EFFECT OF CATTANEO-CHRISTOV HEAT FLUX ON MHD CASSON FLOW OVER VARIOUS GEOMETRIES WITH THERMOPHORESIS AND BROWNIAN MOMENT

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ABSTRACT
A theoretical investigation is carried out to investigate the 2D flow, heat and mass transfer of magneto hydrodynamic flow of Casson fluid over three different geometries. Cattaneo-Christov heat flux with transverse magnetic field, thermophoresis and Brownian movement effects are considered. shooting technique is employed to solve the altered governing nonlinear equations. The influences of the parameters of concern on the velocity, temperature, and concentration are conversed (in three cases). By viewing the same parameters, skin friction coefficient, heat and mass transfer rates are discussed with the assistance of graphs and tables. It is found that the momentum and thermal boundary layers are not same for the MHD flow over a vertical cone, wedge, and a plate.

INTRODUCTION
Nowadays, researchers have attracted by the fluid flow acrossa slant surfaces as it is a wide field of research. Also, it has enormous applications in several fields such as cooling of the elastic sheet, polymer engineering, and fiber technology. Cone shaped bodies frequently come across in several engineering applications. When we consider stationary cone as a domain, heat transfer problems of mixed convection boundary layer flow has several significant applications like a nuclear reactor cooling system and geothermal reservoirs. Initially, Shen [1] discussed the hypersonic flow over a slender cone. Further, Ackerberg [2] studied the steady incompressible flow through a right circular cone. He found that the classical boundary-layer theory is legitimate for Reynolds numbers of the order of 10^2. Ece [3] studied the free convective flow past a cone and found that the magnetic field stretch improved both skin friction coefficient and the heat transfer rate. Further,the authors [4-6] explained the free convective flow across a vertical cone embedded in the non-Darcy porous medium. Later on, Raju etal. [7, 8] and Jayachandra Babu et al. [9] studied the different nanofluid flows past a cone by considering various parameters like thermophoresis, Brownian motion.

NOMENCLATURE

a, b		Constants
B_0	$[Nm^{-1}A^{-1}]$	Magnetic field strength
C	$[kg\,M^{-3}]$	Concentration of the fluid
C_f		Skin friction coefficient
C_f^*		Dimensional wall shear stress
c_p	$[J\,kg\,K^{-1}]$	Specific heat at constant pressure
C_∞	$[kg\,m^{-2}]$	Ambient concentration of the fluid
D_B		Brownian coefficient
D_T		Thermophoresis coefficient
f		Dimensionless velocity
g	$[ms^{-2}]$	Acceleration due to gravity
Gc		Solutal Grashof number
Gr		Thermal Grashof number
h	$[W\,m^{-2}\,K^{-1}]$	Heat transfer coefficient
k	$[W\,m^{-1}\,K^{-1]}$	Thermal conductivity
l	$[m]$	Characteristic length

Sc		Schmidt number
M		Magnetic field parameter
Nb		Brownian motion parameter
Nt		Thermophoresis parameter
Nu		Local Nusselt number
$\Pr$		Prandtl number
q		Wall concentration parameter
S		Wall temperature parameter
Sh		Local Sherwood number
T	$[K]$	Temperature of the fluid
T_∞	$[K]$	Ambient temperature of the fluid
u, v	$[m\,s^{-1}]$	Velocity components in x, y directions

Greek Symbols

τ		Thermophoretic parameter
ϕ		Dimensionless concentration
ς		Similarity variable
β		Casson Parameter
σ	$[S\,m^{-1}]$	Electrical conductivity
γ		Half angle of cone or wedge
Ω		Full angle of wedge
θ		Dimensionless temperature
ρ	$[kg\,m^{-3}]$	Density
μ	$[kg\,m^{-1}s^{-1}]$	Dynamic viscosity
υ	$[m^2\,s^{-1}]$	Kinematic viscosity
δ		Relaxation time of heat flux
β_1		Thermal relaxation parameter

Hayat et al. [10, 11] investigated the influence of Cattaneo-Christov heat flux on stagnation point flow of non-Newtonian fluids across a stretched surface with variable propertiesWaqas et al. [12] used Cattaneo-Christov heat flux model to analyze the heat transfer characteristics of the generalized Burgers model. Hayat et al. [13] modelled the Jeffrey fluid flow over a stretching sheet. And found that the effects of the homogeneous reaction parameter and the heterogeneous reaction parameters on the concentration profile are quite opposite to each other. Anantha Kumar et al. [14]

