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Thermophoresis, Brownian Motion and Binary Chemical Reaction On Casson Fluid Flow Over A Permeable Stretching Sheet

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Abstract

Current study examines the consequences of thermophoresis, Brownian motion on non-newtonian Casson liquid stream along a porous extending sheet. Binary chemical reaction is also under consideration. The primary structure of partial differential equations attained within the form of momentum, energy and concentration equations. For a self-comparable arrangement, the system of governing PDEs assimilated into the set of nonlinear ordinary differential equations by applying suitable similarity transformation. Resulting nonlinear Ordinary differential equations are effectively solved via MATLAB bvp5c. All obtained unknown functions are discussed in detail after plotting the numerical consequences against different arising physical parameters.

Keywords: Thermophoresis, Brownian motion, non-newtonian fluid, Arrhenious function, Binary Chemical reaction, MATLAB bvp4c.

1.INTRODUCTION

The idea of non-Newtonian fluid flow over a permeable stretching surface with binary chemical reaction has emerge as a field of energetic research for the last few decades because of its huge variety of applications in era and industry. Owing to their enhanced features, non-newtonian fluids have immense applications in synthetic fibers, warm rolling, cooling of metallic sheets or electronic chips and a lot more. Mittal and Patel [1] had considered two dimensional Casson fluid flow with thermophoresis and Brownian motion effects using HAM method. Anjum et al. [2] and Malek et al. [3] reported binary chemical reaction effects on MHD flow utilizing HAM technique. Activation energy and binary chemical reaction effects in mixed convective nanofluid flow was examined by Dhalamini et al. [4] using spectral quasi-linearization technique. Vijayaragavan [5] have analysed thermophoresis and Brownian motion effects on MHD non-newtonian Casson fluid flow past a nonlinear stretching sheet. Mabood et al. [6] using analytical technique to explore the characteristics of thermophoresis and Brownian motion on micropolar fluid flow towards continuously moving flat plate. Rafique et al. [7] had considered Buongiorno Model with Brownian and Thermophoretic Diffusion for Casson Nanofluid over an Inclined Surface using Keller-Box method. Reddy et al. [8] solved the problem of an unsteady MHD nanofluid flow by utilizing the R-K Fehlberg numerical technique. Gopal and Kishan [9] had given a mathematical model to look into the problem of MHD Casson nanofluid over a chemically reacting stretching sheet with inclined magnetic field. Heat and Mass transfer analysis of Casson fluid flow was examined by Raju et al. [10]. Mehta and Kataria [11] determined the effects of Brownian motion and thermophoresis on MHD

viscoelastic fluid flow over stretching /shrinking sheet. Reza et al. [12] characterized the effects of heat and mass transport on MHD time dependent casson fluid flow over a stretching sheet using Explicit Finite Difference method. Numerical analysis of

MHD Non-Newtonian Fluid over a Stretching Sheet with Thermophoresis and Brownian Moment was developed by Avinash et al. [13]. Sreedivya et al. [14] adopted R-K fifth order method to report the convective flow past a permeable stretching sheet. Ullah et al. [15] studied an electrically conducting mixed convection flow of Casson fluid induced by moving wedge using Keller-Box scheme. Kho et al. [16] investigated Thermal Radiation Effects on MHD with Flow Heat and Mass Transfer in Casson Nanofluid over a Stretching Sheet. Reddy et al. [17] had observed the theoretical study of two-dimensional MHD convective boundary layer flow of a Casson fluid over an exponentially inclined permeable stretching surface in the presence of thermal radiation and chemical reaction using Shooting technique with Fourth order R-K method. The problem of heat transport effects on Casson fluid flow due to an exponentially stretching surface was considered by Sharada and Shankar [18] using Finite difference scheme. Dual Solutions of Non-Newtonian Casson Fluid Flow over an Exponentially Permeable Shrinking Sheet with Viscous Dissipation was developed by Zaib et al. [19]. Dessie [20] and Mehmood et al. [21] discussed stagnation point flow of casson fluid over a stretching surface utilizing numerical shooting technique. A numerical investigation is performed by Reddy et al. [22] and Abbas et al. [23] to analyze the binary chemical reaction on non-newtonian fluid flow. Yesodha et al. [24] explored the problem of MHD Convective heat and mass transfer of chemically reacting fluids with activation energy with radiation and heat generation. Three dimensional MHD slip flow of nanofluid over a stretching sheet were examined by Babu and Sandeep [25]. Hazarika and Ahmed [26] developed numerical investigation of micropolar nanofluid with Brownian motion and thermophoresis effect. Srinivasa babu et al. [27] addressed the MHD convective flow of Carreau nanofluid with activation energy and viscous dissipation using Shooting based R-K 4th order technique. Numerical analysis of MHD Casson and Williamson fluid flow was explained by Kumaran and Sandeep [28]. Naramgari and Sulochana [29] established MHD nanofluid flow over a permeable stretching/shrinking sheet. Gireesha et al. [30] and Anantha Kumar et al. [31] had examined the stagnation point flow over an elastic sheet under the consideration of thermal radiation, chemical reaction and non-uniform heat source/sink.

