explored through the use of graphs. The suggested problem leads to hike in the Casson fluid mass transition rate and energy transition rate with the flourishing trend in the chemical reaction and heat source parameter, respectively. Casson fluid velocity can be elevated by the rising effect of thermal and mass Grashof number. The friction factor, the rate of heat transfer and rate of mass transfer are also provided with recognize to the controlled parameters.

Keywords: **Casson fluid, Chemical reaction, Heat source, Magentohydrodynamics (MHD), Non-newtonian fluid, Stretching sheet and Thermal Radiation.**

I. INTRODUCTION

In present days exquisite deal of work has been completed to disclose the effect of heat and mass transfer on MHD Non-Newtonian fluid flow beyond a permeable stretching sheet under the presence of higher order chemical reaction and thermal radiation. It perceives many applications in physics and engineering tactics like, nuclear power plants, gas turbines, wind tunnels, aircraft, space vehicles, fossil fuels, photo ionization and lots of others. Casson fluid has exclusive features in the list of non- newtonian fluids. Kandasamy et al. [1] had examined thermal stratification and chemical reaction effects of MHD flow over a vertical surface. Makinde [2] conducted the analysis on Mixed convection MHD flow past a vertical porous plate in porous medium channel with thermal radiation and higher order chemical reaction. Rahman and Al-Lawatia [3] studied higher order chemical reaction on micropolar fluid flow on a permeable extending sheet in a porous medium channel. Animasaun [4] studied effects of thermophoresis and thermal conductivity on MHD casson fluid flow with nth order chemical reaction using Muller's scheme. Mallikarjuna and Bhuvanavijaya [5] established combined effects of non-uniform heat source/sink and higher order chemical reaction on MHD non-darcy convective flow over a vertical plate embedded in a fluid saturated porous medium. An analytical solution of MHD casson fluid flow with suction and chemical reaction was addressed by Shehzad et al. [6]. Uwanta and Usman [7] performed both analytical and numerical investigation of Heat and mass transfer convective flow in a porous medium channel with nth order chemical reaction. Kameswaran et al. [8] analyzed dual solutions of stagnation point flow over a stretching or shrinking sheet. Arthur et al. [9] investigated numerical analysis of non-newtonian fluid flow over a vertical porous surface using the Newton Raphson shooting method alongside the Forth-order Runge-Kutta algorithm. Sathies kumar and Gangadhar [10] considered two- dimensional stagnation point flow analysis of MHD casson fluid over a stretching sheet with chemical reaction. Mythili et al. [11] paid the attention on an unsteady casson fluid flow over a vertical cone with higher order chemical reaction and non-uniform heat source /sink by using Crank Nicolson numerical method. Steady MHD radiative casson fluid flow with heat source/sink was discussed by Vijayaragavan [12]. Palani et al. [13]

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discussed time dependent boundary layer flow over an elastic sheet with chemical reaction using numerical shooting technique. Raju et al. [14] examined two-dimensional heat and mass transfer behavior of non-newtonian Casson fluid flow on an exponential permeable surface by using Matlab bvp4c.An unsteady Falkner-Skan flow of Casson nanofluid with chemical reaction was analyzed by Ullah et al. [15].Anuradha and yegammai [16] reported on two-dimensional viscoelastic fluid flow due to a vertical elastic sheet with nth order chemical reaction effect by utilizing Nactsheim-Swigert shooting technique with sixth order Runge-Kutta iteration Method. Harikrishna et al. [17] obtained numerical solution of boundary layer flow due to a porous stretching sheet in presence of chemical reaction effect using Mathematica. Ullah et al. [18] have applied Keller box method for computing the solution of MHD slip flow along nonlinear permeable stretching cylinder with Chemical Reaction, Viscous Dissipation, and Heat Generation/Absorption. Idown et al. [19] employed free convective flow of dissipative casson fluid with thermal conductivity and variable viscosity effects using Chebyshev Spectral Collocation method. Manjula and Chandra sekhar [21] developed heat and mass transfer for boundary layer Casson fluid flow on a permeable vertical surface using laplace transform procedure. Raju et al. [22] had observed Casson fluid flow past an elastic sheet with convective boundary condition. Reddy [24] established numerical solution of two dimensional casson fluid flow over an inclined permeable stretching surface. Comparative analysis of MHD fluids were investigated by Jabeen et al. [25] with thermophoresis, radiation and chemical reaction using semi analytical techniques.