The free convective heat transfer over a wedge is useful in several applications such as the nuclear reactors, steam generators, design of spacecraft, solar power collectors etc. Hossain et al. [15] theoretically investigated the forced convection boundary layer flow across a wedge. Later on, Chamkhaet al. [16] examined the MHD flowacross a non-isothermal wedge with various parameters. Atalik and Sonmezler [17] developed a similarity solution for the boundary layer flow across a wedge. They observed that there is a hike in the heat transfer enhancement with the rise in the measure of the proportion of ion kinetic work parameter to Joule heating parameter. Furthermore, Chamkhaet al. [18] and James et al. [19] modeled the nanofluid flows across a wedge plunged in a porous medium by considering the various parameters. Khan et al. [20] and Benazir et al. [21] examined the convective power law nanofluid and Casson fluid flows in a porous medium. Recently, Raju and Sandeep [22] presented dual solutions to the MHD bio-convection Casson fluid flow across a vertical rotating cone/plate. Peddieson [23] used local similarity method to get approximate solutions for the second-order fluid flow across wedges and cones. Yasmeen et al. [24]analyzed theFerro fluid flow across a horizontal stretched surface. Numerical investigation of of ferrous nanofluid over various geometries was studied by Raju and Sandeep [25].

The aforementioned literature is limited to one of the three domains or the combination of two of those domains. As per the author's knowledge, no effort has been done to discuss the effects MHD flow over these three domains in the presence of thermophoresis and Brownian motion effects. Shooting method is employed to solve the alteredgoverning nonlinear equations. Influences of the pertinentparameters of concern on the common profiles (velocity, temperature, and concentration) are conversed (in three cases).

MATHEMATICAL FORMULATION

Consider a two-dimensional,electrically conducting Casson fluid over three different geometries (vertical cone, vertical wedge and a vertical plate). The x-axis is along the surface of the body, y-axis is outward to it. A transverse magnetic field of strength B_0 is applied along the flow as depicted in Fig.1. The temperature and concentration near the surface is considered as $T_w = T_\infty + ax^S$ and $C_w = C_\infty + bx^q$, where S, q are the wall temperature and concentration parameters (the temperature and concentration at the wall are constant when $S = q = 0$). Cattaneo-Christov heat flux, thermophoresis and Brownian motion effects are taken into account.

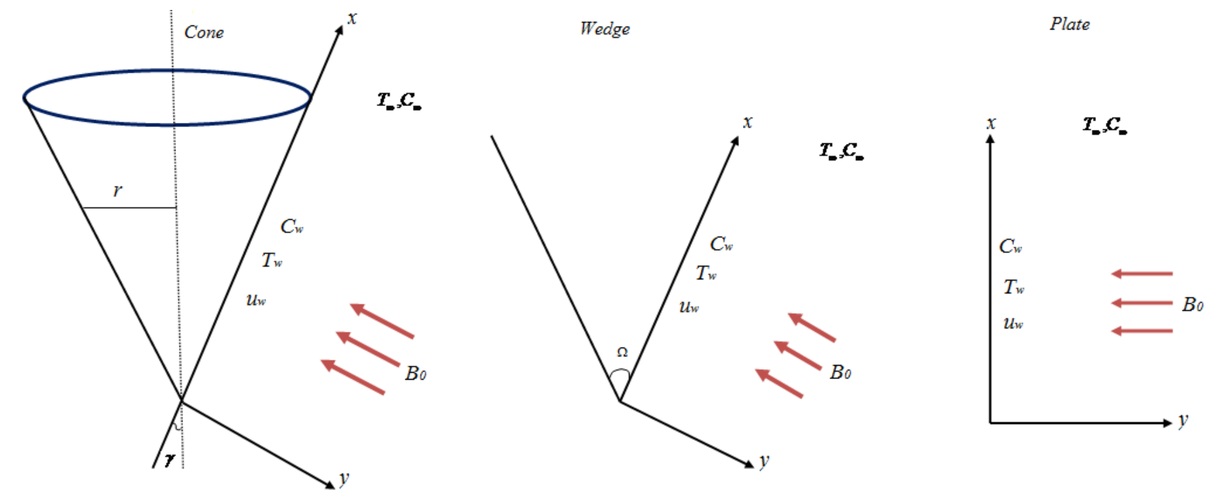

Figure 1 Physical configuration of the problem

Under the above assumptions, the governing equations in terms of similarity variable ξ can be written as

$$\frac{\partial}{\partial x}\left(r^m \frac{\partial \xi}{\partial y}\right)-\frac{\partial}{\partial y}\left(r^m \frac{\partial \xi}{\partial x}\right)=0, \qquad (1)$$

$$\frac{\partial \xi}{\partial y}\frac{\partial^2 \xi}{\partial x \partial y}-\frac{\partial \xi}{\partial x}\frac{\partial^2 \xi}{\partial y^2}=\upsilon\left(1+\frac{1}{\beta}\right)\frac{\partial^3 \xi}{\partial y^3}-\frac{\sigma B_0{}^2}{\rho}\frac{\partial \xi}{\partial y}+\left(g\beta_T(T-T_\infty)+g\beta_C(C-C_\infty)\right)\cos\gamma, \qquad (2)$$

