A CASSON FLUID FLOW THROUGH AN INCLINED VERTICAL POROUS PLATE WITH THERMAL DIFFUSION

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Abstract

Magnetic field influence on thermal diffusion and chemical reaction of MHD Casson fluid flow over inclined vertical porous plates have been examined. There are coupled, coupled linear equations governing the dimensionless system. To solve these equations analytically, the perturbation approach is used. In various controlling factors, the results are displayed visually and tabulated. Our illustrations show that an intensified magnetic parameter induces a downward magnetic field. As the heat absorption increases, the temperature profile is accelerated due to higher energy levels. This can be seen in the form of higher peak temperatures and a sharper gradient in the temperature profile. On the other hand, as the chemical reaction and Schmidt number increase, the concentration distribution slows down. This is because the diffusion of the molecules is hindered by higher concentrations, resulting in a slower rate of change. This can be seen in the form of lower peak concentrations and a flatter gradient in the concentration distribution. As a result, increasing heat absorption and chemical reaction leads to a faster temperature profile and slower concentration profile.

Keywords: Magnetic Field, Casson Fluid, Slip Flow Regime, Thermal Diffusion and Chemical Reaction.

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1. INTRODUCTION

In non-Newtonian Casson fluid analysis, a shear thinning liquid at zero rate of shear has an infinite viscosity, with a yield stress below zero viscosity, and is free of flows. The fluid acts like a solid when the yield stress is more than the shear stress, however when the yield stress is less than the shear stress, the fluid begins to flow. Few examples of Casson fluids are sauce made from tomatoes, jelly-like substance, saturated juice from fruits, honey, and the blood etc. The effects of mass transfer on the MHD Casson fluid flow with a chemical reaction were reported by Shehzad et al. [1]. Vajravelu et al. [2] examined the dispersion of chemically reactive species over a porous, unstable stretched surface in the Casson fluid flow. The heat transfer and boundary layer flow of a Casson fluid through an oscillating Newtonian heating system with a vertical plate were explored by Abid et al. [3]. An unstable MHD Casson fluid pasta permeable semi-infinite vertical moving plate with a heat source/sink was investigated by Sekhar et al. [4]. The effects of thermal conductivity, variable viscosity, and thermophoresis in non-Darcian non-Darcian MHD convection of dissipative Casson fluid flow with nth order chemical reaction were proved by Animasaun [5]. The effects of radiation and chemical reactions on fluids have drawn the attention of several researchers. The impact of radiation absorption on the MHD dissipative fluid flowing through a vertical porosity plate submerged in porous media was examined by Obulesu et al. [6]. Obulesu et al. have addressed the effects of the absorption of radiation and chemical reactions on the MHD thermal radiation source/sink fluid across a vertical porous plate. [7]. Obulesu et al. have addressed the effects of an angled magnetic field and radiation absorption on the mixed convection flow of a chemically reacted and radiating fluid via a semi-infinite porous plate. [8]. Obulesu et al. [9] have addressed the effects of joule-based heating and thermal diffusion on MHD fluid flow over a vertical porous plate immersed in a porous medium. The effects of heat source and thermal radiation on MHD flow via porous stratum over a permeability stretched sheet with chemical reaction were depicted by Suneetha et al. [10]. Hall current impacts on MHD convective flow via a porous plate with heat radiation, chemical reaction, and thermophoresis were established by Obulesu et al. [11]. A vertical porous tube with contraction and expansion was used by Vijaya et al. [12] to investigate the effects of radiation and Soret on erratic Casson fluid flow. The numerical computations of unsteady transfer of heat flow caused by MHD across a surface that is stretched with the injection or suction were provided by Ramana Reddy et al. [13]. Dastagiri et al. reported the influence of many factors on the MHD transient flow via a plate in their study [14]. An unsteady MHD flow through a porous medium between two porous vertical plates has been studied by Raghunath et al. [15]. Obulesu et al. [16] discussed the impact of the hall current on MHD convective flow via a porous plate with heat radiation, chemical reaction, and radiation absorption. Sandhya et al. [17] had explained steady flow of MHD involving radiation occurrence and including the influence of the heat source on a porous material. Das et al. [18] have made an effort to examine the diverse effects on Casson fluid, such as chemical reaction, heat absorption, and thermal radiation. The existence of thermal radiation on MHD viscoelastic fluid, including species concentration, was briefly demonstrated by Vijay Kumar [19]. Obulesu et al. [20] created the MHD double diffusive visco-elastic flow of fluid through an infinite vertical porous plate under the impact of radiation absorption. By connecting momentum, energy, and mass with one another using the diffusion equation, Raghunath and Obulesu [21] provided a vivid illustration of the chemical reaction on unstable MHD through the Casson fluid. Jayalakshmi et al. [22] chose to look at the Sisko fluid in order to look at the fluid flow characteristics. Raghunadh et al.'s [23] observations of various MHD flow effects led to several conclusions regarding the flow parameters, which also took into account radiation impacts. Yu-Ming et al.'s [24] research looked at how thermal effects on a plate affected nano fluid characteristics. According to Gangadhar et al. [25], Casson flow of fluid on the shrinking sheet offers dual solutions.