The main purpose of this study is to extend the work of Asogwa and Ibe [20] with the aid of including the consequences of thermal radiation, non-uniform heat source /sink and nth order chemical reaction. Results are plotted and displayed. The important observations of investigation are recorded within the conclusions.

II. MODEL FEATURES AND NUMERICAL MODELING

Consider time dependent, two-dimensional (2D) boundary layer Magnetohydrodynamics (MHD) flow of an incompressible, viscous fluid that conducts electricity along a permeable, vertical stretched sheet with higher order chemical reaction. As seen in Fig. 2.1, dual equal and opposite forces are introduced along the x-axis to stretch the sheet while maintaining the origin fixed at y=0. A uniformly strong magnetic field of B_0 is applied in the y-direction. Compared to the applied magnetic field away from the plate, the effect of the induced magnetic field is not entirely ignored. The co-ordinate system is selected as x-axis along the direction of the plate and y-axis normal to it.

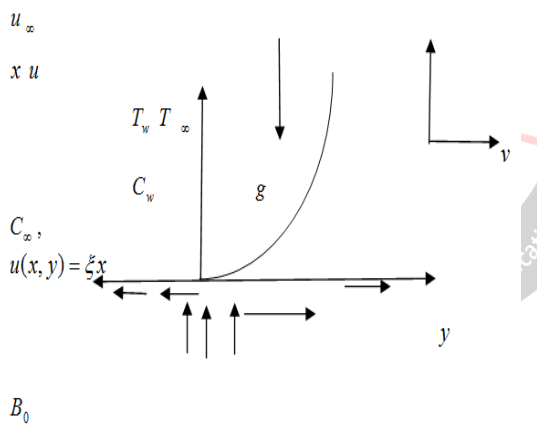

Fig.2.1 Geometry of the fluid flow

For an isotropic and incompressible flow of a Casson fluid, the rheological equation is expressed as follows:

$$\tau_{ij} = \left\{ 2\left(\mu_B + \frac{p_z}{\sqrt{2\pi}}\right) e_{ij,} \pi > \pi_c \right.$$

$$\left\{ 2\left(\mu_B + \frac{p_z}{\sqrt{2\pi}}\right) e_{ij,} \pi < \pi_c \right.$$

Where $\pi = e_{ij}$

e_{ij} = The (i, j) th component of the deformation rate

π = The product of the component of the deformation rate

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π_c = Critical value of this product based on the non-Newtonian fluid

μ_B = Plastic dynamic viscosity

P_z = Yield stress

The following equations are the vital equations in the boundary layer approximations

$$u_x + v_y = 0 \tag{1}$$

$$uu_x + vu_y = \vartheta\left(1+\frac{1}{\beta}\right)u_{yy} + g\beta_1(T-T_\infty) + g\beta_2(C-C_\infty) - \frac{\sigma B_0^2}{\rho}(u-U_\infty) \tag{2}$$

$$uT_x + vT_y = \alpha T_{yy} + \frac{\mu}{\rho c_p}\left(1+\frac{1}{\beta}\right)(u_y)^2 + \frac{\sigma B_0^2}{\rho}(u-U_\infty)^2 - \frac{1}{\rho c_p}\left(\frac{\partial q_r}{\partial y}\right) + \frac{Q_0}{\rho c_p}(T-T_\infty) \tag{3}$$

$$uC_x + vC_y = DC_{yy} - K(C-C_\infty)^n \tag{4}$$

where, u and v are referring to velocity segments in the direction of x and y correspondingly, υ is refer to kinematic viscosity, ξx is refer to assumed wall velocity, K is refer to the chemical reaction term, μ is refer to viscosity of the fluid, $\alpha = \frac{k}{\rho c_p}$ is refer to thermal diffusivity, k is refer to the thermal conductivity, ρ is refer to fluid density, cp is refer to specific heat at constant pressure, β_1, β_2 are the thermal and concentration expansions of fluid, β is refer to Casson fluid parameter, D is refer to diffusion term.