$$\frac{\partial \xi}{\partial y}\frac{\partial T}{\partial x}-\frac{\partial \xi}{\partial x}\frac{\partial T}{\partial y}=\frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y^2}-\delta\left\{\begin{pmatrix}\frac{\partial \xi}{\partial y}\frac{\partial^2 \xi}{\partial x \partial y}\frac{\partial T}{\partial x}+\frac{\partial \xi}{\partial x}\frac{\partial^2 \xi}{\partial y \partial x}\frac{\partial T}{\partial y}-\frac{\partial \xi}{\partial x}\frac{\partial^2 \xi}{\partial y^2}\frac{\partial T}{\partial x}\\ -2\frac{\partial \xi}{\partial y}\frac{\partial \xi}{\partial x}\frac{\partial^2 T}{\partial x \partial y}+\left(\frac{\partial \xi}{\partial y}\right)^2\frac{\partial^2 T}{\partial x^2}+\left(\frac{\partial \xi}{\partial x}\right)^2\frac{\partial^2 T}{\partial y^2}\end{pmatrix}+\tau\left(D_B\frac{\partial C}{\partial y}\frac{\partial T}{\partial y}+\frac{D_B}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right),\right\} \qquad (3)$$

$$\frac{\partial \xi}{\partial y}\frac{\partial C}{\partial x}-\frac{\partial \xi}{\partial x}\frac{\partial C}{\partial y}=D_B\frac{\partial^2 C}{\partial y^2}+\frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2}, \qquad (4)$$

with the boundary conditions

$$u=u_w=\upsilon x/l^2,\ v=0,$$
$$T=T_w=T_\infty+ax^S,\ C=C_w=C_\infty+bx^q,\ at\ \ y=0,$$
$$u(x,\infty)=0,\ T(x,\infty)=T_\infty,\ C(x,\infty)=C_\infty, \qquad (5)$$

The proposed problem shows three-different geometries based on the following assumptions:

(i) $m=0$ and $\gamma\neq 0$:flow caused by a wedge.

(ii) $m=1$ and $\gamma\neq 0$:flow caused by a cone.

(iii) $m=0$ and $\gamma=0$: flow caused by a plate.

We now introduce the similarity transforms as

$$\zeta=\frac{y}{l},\ u=\frac{\upsilon x}{l^2}\frac{\partial f}{\partial \zeta},\ v=\frac{-\upsilon(m+1)}{l}f(\zeta), \qquad (6)$$

$$T=T_\infty+(T_w-T_\infty)\theta(\zeta), C=C_\infty+(C_w-C_\infty)\phi(\zeta), \qquad (7)$$

Now substituting equations (6) and (7) into equations (1) to (4), gives

$$\left(1+\frac{1}{\beta}\right)\frac{\partial^3 f}{\partial \zeta^3}+(m+1)f\frac{\partial^2 f}{\partial \zeta^2}-\left(\frac{\partial f}{\partial \zeta}\right)^2+\left(Gr\theta+Gc\phi\right)\cos\gamma-M\frac{\partial f}{\partial \zeta}=0, \qquad (8)$$

$$\left.\begin{array}{r}\dfrac{\partial^2\theta}{\partial\zeta^2}-\Pr\beta_1\left[\begin{array}{l}s\left(\left(\dfrac{\partial f}{\partial\zeta}\right)^2\theta-(m+1)f\dfrac{\partial^2 f}{\partial\zeta^2}\theta-2(m+1)f\dfrac{\partial f}{\partial\zeta}\dfrac{\partial\theta}{\partial\zeta}+(S-1)\left(\dfrac{\partial f}{\partial\zeta}\right)^2\theta\right)\\+(m+1)^2\left(f^2\dfrac{\partial^2\theta}{\partial\zeta^2}+f\dfrac{\partial f}{\partial\zeta}\dfrac{\partial\theta}{\partial\zeta}\right)\end{array}\right]\\+\Pr\left[\left((m+1)f\dfrac{\partial\theta}{\partial\zeta}-s\dfrac{\partial f}{\partial\zeta}\theta\right)+\left(Nb\dfrac{\partial\theta}{\partial\zeta}\dfrac{\partial\phi}{\partial\zeta}+Nt\left(\dfrac{\partial\theta}{\partial\zeta}\right)^2\right)\right]=0,\end{array}\right\} \tag{9}$$

$$\frac{\partial^2\phi}{\partial\zeta^2}+\frac{Nt}{Nb}\frac{\partial^2\theta}{\partial\zeta^2}+Sc\left((m+1)f\frac{\partial\phi}{\partial\zeta}-q\frac{\partial f}{\partial\zeta}\phi\right)=0, \tag{10}$$