2. FORMULATION IN MATHEMATICS

A two-dimensional study is conducted on the motion of an incompressible viscous fluid across an infinite vertical porous plate with erratic free convection flow. We create a rectangular Cartesian coordinate system using the x-axis parallel to the plate according to the direction of flow and the y-axis perpendicular to it. When a heat source with a temperature gradient is present, the flow is also considered. The analysis of a magnetic Reynolds value assumes that the induced magnetic field is negligible, so viscous dissipation and Darcy's dissipation are disregarded for the low velocities of the flow. The sole cause of the flow in the medium is the buoyancy force caused by the ambient temperature difference between the fluid and the porous plate. The equations governing the conservation of mass, momentum and energy are derived from the Navier-Stokes equations and the continuity equation. The conservation equations are expressed as follows under the abovementioned assumptions.

$$\frac{\partial v^*}{\partial y^*} = 0 \tag{1}$$

$$\frac{\partial u*}{\partial t*}+V*\frac{\partial u*}{\partial y*}=\vartheta(1+\frac{1}{\beta})\frac{\partial^2 u*}{\partial y*^2}+g\beta_T(T*-T_\infty^*)\cos\alpha$$
$$+g\beta_c(C*-C_\infty^*)\cos\alpha-\frac{\sigma B_0^2}{\rho}u*-\frac{\vartheta u*}{K^*} \tag{2}$$

$$\frac{\partial T*}{\partial t*}+V*\frac{\partial T*}{\partial y*}=\frac{K_T}{\rho C_p}\frac{\partial^2 T*}{\partial y*^2}-\frac{1}{\rho C_p}\frac{\partial q_r*}{\partial y*}-\frac{Q_1}{\rho C_p}(T*-T_\infty^*) \tag{3}$$

$$\frac{\partial C*}{\partial t*}+V*\frac{\partial C*}{\partial y*}=D\frac{\partial^2 C*}{\partial y*^2}-K_c^*(C*-C_\infty^*)+D_1\frac{\partial^2 T*}{\partial y*^2} \tag{4}$$

Where $L_1= (2-M_x)/ M_x$ (5)

Assuming that $V^* = - U_0 (1+\varepsilon e^{-n^*t^*})$, since the equation of continuity indicates that V*is either a constant or some function of time.

$V^* = - U_0 (1+\varepsilon e^{-n^*t^*})$ (6)

Here the suction velocity is acting towards the plate, as shown by the negative sign.
Consider the optically thin, low-density fluid, where the radioactive heat flux is provided by the following expression.

$$\frac{\partial q_r*}{\partial y*}=4I^*(T*-T_\infty^*) \tag{7}$$

In a non-dimensional form, the permeability of the porous media is taken to be

$K^* = K_0^* (1+\varepsilon e^{-n^*t^*})$ (8)

By introducing the following non-dimensional quantities,

$$u=\frac{u*}{U_0},y=\frac{U_0y*}{\vartheta},T=\frac{T*-T_\infty^*}{T_w^*-T_\infty^*},C=\frac{C*-C_\infty^*}{C_w^*-C_\infty^*},\Pr=\frac{\mu C_p}{K_T},Sc=\frac{\vartheta}{D},M=\frac{\sigma B_0^2\vartheta}{\rho U_0^2},$$
$$Gr=\frac{\vartheta g\beta_T(T_w^*-T_\infty^*)}{U_0^3},Gm=\frac{\vartheta g\beta_c^*(C_w^*-C_\infty^*)}{U_0^3},\quad K=\frac{U_0^2K_0^*}{\vartheta^2},t=\frac{t*U_0^2}{4\vartheta},h=\frac{U_0^2L_1}{\vartheta},$$
$$K_C=\frac{\vartheta K_C^*}{U_0^2},R=\frac{4I^*\vartheta}{\rho C_p v_0^2},Q=\frac{Q_1v}{U_0^2},S_0=\frac{D_1(T_w^*-T_\infty^*)}{\vartheta(C_w^*-C_\infty^*)},R=\frac{4\vartheta n^*}{U_0^2}$$

The governing equations (1) to (4) can be rewritten in the non-dimensional form as follows

$$\frac{1}{4}\frac{\partial u}{\partial t}-(1+\varepsilon e^{-nt})\frac{\partial u}{\partial y}=(1+\frac{1}{\beta})\frac{\partial^2 u}{\partial y^2}+Gr\cos\alpha\,T+Gm\cos\alpha\,C-M_1u \tag{9}$$

$$\frac{\Pr}{4}\frac{\partial T}{\partial t}-\Pr(1+\varepsilon e^{-nt})\frac{\partial T}{\partial y}=\frac{\partial^2 T}{\partial y^2}-\Pr n_1 T \tag{10}$$

$$\frac{Sc}{4}\frac{\partial C}{\partial t}-Sc(1+\varepsilon e^{-nt})\frac{\partial C}{\partial y}=\frac{\partial^2 C}{\partial y^2}-ScK_C C+So\frac{\partial^2 T}{\partial y^2} \tag{11}$$