Thermal radiation is simulated using the Rosseland diffusion approximation and in accordance with this, the radiative heat flux is defined by

$$q_r = -\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y} \tag{5}$$

Here σ^* is the Stefan-Boltzmann constant and k^* is the Rosseland mean absorption coefficient. If the temperature differences within the mass are sufficiently small, then Eq. (5) can be linearized by expanding into the Tayler's series about and neglecting higher order terms, we get

$$T^4 = 4TT_\infty^3 - 3T_\infty^4 \tag{6}$$

Equation (5) becomes

$$\frac{\partial q_r}{\partial y} = \frac{16\sigma^* T_\infty^3 (T-T_\infty)}{3k^*} \tag{7}$$

Substituting eqn. (7) into eqn.(4) We get

$$uT_x + vT_y = \alpha T_{yy} + \frac{\mu}{\rho c_p}\left(1+\frac{1}{\beta}\right)(u_y)^2 + \frac{\sigma B_0^2}{\rho}(u-U_\infty)^2 + \frac{1}{\rho c_p}\frac{16\sigma^* T_\infty^3}{3k^*}T_{yy} + \frac{Q_0}{\rho c_p}(T-T_\infty) \tag{8}$$

In that the boundary conditions are specified like

$$u = \xi x, v = v_w, T = T_w, C = C_w \quad \text{at } y = 0$$

$$u \to 0, T \to T_\infty, C \to C_\infty \quad \text{as } y \to \infty \tag{9}$$

Now in this paper, we are going to introduce the subsequent variables:

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$$\eta = y\sqrt{\frac{\xi}{\upsilon}}\ , \quad \psi = \sqrt{\xi \upsilon x}\, f(\eta)\ , \phi(\eta) = \frac{C - C_\infty}{C_w - C_\infty}, \ \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}$$

$$u = \xi x f'(\eta) \quad v = -\sqrt{\xi \upsilon}\, f(\eta) \tag{10}$$

With that the incompressibility eqn. (1) fulfils identically and the laws of conservation of momentum, energy and concentration converted into

$$\left(1+\frac{1}{\beta}\right) f''' + ff'' - f' - M\left(f' - 1\right)^2 + Gr\theta + Gc\phi = 0 \tag{11}$$

$$\frac{1}{Pr}\left(1+\frac{4}{3}R\right)\theta'' + f\theta' + Ec\left(1+\frac{1}{\beta}\right) f''^2 + EcM\left(f' - 1\right)^2 + S\theta = 0 \tag{12}$$

$$\phi'' + Scf\phi' - Sc\gamma\phi^n = 0 \tag{13}$$

And the equivalent boundary conditions are given by

$$\eta = 0: \qquad f(0) = f_w, f'(0) = 1, \theta(0) = 1, \phi(0) = 1$$

$$\eta \to \infty: \qquad f(\infty) = 0, \theta(\infty) = 0, \phi(\infty) = 0 \tag{14}$$

where M stands for the Magnetic parameter, Pr stands for the Prandtl number, R stands for the thermal radiation parameter, Gr stands for the thermal grashof number, Gc stands for the mass grashof number, γ stands for the Chemical reaction parameter Sc stands for the Schmidt number, S stands for the heat generation parameter, n stands for the order of chemical reaction and *Ec* stands for the Eckert number and they are defined as

$$M = \frac{\sigma B_0^2}{\rho \xi}, R = \frac{4\sigma^* T_\infty^3}{kk^*}, Gr = \frac{g\beta_1\left(T_w - T_\infty\right)}{\xi u}, Gc = \frac{g\beta_2\left(C_w - C_\infty\right)}{\xi u}, S = \frac{Q_0}{U_w \rho c_p}$$

$$Ec = \frac{u^2}{c_p(T_w - T_\infty)}, Sc = \frac{\upsilon}{D}, \gamma = \frac{K_c\left(C_w - C_\infty\right)^{n-1}}{\xi}, \Pr = \frac{\mu c_p}{k}, f_w = -\frac{v_w}{\sqrt{\xi \upsilon}}$$

The skin-friction, heat and Mass transfer coefficients are given by

$$\mathrm{Re}_x^{1/2} C_f = \left(1+\frac{1}{\beta}\right) f''(0) \tag{15}$$

$$\mathrm{Re}_x^{-1/2} Nu_x = -\theta'(0) \tag{16}$$

$$\mathrm{Re}_x^{-1/2} Sh_x = -\phi'(0) \tag{17}$$

Where $\mathrm{Re}_x = \dfrac{U_w x}{\upsilon}$ is the Reynold's number.