with the transformed conditions

$$\left.\begin{array}{ll}f=0, f'=1,\theta=1,\phi=1 & \text{at } \zeta=0,\\ f'=0,\theta=0,\phi=0 & \text{as } \zeta\to\infty,\end{array}\right\} \tag{11}$$

where M, Gr, Gc, $\Pr$, β_1, Nb, Nt and Sc are defined as

$$\left.\begin{array}{l}M=\dfrac{\sigma_0 {B_0}^2 l^2}{\rho\upsilon}, Gr=\dfrac{l^2 g\beta_T(T_w-T_\infty)}{\upsilon u_w}, Gc=\dfrac{l^2 g\beta_C(C_w-C_\infty)}{\upsilon u_w},\\ \Pr=\dfrac{\mu c_p}{k},\beta_1=\dfrac{\delta\upsilon}{l^2}, Nb=\dfrac{\tau D_B\left(C_w-C_\infty\right)}{\upsilon}, Nt=\dfrac{\tau D_T\left(T_w-T_\infty\right)}{\upsilon T_\infty}, Sc=\dfrac{\upsilon}{D_B}\end{array}\right\} \tag{12}$$

For engineering interest, the friction factor (C_f), local Nusselt number (Nu) and local Sherwood number (Sh) are given by

$$C_f=\left(1+\frac{1}{\beta}\right)\frac{{C_f}^*}{\mu u_w}=\left(1+\frac{1}{\beta}\right)f''(0),$$

$$Nu=\frac{hl}{k(T_w-T_\infty)}=-\theta'(0), Sh=\frac{h_m l}{(C_w-C_\infty)}=-\phi'(0), \tag{13}$$

RESULTS AND DISCUSSION

The set of transformed equations (8) - (10) subject to the conditions (11)resolved with the help of Shooting technique. To examine the effects of various parameters on different profiles, we assign values to the parameters as $M=1,\ Gr=0.5,\ Gc=0.5,$ $\Pr=6, \beta=0.5,\ \beta_1=0.02,\ Nb=0.5,$ $Nt=0.5,\ S=2,\ q=2,\ Sc=1.$ We use graphs to analyse the influence of diverse parameters velocity, temperature, and concentration fields. With the aid of tables, skin friction coefficient, heat and mass transfer rates are discussed for the aforementioned parameters.

It is evident from the Figures 2 to 4 that increasing values of the magnetic field parameter M declines the velocity but increase the thermal and concentration fields.When we increase the values of M, we can observe arise in the Lorentz force, which developsthe resistance force opposite to the flow.Thermal and solutal Grashof numbers (Gr, Gc) both encourages the velocity profiles and lessen the temperature and concentration profiles which is shown in Figures 5 to 10. Figure11depicts that the temperature increases with the rise in thermophoresis parameter Nt. It is clear from the Figures 12 to 13 that the effect of Brownian motion parameter Nb on temperature and concentration profiles is not same.

Figures 14and 16 demonstrated that the effect of wall temperature parameter S and thermal relaxation parameter β_1 on temperature profile is same. When we raisethe value of the thermal relaxation parameter, the particles of the material may need much time to transmit energy to their contiguous particles. Increasing the wall concentration parameter q lessen the concentration which is presented in Figure 15.

Table 1 depicts the comparison of the present results with the published results and found a reasonable agreement of the present results under some special cases. Tables 2, 3 & 4 display the influence of aforementioned parameters on skin friction, heat and mass transfer rates for three domains. In all domains, all parameters exhibited the same behaviour. It is clear from the tables that the magnetic field parameter M, thermophoresis parameter Nt, Brownian motion parameter Nb and wall concentration parameter q lessen the rate of heat transfer. Wall temperature and concentration parameters (S, q) reduce the skin friction coefficient. Thermal and solutal Grashof numbers (Gr, Gc) improve both the heat and mass transfer rates.