Where $n_1=R+Q$,
The corresponding boundary conditions are given by

$$u=h(\frac{\partial u}{\partial y}),\quad T=1,\quad C=1,\quad at\quad y=0$$
$$u\to 0,\quad T\to 0,\quad C\to 0\quad as\quad y\to\infty \tag{12}$$

Solution of the Problem
We convert the partial differential equations (9), (10), and (11) into ordinary differential equations before solving them. We use the Gersten and Gross method to arrive at the answer. We therefore assume that velocity, temperature, and concentration formulas take the following form**.**

$$U(y,t)=F_0(y)+\varepsilon F_1(y)e^{-nt}$$
$$T(y,t)=G_0(y)+\varepsilon G_1(y)e^{-nt}$$
$$C(y,t)=H_0(y)+\varepsilon H_1(y)e^{-nt} \tag{13}$$

The following set of ordinary differential equations is created by substituting the aforementioned expressions

(13) into Eqs (9), (10), and (11) and equating the coefficient of ε^0 and ε^1 (while ignoring ε^2 terms, etc.).
Zero order terms:

$$(1+\frac{1}{\beta})F_0''+F_0'-\mathrm{M_1F_0}=-\mathrm{Gr}\cos\alpha\ G_0-\mathrm{Gm}\cos\alpha\ H_0 \tag{14}$$

$$G_0''+\Pr G_0'-\Pr\ n_1\ \mathrm{G_0}=0 \tag{15}$$

$$H_0''+Sc\ H_0'-\mathrm{ScK}c H_0=-\mathrm{S_0\ Sc}\ G_0'' \tag{16}$$

First order terms:

$$(1+\frac{1}{\beta})F_1''+F_1'+\mathrm{M_2F_1}=-\mathrm{Gr}\cos\alpha\, G_1-\mathrm{Gm}\cos\alpha\, H_1-F_0' \tag{17}$$

$$G_1''+\Pr G_1'+(\frac{n\Pr}{4}-n_1\Pr)G_1=-\Pr G_0' \tag{18}$$

$$H_1''+ScH_1'+Sc(\frac{n}{4}-Kc)H_1=-S_0ScG_1''-ScH_0' \tag{19}$$

As a result, boundary conditions (12) are reduced to

$$F_0=h(\frac{\partial F_0}{\partial y}),F_1=h(\frac{\partial F_1}{\partial y}),\ G_0=1,\ G_1=0,\quad H_0=1,H_1=0\quad at\quad y=0$$
$$F_0\to 0,\quad F_1\to 0,\quad G_0\to 0,G_1\to 0,\ H_0\to 0,H_1\to 0\quad as\quad y\to\infty \tag{20}$$

Using equations (14) to (19) and boundary conditions (20), the following solutions are obtained.

$$G_0=\exp(-l_1 y) \tag{21}$$

$$H_0 = b_1 \exp(-l_1 y) + b_2 \exp(-l_2 y) \tag{22}$$

$$F_0 = b_3 \exp(-l_1 y) + b_4 \exp(-m_2 y) + b_5 \exp(-l_3 y) \tag{23}$$

$$G_1 = b_6 \exp(-l_1 y) - b_6 \exp(-l_4 y) \tag{24}$$

$$H_1 = b_7 \exp(-l_1 y) + b_8 \exp(-l_2 y) + b_9 \exp(-l_4 y) + b_{10} \exp(-l_5 y) \tag{25}$$

$$F_1 = b_{11} \exp(-l_1 y) + b_{12} \exp(-l_2 y) + b_{13} \exp(-l_3 y) + b_{14} \exp(-l_4 y) + b_{15} \exp(-l_5 y) + b_{16} \exp(-l_6 y) \tag{26}$$

A velocity temperature concentration field can be derived by substituting equations (21)-(26) into equation (13).

$$U(y,t) = b_3 \exp(-l_1 y) + b_4 \exp(-m_2 y) + b_5 \exp(-l_3 y) + \varepsilon(b_{11} \exp(-l_1 y) + b_{12} \exp(-l_2 y) + b_{13} \exp(-l_3 y) + b_{14} \exp(-l_4 y) + b_{15} \exp(-l_5 y) + b_{16} \exp(-l_6 y))e^{-nt} \tag{27}$$

$$T(y,t) = \exp(-l_1 y) + \varepsilon(b_6 \exp(-l_1 y) - b_6 \exp(-l_4 y))e^{-nt} \tag{28}$$

$$C(y,t) = b_1 \exp(-l_1 y) + b_2 \exp(-l_2 y) + \varepsilon(b_7 \exp(-l_1 y) + b_8 \exp(-l_2 y) + b_9 \exp(-l_4 y) + b_{10} \exp(-l_5 y))e^{-nt} \tag{29}$$

Skin friction:
At the surface, non-dimensional skin friction is given by

$$\tau = \left(\frac{\partial U}{\partial y}\right)_{y=0}$$

$$\tau = -(l_1 b_3 + l_2 b_4 + l_3 b_5) - \varepsilon(l_1 b_{11} + l_2 b_{12} + l_3 b_{13} + l_4 b_{14} + l_5 b_{15} + l_6 b_{16})e^{-nt} \tag{30}$$