The leading motivation of the present work is to investigate the two-dimensional examination for the Casson fluid model conceited the permeable stretching sheet with Binary chemical reaction. Moreover, the thermophoresis and Brownian motion effects are examined. Using suitable similarity transformations, the system of nonlinear partial differential equations reduced to the system of nonlinear ordinary differential equations. Nondimensionalized corporeal constraints particularly thermophoresis parameter, Brownian motion parameter, Activation energy, Chemical reaction rate constant, Schmidt number and Fitted rate constant parameter appear after applying the suitable similarity modifications. Nonlinear coupled equations are then tried numerically to get the solutions, after which, fleshly behaviors of each of the parameter are exposed graphically.

2. FORMULATION OF THE PROBLEM

In order to formulate the governing equations for the present flow problem, the following assumptions have been made:

- Time independent, laminar, 2D, incompressible boundary layer flow. Here x-axis is taken along the direction of the plate and y-axis is normal to it.
- Heat and mass transfer with nonlinear thermal radiation, Binary chemical reaction, thermophoresis, Brownian motion are also taken into account.
- A constant magnetic field of magnitude B0 is applied in y-direction. Dual forces are introduced along the x-axis so that the sheet is stretched keeping the origin fixed y=0. The fluid temperature and species concentration near the sheet are T_w and C_w respectively, whereas the ambient fluid temperature and species concentration are T_∞ and C_∞ respectively.

Based on above introduced assumptions the ruling equations in the succeeding forms:

Continuity Equation

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

Momentum Equation

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

Temperature Equation

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

Concentration Equation

$$uC_x + vC_y = D_B C_{yy} + \frac{D_T}{T_\infty}T_{yy} - k_r^2\left(\frac{T}{T_\infty}\right)^m \exp\left(\frac{-E_a}{KT}\right)\left(C-C_\infty\right) \quad (4)$$

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_r^2 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, ρ is refer to fluid density, cp is refer to specific heat at constant pressure, D_B, D_T is refer to Brownian motion and thermophoresis parameter, β is refer to Casson fluid parameter. The boundary conditions are specified like

$$u = \xi x, v = v_w, T = T_w, C = C_w \quad D_B\frac{\partial C}{\partial y} + \frac{D_T}{T_\infty}\frac{\partial T}{\partial y} = 0 \quad \text{at } y = 0$$

$$u \to 0, T \to T_\infty, C \to C_\infty \quad \text{as } y \to \infty \quad (5)$$

In order to transform equations (1)-(4) to the nondimensional form, the following transforms are applied

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

$$u = \xi x f'(\eta) \qquad v = -\sqrt{\xi \upsilon}\, f(\eta) \quad (6)$$

Substituting equation (6) in (1)-(4) equation (1) is automatically satisfied. The laws of conservation of momentum, energy and concentration converted into

$$\left(1+\frac{1}{\beta}\right)f''' + ff'' - f' - M\left(f'-1\right) + Gr\theta + Gc\phi = 0 \quad (7)$$

$$\frac{1}{Pr}\left(1+\frac{4}{3}R\right)\theta'' + f\theta' + Ec\left(1+\frac{1}{\beta}\right)f''^2 + EcM\left(f'-1\right)^2 + Nb\phi'\theta' + Nt\theta'^2 + S\theta = 0 \quad (8)$$

$$\phi'' + Scf\phi' + \frac{Nt}{Nb}\theta'' - Sc\sigma\left(1+\delta\theta\right)^m \exp\left(\frac{-E}{(1+\delta\theta)}\right)\phi = 0 \quad (9)$$