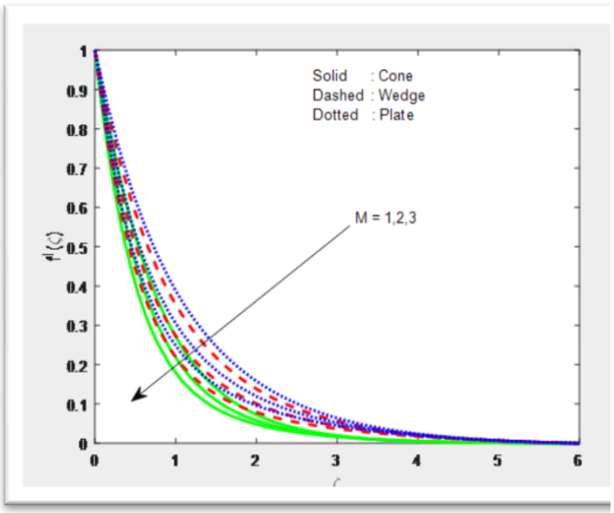

Figure 2 Velocity field for various values of M

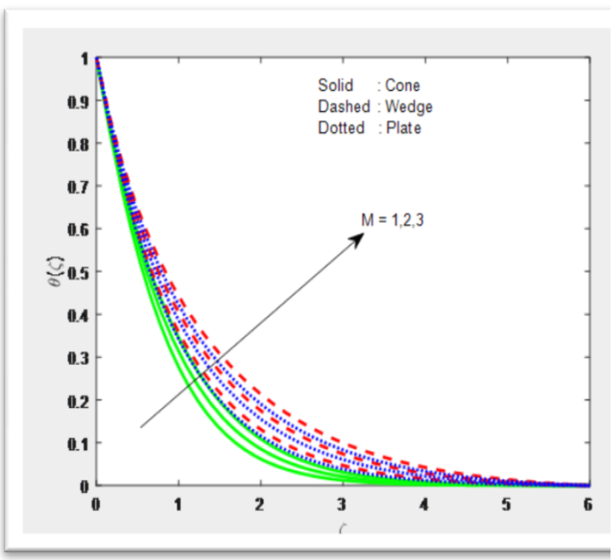

Figure 3 Temperature field for various values of M

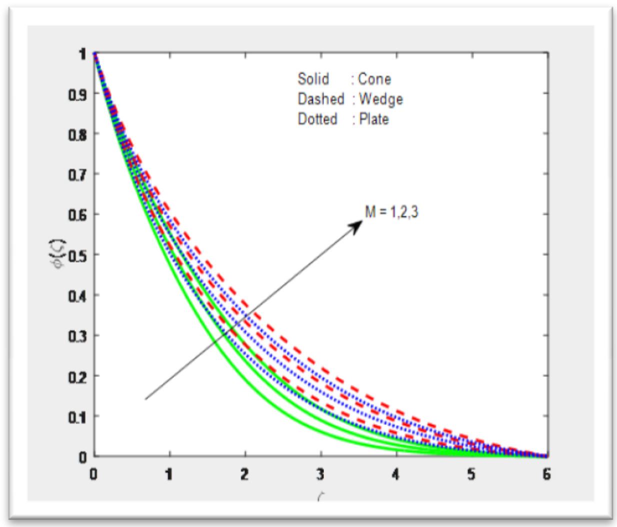

Figure 4 Concentration field for various values of M

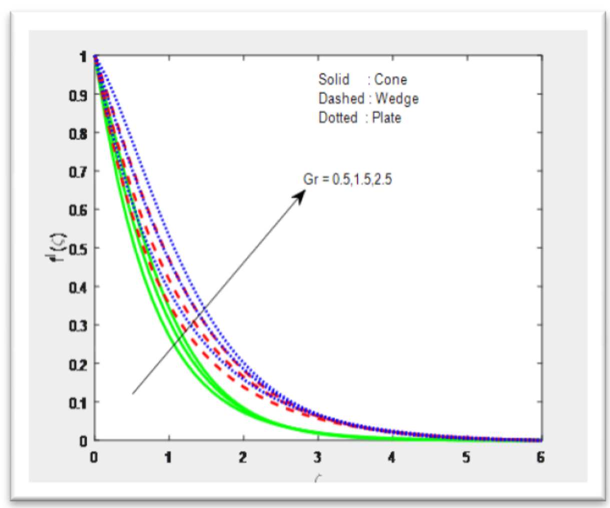

Figure 5 Velocity field for various values of Gr

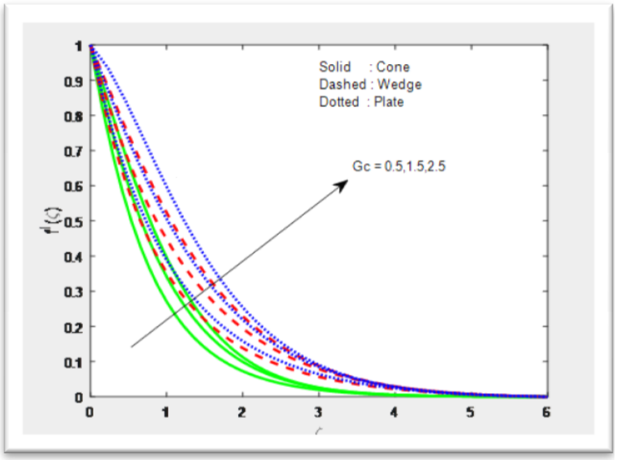

Figure 6 Velocity field for various values of Gc

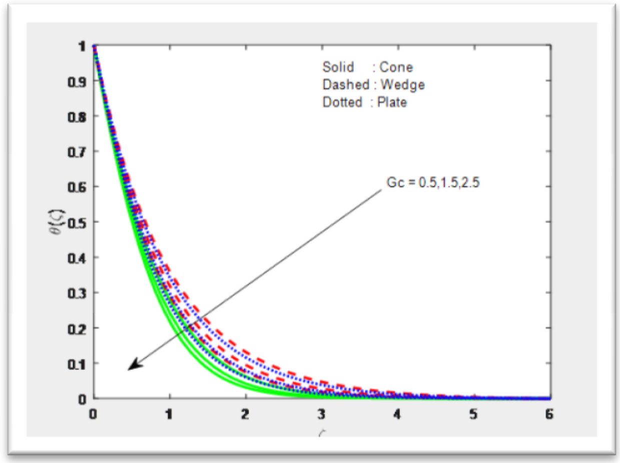