Rate of Heat Transfer:
Nusselt number is used to calculate heat transfer rate that is given by

$$Nu = -\left(\frac{\partial T}{\partial y}\right)_{y=0}$$

$$Nu = l_1 - \varepsilon(l_4 b_6 - l_1 b_6)e^{-nt} \tag{31}$$

Rate of Mass Transfer:
Sherwood number is used calculate the mass transfer rate and is given by

$$Sh = -\left(\frac{\partial C}{\partial y}\right)_{y=0}$$

$$Sh = (l_1 b_1 + l_2 b_2) + \varepsilon(l_1 b_7 + l_2 b_8 + l_4 b_9 + l_5 b_{10})e^{-nt} \tag{32}$$

3. RESULTS AND DISCUSSION

Figs 1 to 11 illustrate the effect of different parameters on velocity distribution, temperature distribution, and concentration distribution, all while keeping the other parameters constant. It consists of slip parameter h, Grashof number Gr, magnetic parameter M, permeability of a porous medium K, heat source parameter Q, radiation parameter R, chemical reaction parameter Kc, Schimdt number Sc and modified Grashof number Gm A velocity profile with variations is shown in fig.1. Due to the Casson parameter, the velocity rises as it gets closer to the plate and decreases as it gets further away. Gr's impact on velocity distribution is shown in Fig.2. The velocity in Fig. 3 rises as Gm rises. It can be seen from this graph that the velocity rises as Gm rises. The effects of M on velocity are seen in Fig. 4. It can be seen from this graphic that velocity reduces as M rises. The velocity is dragged by Lorentz's force, which is caused by the applied magnetic field. The velocity in Fig. 5 rises as K rises. As Pr, R, and Q increase, the temperature drops, as seen in Figs. 6, 7, and 8. As Sc rises, the concentration drops, as seen in Fig. 9. Similar to Fig. 10, where concentration drops as Kc increases, Fig. 11 shows an increase in concentration as So rises.

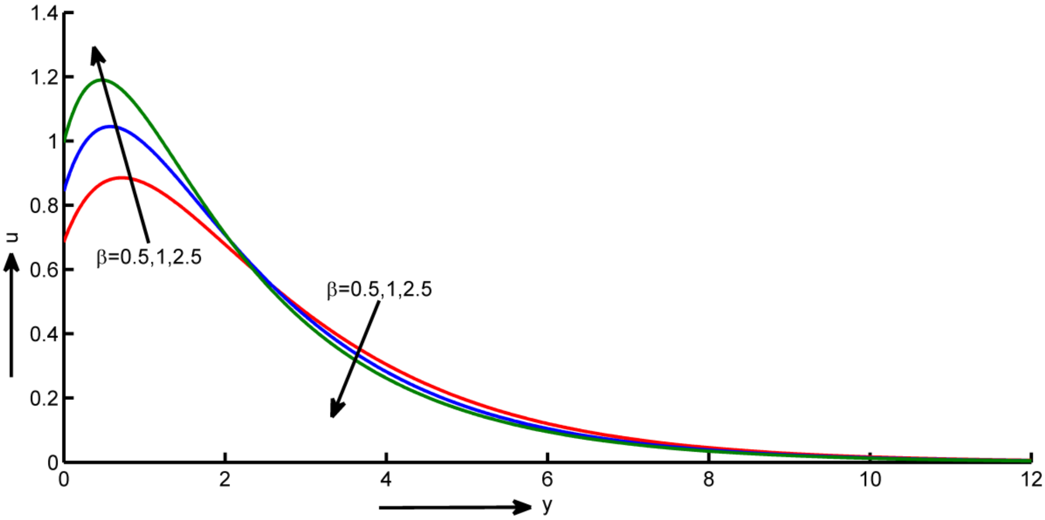

Fig.1. Effects of Casson parameter (β) on velocity.

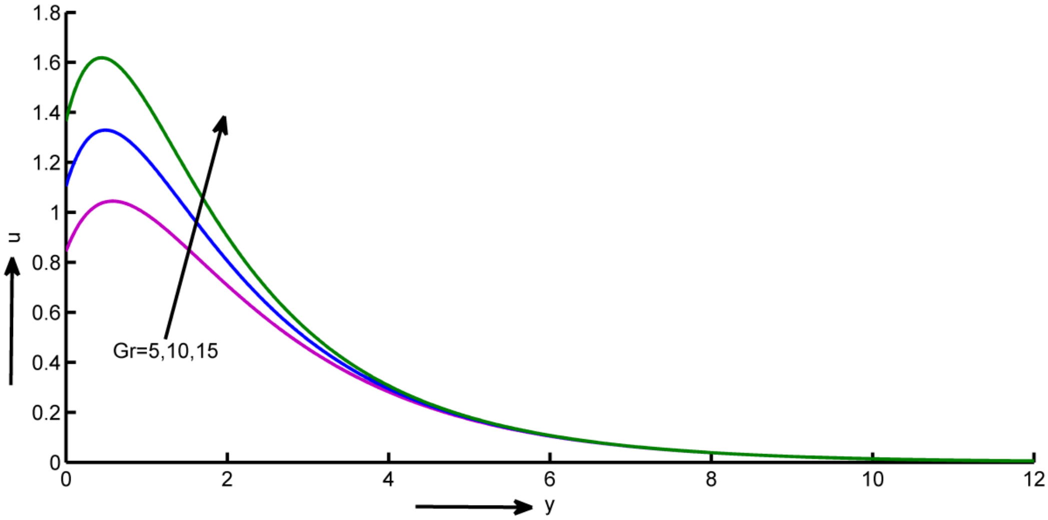

Fig.2. Variation of velocity with Grashof number (Gr).