Equations (11)-(13) together with the related boundary conditions (14) were reduced to a system of first order differential equations and then solved using a MATLAB boundary value problem solver called bvp4c. The details of the solution method are offered in Kierzenka and Shampine [23]. From the process of numerical computation, the skin-friction coefficient, the local Nusselt number and the local Sherwood number, which are respectively proportional to $-f''(0)$, $-\theta'(0)$ and $-\phi'(0)$ are computed and displayed below. The set of non-linear system of ordinary differential equations along with appropriate boundary functions form a two-point boundary value problem. These equations are solved by using Shooting technique, by changing them to an initial value problem. For this, the ODE's are changed into a set of first order differential equations as follows:

$$f = y1, f' = y2, f'' = y3, \theta = y4, \theta' = y5, \phi = y6, \phi' = y7 \tag{18}$$

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$$
\begin{aligned}
&y1' = y2 \\
&y2' = y3 \\
&y3' = \frac{-y1*y3 + M\left(y2-1\right)^2 + y2 - Gr_T*y4 - Gr_C*y6}{\left(1+\dfrac{1}{\beta}\right)} \\
&y4' = y5 \\
&y5' = \frac{-\Pr\left(y1*y5\right) - \Pr*Ec*\left(1+\dfrac{1}{\beta}\right)*(y3)^2 - \Pr*Ec*\left(y2-1\right)^2.M - \Pr*S*y4}{\left(1+\dfrac{4}{3}\right)R} \\
&y6' = y7 \\
&y7' = -Sc*y1*y7 + Sc*k*y6\hat{}n
\end{aligned}
\tag{19}
$$

III. GRAPHICAL SOLUTION

To assess the actual concept of issue, we exhibited physical non-dimensional parameters specifically, the Magnetic parameter, Prandtl number, Thermal radiation parameter, Thermal Grashof number, Mass Grashof number, Chemical reaction parameter, Schmidt number, heat generation parameter, order of chemical reaction and Eckert number to attain the impacts of these parameters on dimensionless velocity, temperature and concentration distributions. The fixed non-dimensional parameter values as

M=0.5; β=0.5; Gr=3.0; Gc=3.0; Sc=0.6; K=0.3; Ec=0.1; fw =1.0; R=0.5; Pr=0.71; n=1.0; S=0.1.

4.1 Velocity and Temperature description for Magnetic parameter (M), Prandtl number (Pr), Grashof number (Gr and Gc) and Casson fluid parameter (β):

Fig.1- 10 clearly gives the information about the impact of Magnetic parameter (M), Prandtl number (Pr), thermal and mass Grashof number (Gr and Gc) on the dimensionless velocity and temperature profiles. Fig.1&2 It is observed that greater values of M reduce the velocity boundary layer thickness shorter and increases the temperature distribution. Fig.3&4 shows that the ascent in Pr results falls in the both velocity and temperature distribution due to heat defuse from the sheet faster than for higher Pr. Fig.5-8 outlines that the fluid velocity progresses with increase in thermal and mass grashof numbers (Gr and Gc) due to the enhancement of thermal buoyancy force. but an opposite result obtained for temperature distribution for both parameters.Fig.9&10 an expansion in β leads to reduce the velocity boundary layer thickness and improves the thermal flow field due to more viscous with mounting β.