Figure 9 Temperature field for various values of Gc

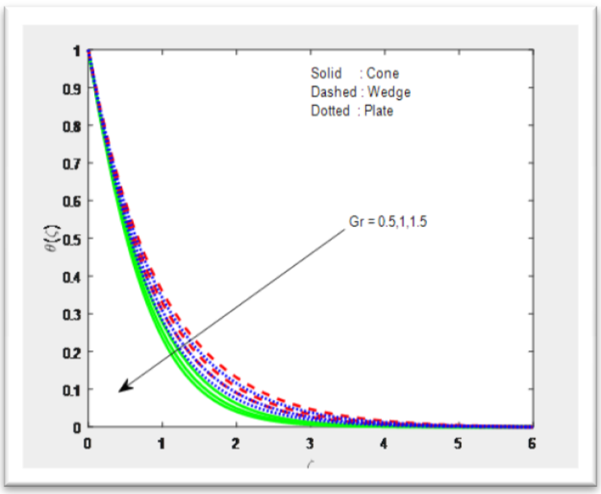

Figure 7 Temperature field for various values of Gr

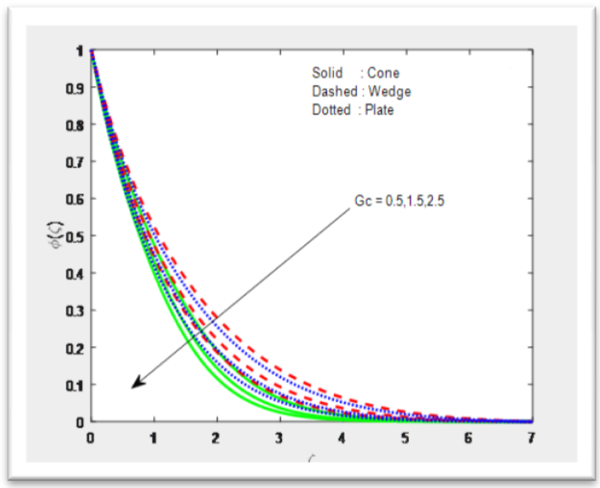

Figure 10 Concentration field for various values of Gc

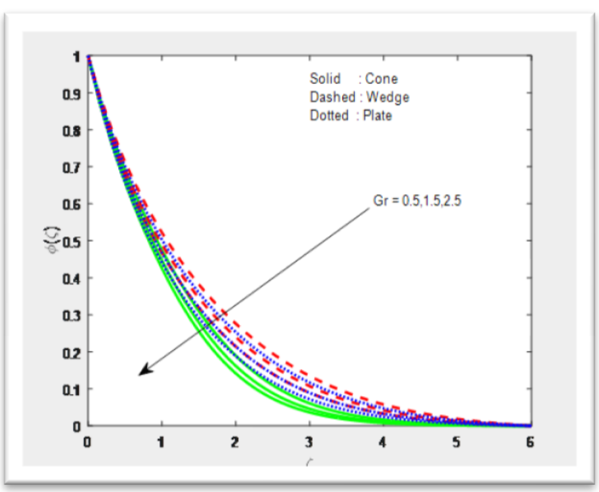

Figure 8 Concentration field for various values of Gr

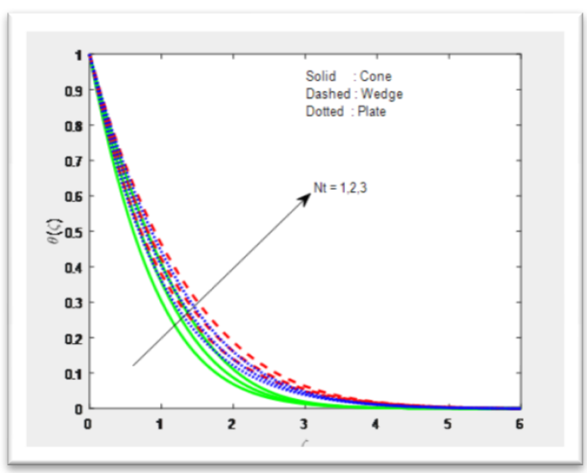

Figure 11 Temperature field for various values of Nt

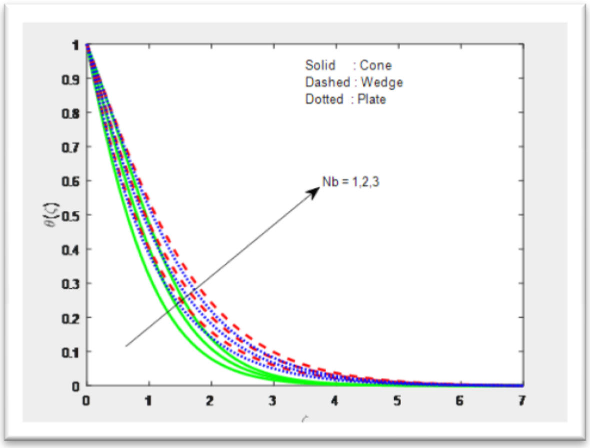

Figure 12 Temperature field for various values of Nb