Boundary conditions are given by

$$\eta = 0: \quad f(0) = f_w, f'(0) = 1, \theta(0) = 1, \phi(0) = 1, \; Nb\phi' + Nt\theta' = 0$$

$$\eta \to \infty: \quad f(\infty)=0, \theta(\infty)=0, \phi(\infty)=0 \tag{10}$$

where Nb stands for brownian motion parameter, Nt stands for thermophoresis parameter, 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, σ stands for the Chemical reaction rate parameter, E stands for an activation energy, δ stands for temperature relative parameter, Sc stands for the Schmidt number, S stands for the heat generation parameter, m stands for the fitted rate constant and *Ec* stands for the Eckert number and they are defined as

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

$$Ec=\frac{u^2}{c_p(T_w-T_\infty)}, Sc=\frac{\upsilon}{D}, \sigma=\frac{k_r^2}{\zeta}, \Pr=\frac{\mu c_p}{k}, f_w=-\frac{\nu_w}{\sqrt{\xi\upsilon}}$$

$$Nb=\frac{\tau D_B(C_w-C_\infty)}{\upsilon}, Nt=\frac{\tau D_T(T_w-T_\infty)}{\upsilon T_\infty}, E=\frac{E_a}{T_\infty}, \delta=\frac{T_w-T_\infty}{T_\infty}$$

An Undimensioned mode the skin-friction, heat and Mass transfer coefficients are given by

$$\mathrm{Re}_x^{1/2} C_f=\left(1+\frac{1}{\beta}\right) f''(0) \tag{11}$$

$$\mathrm{Re}_x^{-1/2} Nu_x=-\theta'(0) \tag{12}$$

$$\mathrm{Re}_x^{-1/2} Sh_x=-\phi'(0) \tag{13}$$

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

3.RESULTS AND DISCUSSION

This section is displayed to captivate the focus of researchers by exploring the impact of adopted parameters on transport equations. The requisite partial differential equations under the frame work of two-dimensional MHD flow over a permeable stretching sheet with Casson fluid are transmuted into nonlinear ODE by implementing appropriate similarity transformations and then solved numerically using MATLAB package bvp5c. The influence of various parameters namely, Thermophoresis parameter (Nt), Brownian motion parameter (Nb), Activation energy (E), Temperature relative parameter (δ), Chemical reaction rate constant (σ), Fitted rate constant (m) and Schmidt number (Sc). The obtained computational results are presented graphically in Fig.1-12 and the variations in velocity, temperature and concentration fields are discussed.

3.1 Thermophoresis parameter (Nt) and Brownian motion parameter (Nb):

Fig.1 - Fig.5 plots the velocity, temperature and Concentration profiles for varying Thermophoresis parameter (Nt) and Brownian motion parameter (Nb). From, Fig.1-Fig.3 It is apparent that for escalating values of Thermophoresis parameter (Nt) consequences decay in the thermal flow field but we notice an opposite result in the field of velocity and concentration. Generally, enhancing the values of thermophoresis parameter generates a pressure leads to move the fluid particles from the warmer region to the icy regions for which there is gain in the heat transfer rates. A growth in Brownian motion parameter (Nb) enhancing the thermal flow field. Larger Nb generates extra Brownian diffusion with much less viscous forces, which ultimately enhances the temperature of the fluid. However, a contrary influence is presented in the concentration flow field.