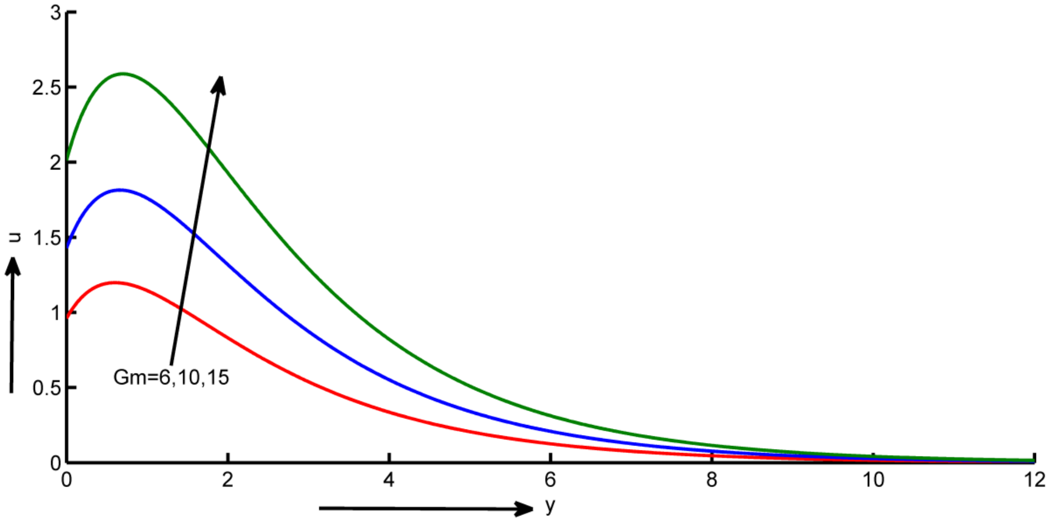

Fig.3. Variation of Grashof number (Gm) with velocity.

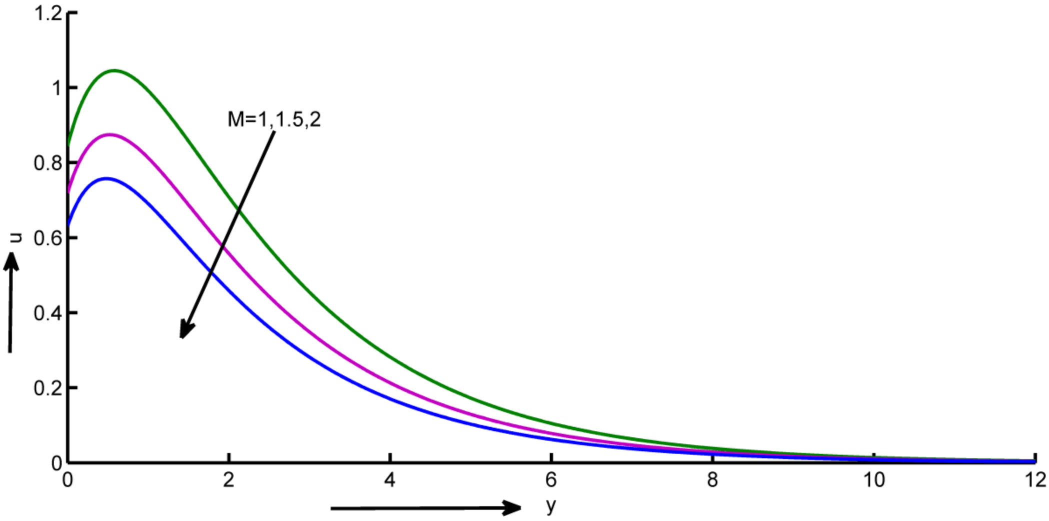

Fig.4. Effects of magnetic parameter (M) on velocity.