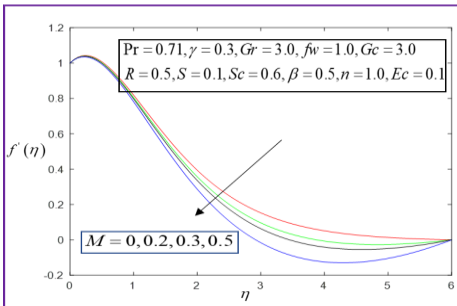

Fig.1 velocity description for different values of M

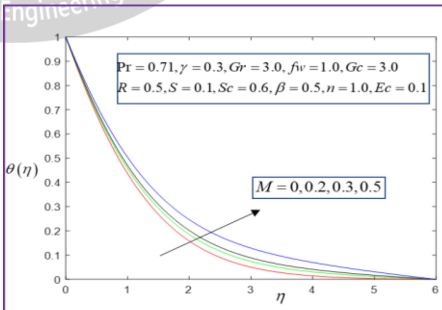

Fig.2Temperature description for different values of M

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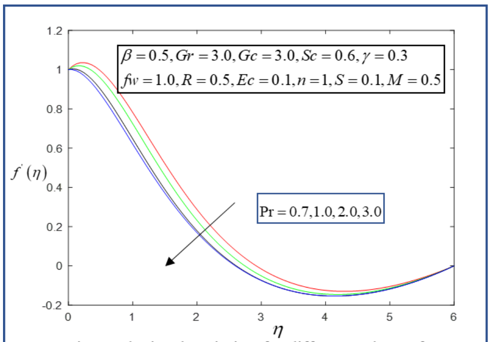