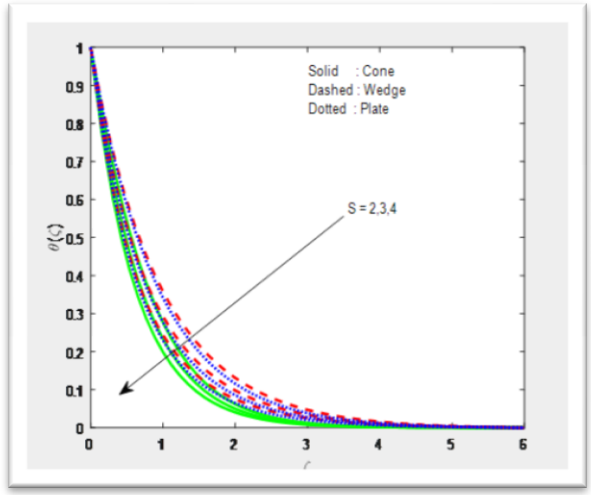

Figure 14 Temperature field for various values of S

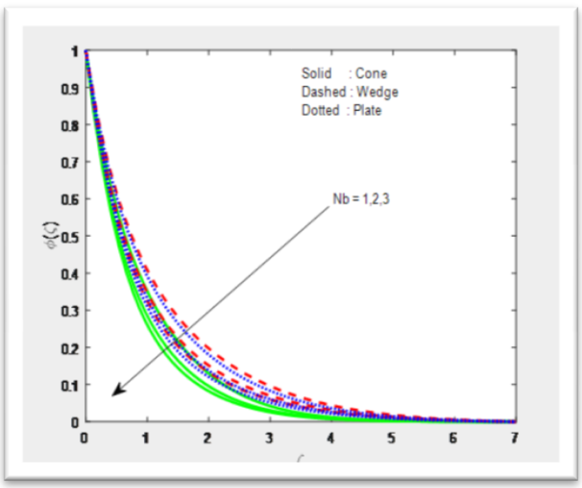

Figure 13 Concentration field for various values of Nb

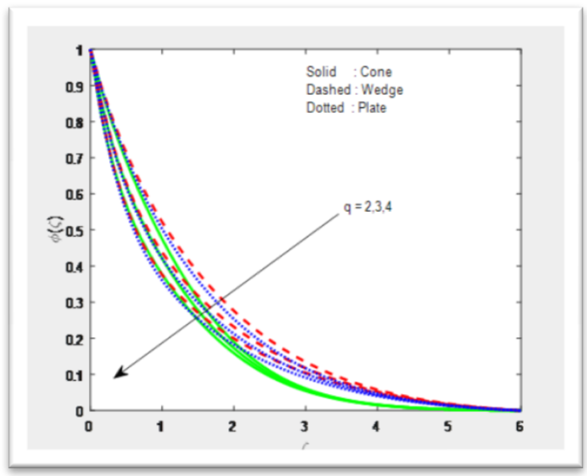

Figure 15 Concentration field for various values of q

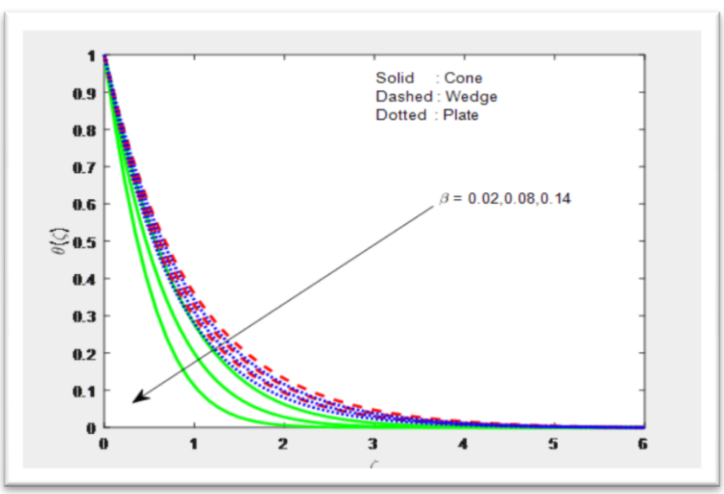

Figure 16 Temperature field for various values of β_1

Table 1 Validation of the results of $-\theta'(0)$ when $Sc = \beta_1 = Nt = Nb = 0, \beta \to \infty$, for the flow over a wedge