3.2 Activation energy (E), Temperature relative parameter (δ), Chemical reaction rate constant (σ) and Fitted rate constant (m):

Fig.6-Fig.9 are sketched to analyse the outcomes of Activation energy (E), Temperature relative parameter (δ), Chemical reaction rate constant (σ) and Fitted rate constant (m) on concentration fields. For upsurging values of E improves the

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concentration profile. The activation energy E will become large, the modified Arrhenius mechanism decays. This ultimately stimulates the generative chemical reaction, which causes the concentration profile to growth.Fig.7,8&9 reveals that raising the values of δ, σ and m leads to falling in ϕ(η). It is revealed that the factor $\sigma\ (1\ +\delta\theta)^m \exp\ (\ -E\ /(1+\ \delta\theta))$ complements for dominant σ. Therefore, concentration gradient enhances at the wall. Hence concentration profile diminishes. When enhances, there may be an increment in σ so automatically the liquid species terminate or dissolve and reduces concentration field ϕ (η).

3.3 Schmidt Number (Sc):

Fig.10-12 are delineated to examine the behavior of Sc on velocity, temperature and concentration profiles. we understand that, rise in Schmidt number (Sc) values the velocity and concentration fields come down rapidly whereas reverse aspect is noticed for temperature profile. The heavier diffusing species have more prominent hindering impact on the velocity and concentration for the flow field.