Fig.3 Velocity description for different values of Pr

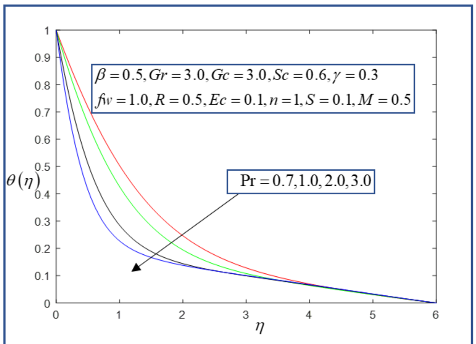

Fig4.Temperature description for different values of Pr

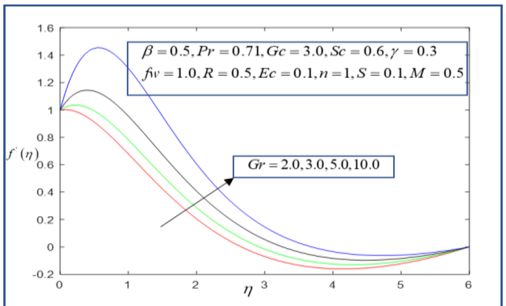

Fig5.Velocity description for different values of Gr

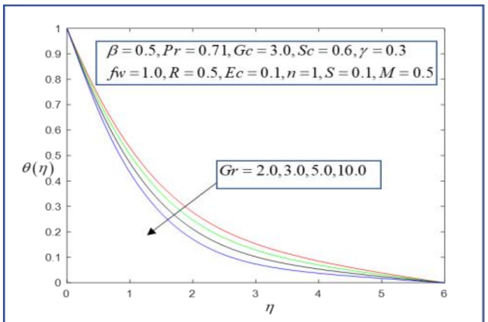

Fig6.Temperature description for different values of Gr

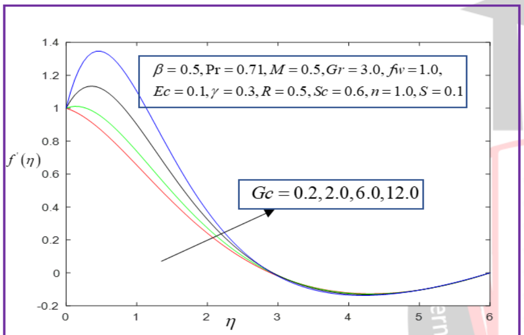

Fig.7Velocity description for different values of Gc

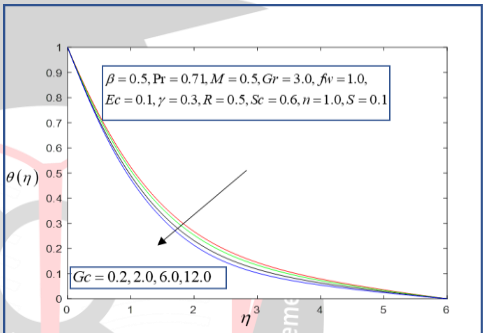

Fig8.Temperature description for different values of Gc

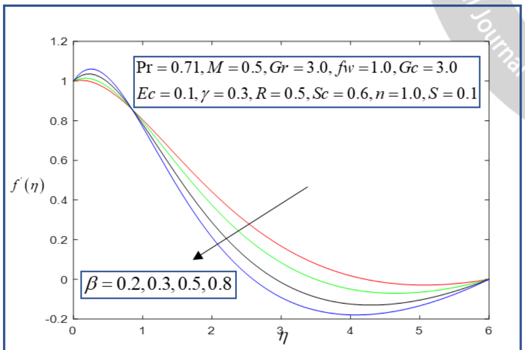

Fig.9 Velocity description for different values of β

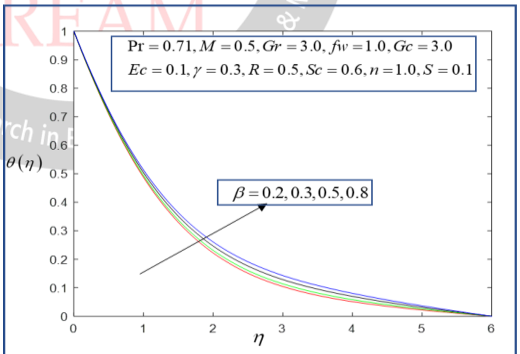

Fig.10 Temperature description for different values of β

4.2 Velocity, temperature and concentration description for Schmidt number (Sc), Radiation parameter (R):

Fig.11-13 speaks to the effect of the Sc on velocity, temperature and concentration distributions. It is noticed that the ascent in the Sc prompts a fall in the velocity and concentration profiles and rise in temperature profile due to the heavier diffusing species have a greater retarding effect on the velocity and concentration profiles of the flow field. Fig.14 elucidates that an increase in the radiation parameter results to an increasing temperature within the boundary layer.

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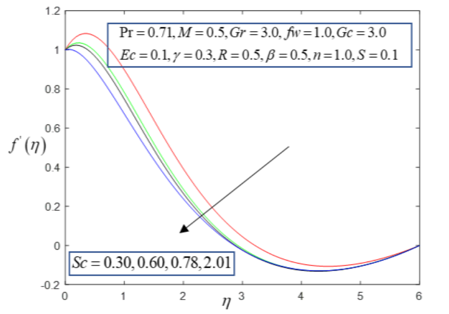