M	S	Gr	Pr	$-\theta'(0)$	Present
1	-2.1	-0.5	0.3	2.236105	2.2361053
1	2.1	-0.5	0.3	2.232736	2.2327362
3	2.1	-0.5	0.3	2.233693	2.2336931

Table 2 Influence of several parameters on $f''(0)$, $-\theta'(0)$ and $-\phi'(0)$ for the flow over a cone

M	Gr	Gc	Nt	Nb	S	$f''(0)$	$-\theta'(0)$	$-\phi'(0)$
1						-1.242263	1.153541	0.789965
2						-1.556445	1.111131	0.710382
3						-1.828157	1.073686	0.645921
	0.5					-1.242263	1.153541	0.789965
	1.5					-1.005048	1.183164	0.843882
	2.5					-0.779787	1.208431	0.887195
		0.5				-1.242263	1.153541	0.789965
		1.5				-0.955214	1.193315	0.875828
		2.5				-0.690400	1.224940	0.936365
			1			-1.203151	1.056697	0.321666
			2			-1.142146	0.900719	-0.275089
			3			-1.097850	0.785968	-0.608178
				1		-1.256045	0.955521	1.186870
				2		-1.253123	0.670325	1.368112
				3		-1.244844	0.487586	1.417526
					2	-1.242263	1.153541	0.789965
					3	-1.247260	1.417293	0.570879
					4	-1.251393	1.662679	0.363873

Table 3 Influence of several parameters on $f''(0), -\theta'(0)$ and $-\phi'(0)$ for the flow over a wedge

M	Gr	Gc	Nt	Nb	S	$f''(0)$	$-\theta'(0)$	$-\phi'(0)$
1						-1.094654	1.051955	0.731717
2						-1.438908	1.002392	0.645153
3						-1.728800	0.959855	0.580132
	0.5					-1.094654	1.051955	0.731717
	1.5					-0.832647	1.086073	0.791493
	2.5					-0.585455	1.114263	0.837880
		0.5				-1.094654	1.051955	0.731717
		1.5				-0.790611	1.095099	0.817943

		2.5				-0.509914	1.128658	0.878123
			1			-1.059502	0.976751	0.298888
			2			-1.005168	0.850794	-0.283980
			3			-0.966381	0.754068	-0.633711
				1		-1.107290	0.894867	1.076742
				2		-1.105112	0.661788	1.238788
				3		-1.097925	0.503723	1.285486
					2	-1.094654	1.051955	0.731717
					3	-1.100637	1.329931	0.504819
					4	-1.105260	1.582628	0.293697

Table 4 Influence of several parameters on $f''(0)$, $-\theta'(0)$ and $-\phi'(0)$ for the flow over a plate

M	Gr	Gc	Nt	Nb	S	$f''(0)$	$-\theta'(0)$	$-\phi'(0)$
1						-0.974344	1.069322	0.765694
2						-1.326536	1.021085	0.680972
3						-1.623469	0.979574	0.615778
	0.5					-0.974344	1.069322	0.765694
	1.5					-0.618674	1.111402	0.835520
	2.5					-0.285338	1.145576	0.888694
		0.5				-0.974344	1.069322	0.765694
		1.5				-0.564458	1.121912	0.865060
		2.5				-0.188258	1.162179	0.933078
			1			-0.928003	0.991637	0.349442
			2			-0.857176	0.860553	-0.186481
			3			-0.807428	0.759628	-0.479955
				1		-0.991028	0.907010	1.108415
				2		-0.987751	0.667632	1.269390
				3		-0.977914	0.505784	1.316026
					2	-0.974344	1.069322	0.765694
					3	-0.982402	1.348007	0.538216
					4	-0.988593	1.601114	0.326617

CONCLUSIONS

A theoretical investigation is carried out to investigate the 2D flow, heat and mass transfer of magneto hydrodynamic flow of Casson fluid over three different geometries. Cattaneo-Christov heat flux with transverse magnetic field, thermophoresis and Brownian movement effects are considered. shooting technique is employed to solve the altered governing nonlinear equations.

The conclusions are as follows:

- Buoyancy force effect is highon the flow over a conewhen compared with the other two geometries.
- The effect of Nt and Nb on the local Sherwood number is quite opposite to each other.
- Rising values of magnetic field decline the heat transfer rate.
- Thermal relaxation parameter enhance the heat transfer rate.

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