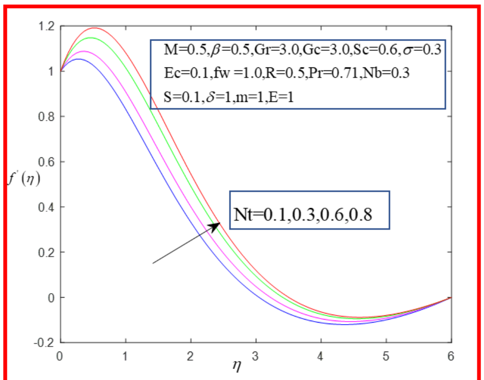

Fig.1 Profiles of velocity for different values of Nt

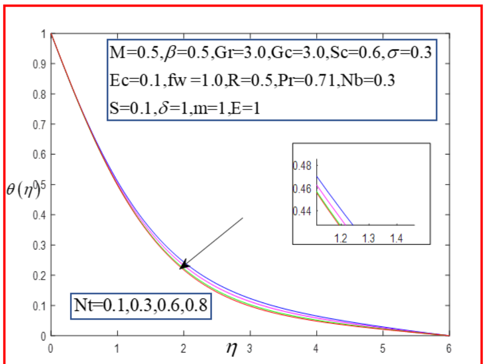

Fig.2 Profiles of temperature for different values of Nt

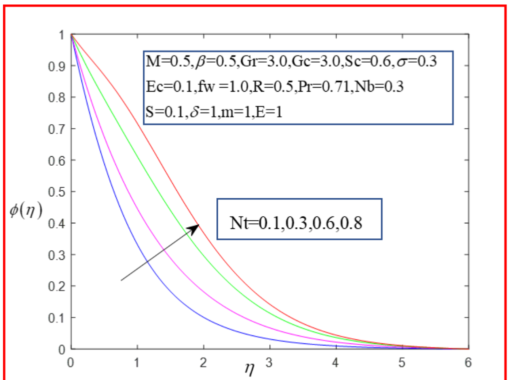

Fig.3 Profiles of concentration for different values of Nt

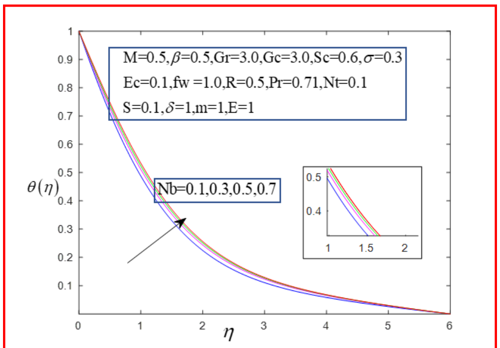

Fig.4 Profiles of temperature for different values of Nb

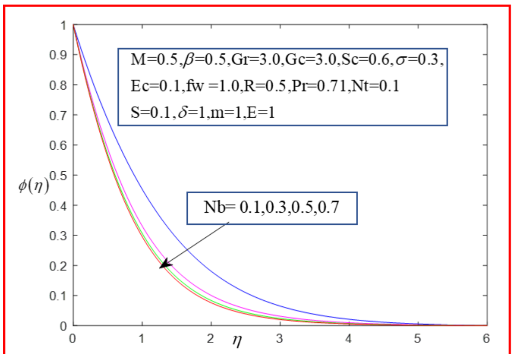

Fig.5 Profiles of concentration for different values of Nb

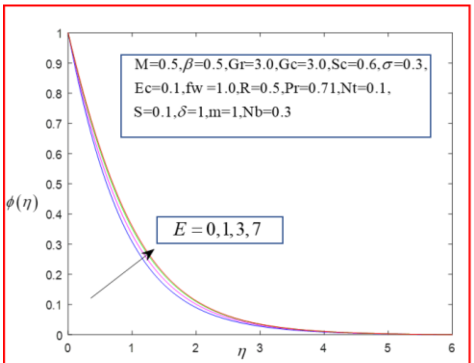

Fig.6 Profiles of concentration for different values of E

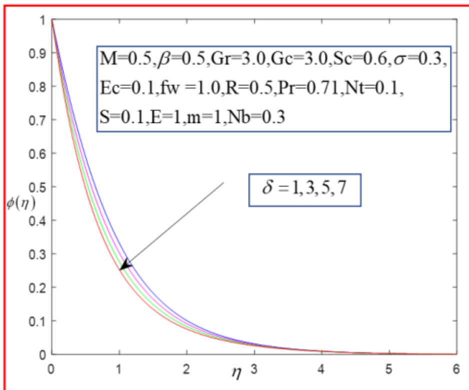

Fig.7 Profiles of concentration for different values of δ

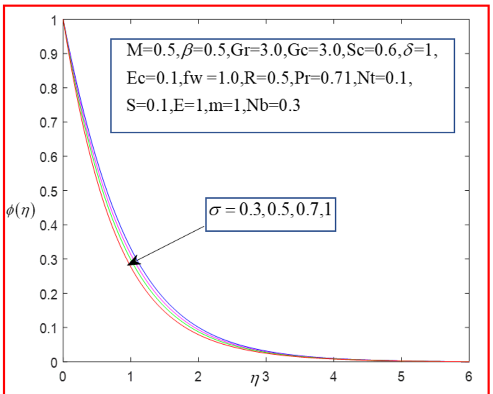

Fig.8 Profiles of concentration for different values of σ

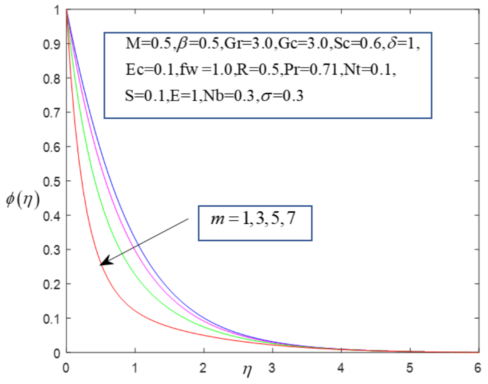

Fig.9 Profiles of concentration for different values of m

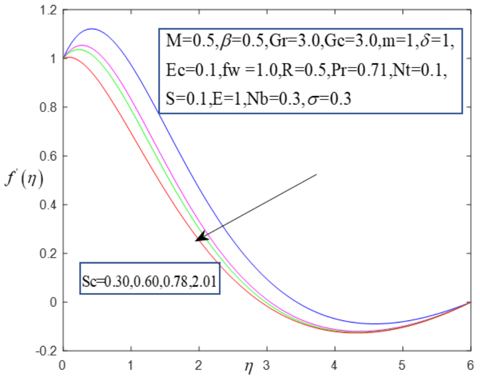

Fig.10 Profiles of velocity for different values of Sc

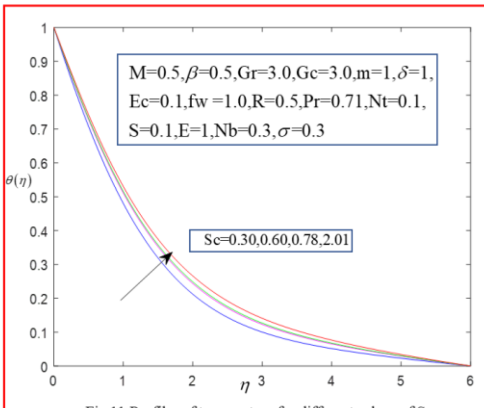

Fig.11 Profiles of temperature for different values of Sc

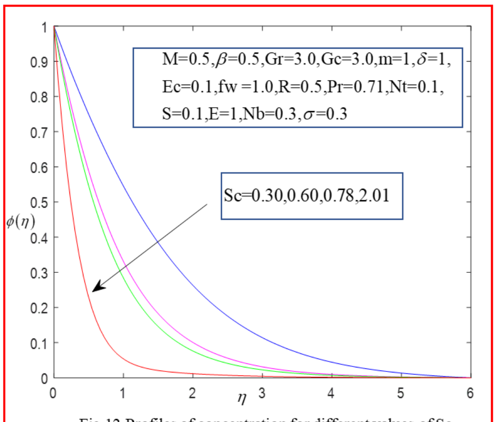

Fig.12 Profiles of concentration for different values of Sc

Table1: Numerical values of the skin-friction, Nusselt number and Sherwood Number for various parameters

M=0.5, β=0.5, Gr=3.0, Gc=3.0, Sc=0.6, σ=0.3, Ec=0.1, fw=1.0, R=0.5, Pr=0.71, Nb=0.3, Nt=0.1, S=0.1, δ=1.0, m=1.0, E=1.

Nt	**Nb**	**E**	**δ**	**σ**	**M**	**Sc**	$\left(1+\frac{1}{\beta}\right)f''(0)$	$-\theta'(0)$	$-\phi'(0)$
0.1	**0.3**	**1.0**	**1.0**	**0.3**	**1.0**	**0.60**	1.2552	0.5832	1.0080
0.3							1.6077	0.5847	0.7861
0.6							2.1059	0.5773	0.4827
	0.2						1.3294	0.6039	0.9416
	0.4						1.2243	0.5654	1.0411
	0.8						1.2085	0.5039	1.0917
		0.0					1.1872	0.5791	1.0941
		1					1.2552	0.5832	1.0080
		3					1.3140	0.5866	0.9286
			1				1.2552	0.5832	1.0080
			3				1.1710	0.5791	1.1553