Fig.11 Velocity description for different values of Sc

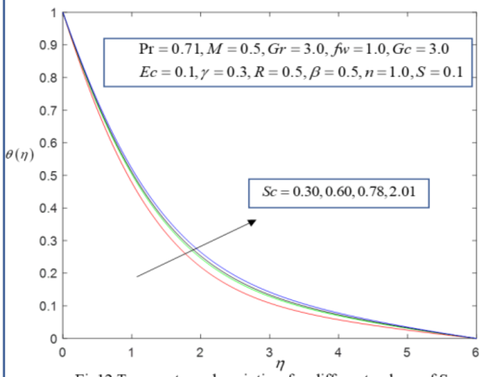

Fig12.Temperature description for different values of Sc

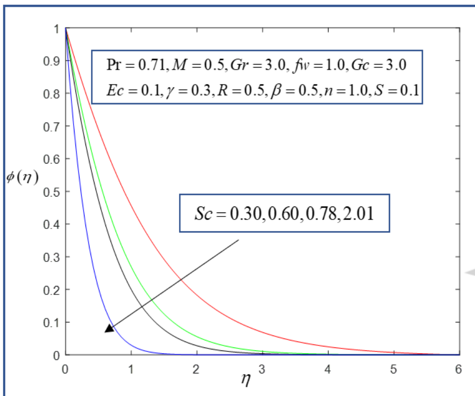

Fig.13 concentration description for different values of Sc

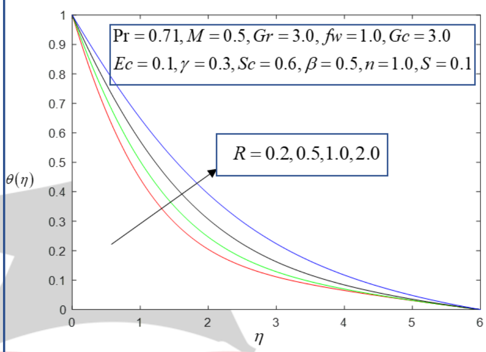

Fig.14Temperature description for different values of R

4.3 Velocity and Temperature description for Eckert number (Ec) and Heat generation parameter (S):

Fig.15-18 portrays the impact of Ec and S on velocity and temperature profiles. Escalating values of Ec and S upgrades the both momentum and thermal boundary layer thickness. Heat generation parameter in the fluid expands the temperature.

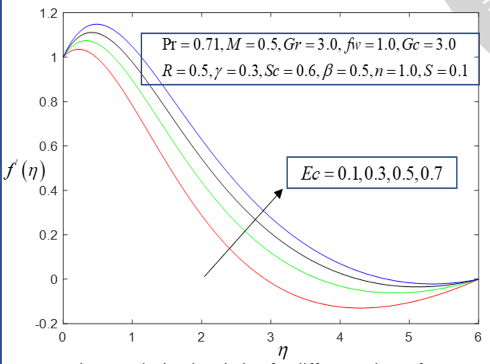

Fig.15 Velocity description for different values of Ec

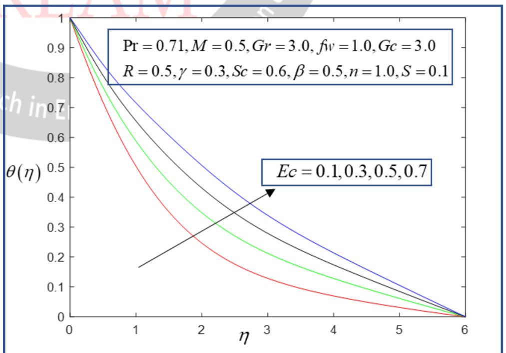

Fig.16 Temperature description for different values of Ec

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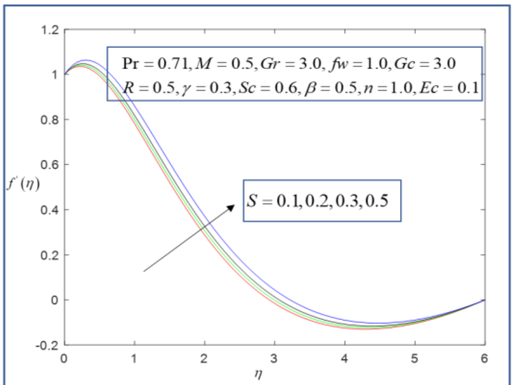