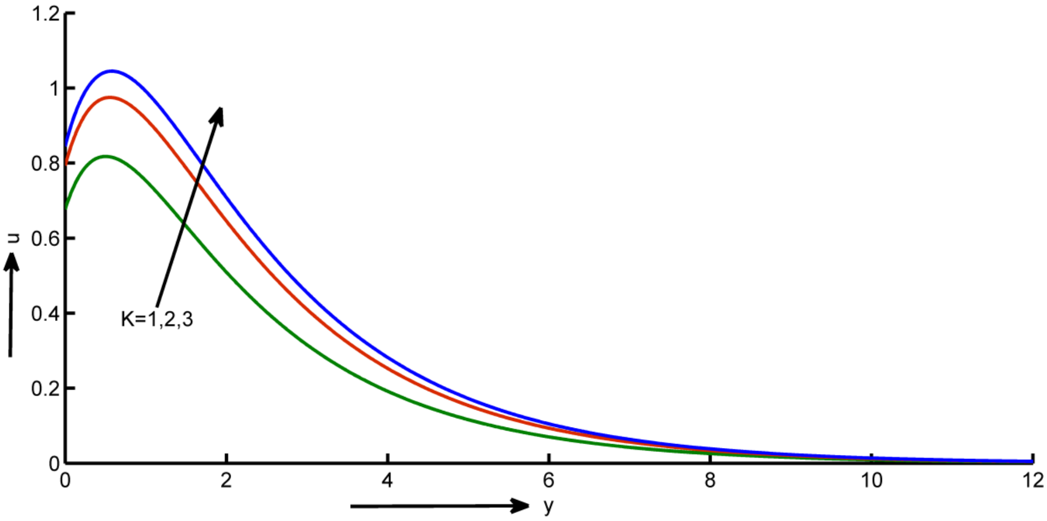

Fig.5. Effects of permeability parameter (K) on velocity.

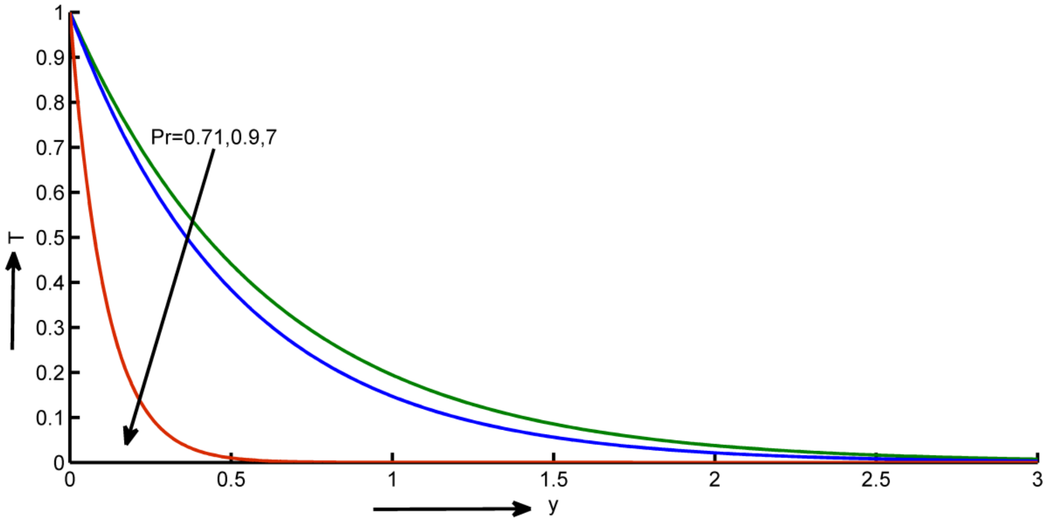

Fig.6. Effect of the Prandtl number (Pr) on temperature.

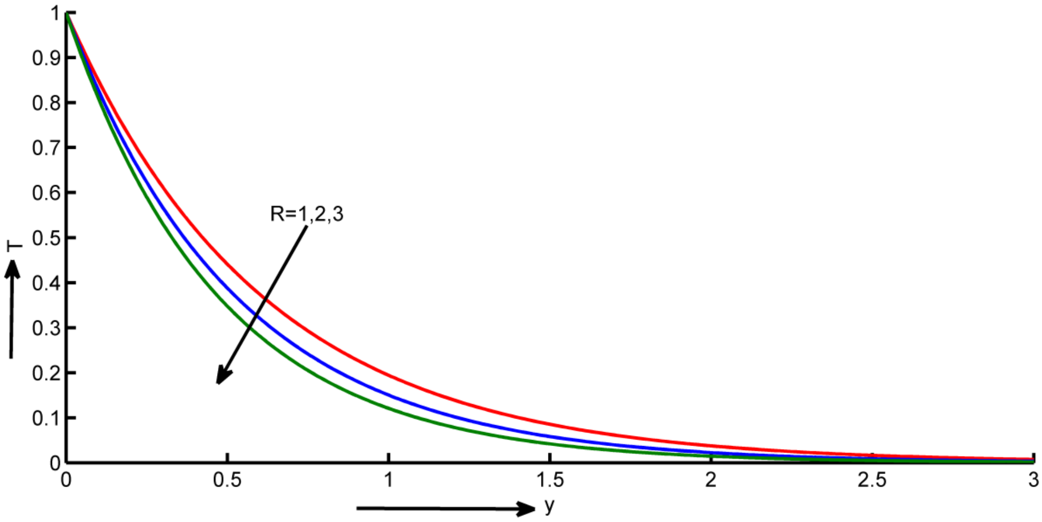

Fig.7. Effects of radiation parameter (R) on temperature.