			5				1.0930	0.5752	1.2967
				0.3			1.2552	0.5832	1.0080
				0.5			1.2060	0.5805	1.0808
				0.7			1.1606	0.5774	1.1501
					3		1.2552	0.5832	1.0080
					5		1.1505	0.5785	1.2306
					7		0.9163	0.5683	1.8715
						0.30	1.8976	0.6315	0.5546
						0.60	1.2552	0.5832	1.0080
						0.70	1.0347	0.5690	1.2516

4.CONCLUSIONS

In the present analysis, an attempt has been made to investigate the consequences of thermophoresis, Brownian motion on non-newtonian Casson liquid flow along a porous extending sheet under the consideration of Binary chemical reaction and activation energy. This has packages in putting off small particles from fuel streams and determining exhaust fuel projectiles. The modern-day research may additionally find importance in several engineering and technological approaches such as extrusion of plastic sheets, manufacture of ceramic objects, metallic plat cooling, polymer manufacturing and smelting, paper manufacturing, twine drawing, meals processing, etc. The most important effects of the prevailing research are offered beneath:

- Raising upsides of Thermophoresis parameter (Nt) consequences decay in the thermal flow field but we notice an opposite result in the field of velocity and concentration. The rate of heat and Mass transfer is reduced for implementing values of Nt.
- A growth in Brownian motion parameter (Nb) improving the thermal flow field. A contrary influence is presented in the concentration flow field. Rate of Mass transfer is increased, whereas a reduction in the magnitude of Nusselt number exists for the Nb parameter.
- For upsurging values of E further develops the concentration profile. Raising the values of δ, σ and m prompts to falling in $\phi(\eta)$.

Ascend in Schmidt number (Sc) values the velocity and concentration fields come down rapidly whereas reverse aspect is noticed for temperature profile.

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