Fig.17 Velocity description for different values of S

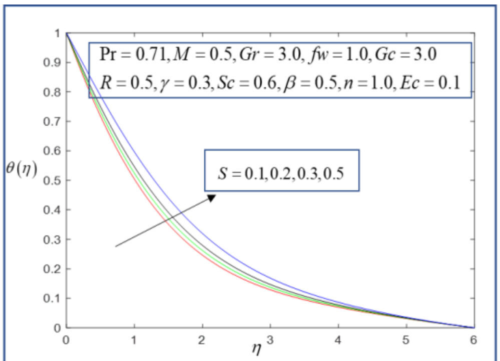

Fig.18 Temperature description for different values of S

4.4 Concentration description for Chemical reaction parameter (γ) and order of chemical reaction (n):

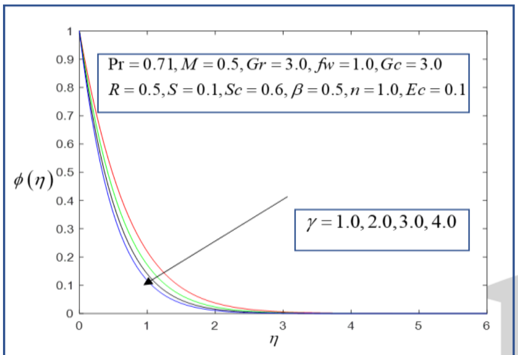

Fig.19 Concentration description for different values of γ

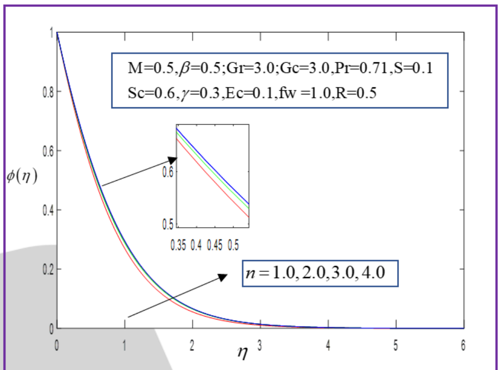

Fig.20 Concentration description for different values of n

Fig.19 &20 indicates the disparity of the concentration profile for various values of γ and n. An augment in γ caused a decrese in concentration profile due to a destructive reaction greater than zero reduces the concentration profile while the opposite inclination is observed with a rise in order of chemical reaction(n).

Table1: Numerical values of $\left(1+\frac{1}{\beta}\right)f''(0), -\theta'(0)$ **and** $-\phi'(0)$ **for various parameters**

M	B	Gr	Gc	Pr	Sc	R	Ec	S	N	$\left(1+\frac{1}{\beta}\right)f''(0)$	$-\theta'(0)$	$-\phi'(0)$
0.2	0.5	3.0	3.0	0.71	0.6	0.5	0.1	0.1	1.0	1.07550	0.68808	1.12745
0.3										1.05751	0.67090	1.12616
0.5										1.02255	0.62603	1.12325
	0.2									0.49669	0.64657	1.12210
	0.3									0.78324	0.63918	1.12236
	0.8									1.16099	0.61311	1.12452
		2.0								0.26700	0.58728	1.10397
		5.0								2.40652	0.66652	1.15395
		10								5.55549	0.67236	1.21116
			2.0							0.54180	0.61726	1.11422
			6.0							2.46711	0.64037	1.14775
			12							5.18022	0.62901	1.18856
				1.01						0.76261	0.79746	1.11373
				2.0						0.34044	1.32665	1.09999
				3.0						0.14168	1.83309	1.09475
					0.30					1.56633	0.66085	0.69806
					0.78					0.83433	0.61705	1.35653
					2.01					0.27362	0.59976	2.79134
						0.2				0.81801	0.75488	1.11571
						1.0				1.28526	0.50434	1.13314
						2.0				1.62912	0.38725	1.14601
							0.3			1.46362	0.50697	1.14093
							0.5			1.78752	0.40293	1.15280
							0.7			2.06614	0.29589	1.16251

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								0.2		1.09832	0.58131	1.12325
								0.3		1.17995	0.53361	1.12907
								0.5		1.36315	0.42764	1.13566
									2.0	1.07268	0.62881	1.07989
									3.0	1.08685	0.62933	1.06187
									4.0	1.09294	0.62951	1.05182

IV. CONCLUSION

We employ a numerical scheme to inspect the solutions of Casson fluid throughout a nonlinear permeable stretching sheet with higher order chemical reaction. This conservation forms mass, momentum and energy is converted into nonlinear ODE's by using suitable similarities. MATLAB bvp4c has been utilizing to obtain the solution of these equations. Actually, the effects of Magnetic parameter, Casson parameter, thermal and mass grashof number, radiation parameter, heat generation parameter, order of chemical reaction, Schmidt number, prandtl number, Eckert number and chemical reaction parameter is considered in particular and the results are scrutinized graphically. The major determination of this article can be reviewed as follows:

- Greater values of M reduce the velocity boundary layer thickness shorter and increases the temperature distribution. An ascent in Pr results falls in the both velocity and temperature distribution.
- The fluid velocity progresses with increase in thermal and mass grashof numbers (Gr and Gc). but an opposite result obtained for temperature distribution for both parameters.
- β leads to reduce the velocity boundary layer thickness and improves the thermal flow field. An ascent in the Sc prompts a fall in the velocity and concentration profiles and rise in temperature profile.
- An increase in the R results to an increasing temperature within the boundary layer. Escalating values of Ec and S upgrades the both momentum and thermal boundary layer thickness.
- An augment in γ caused a decrese in concentration profile and an opposite inclination is observed with a rise in order of chemical reaction(n).

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