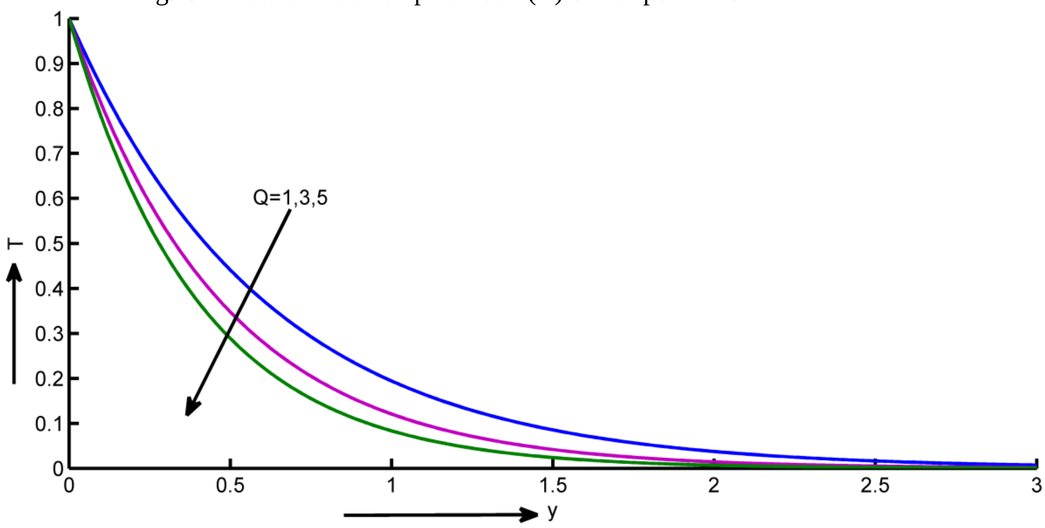

Fig.8. Effects of Heat source parameter (Q) on temperature.

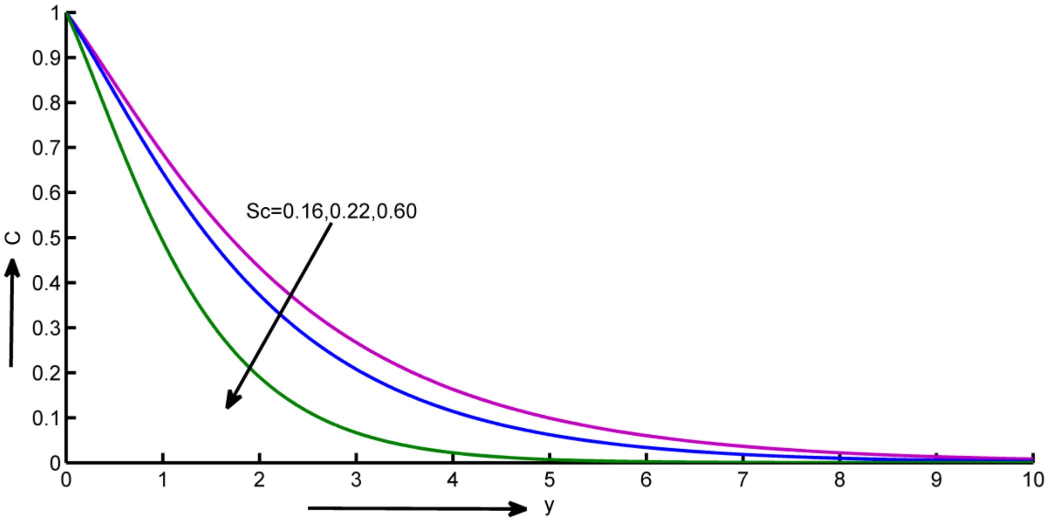

Fig.9. Effects of Schmidt number (Sc) on concentration.

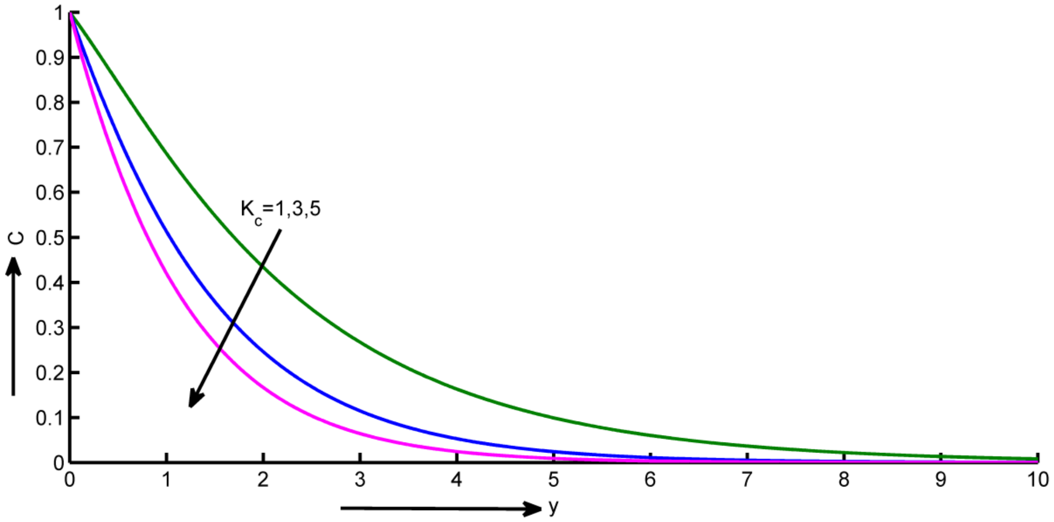

Fig.10. Effects of chemical reaction parameter (Kc) on concentration.

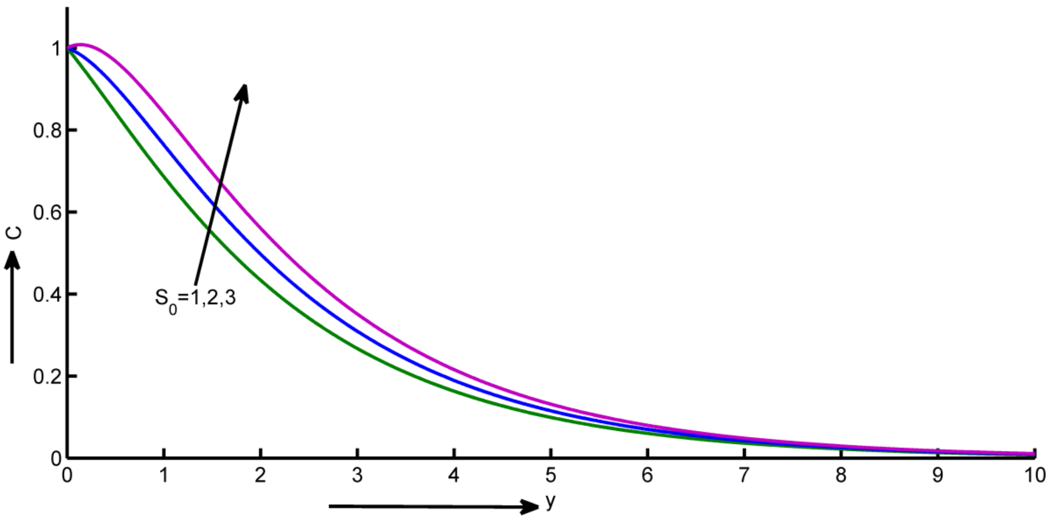

Fig.11. Effects of the Soret number (S_0) on concentration.

The skin-friction values shown in Table 1 correspond to different Grashof numbers (Gr), modified Grashof numbers (Gm), magnetic parameters (M), porosity parameters (K), and Casson parameters (). According to table 1, the skin-friction rises when Grashof number (Gr), modified Grashof number (Gm), and porosity parameter (K) increase, however it reduces when magnetic parameter (M) and slip parameter (h) are present.

Table 1: Skin friction

Gr	Gm	M	K	β	τ
5					0.6835
10					0.7984
15					1.1846
	5				0.6835
	10				1.3865
	15				1.9864
		0.4			0.9986
		0.8			0.7646
		1.2			0.6445
			1		0.7864
			2		0.8684
			3		0.9244
				0.5	0.7845
				1.5	0.9862
				2.5	1.1006

The numerical values of the Nusselt number (Nu) for various values of the Prandtl number (Pr), Radiation parameter (R), and Heat source parameter (Q) are shown in Table 2. Table 2 shows that when the Prandtl number, Radiation parameter, and Heat source parameter rise, so does the Nusselt number.

Table 2: Nusselt number

Pr	R	Q	Nu
0.3			1.2461
0.71			1.6842
0.95			1.8128
	1		1.9712
	2		2.2128
	3		2.4006
		1	1.8264
		2	2.1262
		3	2.2869

Sherwood number (Sh) values are shown numerically in Table 3 together with Schmidt number (Sc), Chemical reaction parameter (Kc), and Soret parameter (S0) distinguishing values. Table 3 shows that the Schmidt number, a chemical reaction parameter, increases with increasing values, but the Soret parameter causes a drop in the Sherwood number.

Table 3: Sherwood number

Sc	Kc	S_0	Sh
0.22			0.2687
0.60			0.3829
0.78			0.4204
	0.5		0.2829
	1.5		0.3986
	2.5		0.5384
		1	0.2586
		2	0.1648
		3	0.0549

4. CONCLUSIONS

Analysis of thermal diffusion and chemical reaction of MHD Casson fluid flow over an inclined vertical porous plate has been explored in this subject. The examination of the flow yielded the following findings:

1. Fluid velocity reduces when the magnetic parameter is present, whereas it increases when the permeability parameter, Grashof number, and modified Grashof number are present.
2. As the Prandtl number, the radiation parameter, and the heat absorption parameter increase, the fluid temperature drops.
3. Concentration drops when the Schmidt number and chemical reaction parameter rise, whereas the Soret effect has the opposite effect.
4. Skin friction was significantly increased when the permeability parameter was increased, and the Grashof number was adjusted. The Grashof number drops when the magnetic parameter (M) and the Casson parameter () are present.
5. As the Prandtl number, the heat absorption parameter, and the radiation parameter rise, the rate of heat transfer increases as well.
6. The rate of mass transfer increased when the Schmidt number, a chemical reaction parameter, increased, but it decreased when the Soret parameter was present.

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