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Effects of Activation Energy Diffusion Thermo and Nonlinear Thermal Radiation on Mixed Convection Casson Fluid Flow Through a Vertical Cone with Porous Media in the Presence of Brownian Motion and Thermophoresis

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ABSTRACT

In this paper, analyze the impact of Activation energy, Diffusion thermo and nonlinear thermal radiation of mixed convection casson fluid flow through a vertical cone with porous material in the presence of Brownian and thermophoresis has been studied. Numerical techniques, namely Runge–Kutta integration and the shooting method, were applied to obtain solutions to similarity-transformed equations governing continuity, momentum, energy and concentration. The study examined the distributions of flow velocity, temperature and concentration under the interactive effects of the fluid. The results revealed that the activation energy of the Arrhenius equation plays an important role in fluid transport mechanisms within a chemically reactive system involving the Soret effect for a low-Schmidt-number fluid. When the activation energy parameter E was greater within the range $0 < E < 5$, the wall shear stress was stronger, heat transfer rate increased, and mass transfer rate decreased.

1. Introduction

Arrhenius proposed “activation energy” as a term that can be used to refer to the energy barrier that should be surmounted for a chemical reaction to occur. A reaction is more unlikely when the corresponding activation energy is higher. The research of Arrhenius explained that chemical reactions often need to be in an endothermic state and proposed the Arrhenius equation. This equation describes the relationship between temperatures, activation energy and reaction rate [1–4]. Heat in boundary layer flows is typically transferred in tandem with mass, and a key factor in a species chemical reaction is the activation energy. This effect has been applied in evaporation, drying, absorption, precipitation, and membrane filtration and distillation applications. For chemical

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processes involving convective and diffusive transport, problems related to heat–mass transfer coupling are prevalent. For this reason, both theoretical models and experimental research are crucial to describe the activation energy's influences in a fluid flow domain. In theoretical models, the complex chemical reaction that occurs in a system must be investigated using the mass transfer equation for the concentration chemical reaction accordingly. Koriko *et al.,* [5] proposed a boundary-layer analysis of transient micropolar fluid flowing over a non-Darcy porous medium along an infinite vertical surface with endothermic and exothermic chemical reactions considering activation energy. They reported that local heat transfer rate decreases with an increase in exothermic/endothermic parameters. RamReddy and Naveen [6] investigated a power-law fluid flow over a permeable inclined plate exerted by thermal radiation and activation energy. They found that higher activation energy engenders both higher velocity and concentration of power-law fluid, whereas higher chemical reaction reduces them. Ahmad *et al.,* [7] discussed the flow, temperature and concentration field distributions of a chemical reaction involving activation energy in endothermic catalysis under the condition of mixed convection flowing past a curved surface. They discovered that the flow velocity was enhanced at a specific activation energy.

Heat and mass transfer in non-Newtonian fluid flow through porous medium in engineering has extensive application, such as ventilation procedure, oil production, solar collection, cooling of nuclear reactors, and electronic cooling. Accordingly, Raghunath *et al.,* [8] have studied unsteady magneto-hydro-dynamics flow of Jeffrey fluid through porous media with thermal radiation, Hall current and Soret effects. Raghunath *et al.,* [9] have reviewed processing to pass unsteady MHD flow of a second-grade fluid through a porous medium in the presence of radiation absorption exhibits Diffusion thermo, hall and ion slip effects. Suresh Kumar *et al.,* [10] have possessed Numerical analysis of magnetohydrodynamics Casson nanofluid flow with activation energy, Hall current and thermal radiation. Omar *et al.,* [11] have expressed Hall Current and Soret Effects on Unsteady MHD Rotating Flow of Second-Grade Fluid through Porous Media under the Influences of Thermal Radiation and Chemical Reactions. Deepthi *et al.,* [12] have reviewed Recent Development of Heat and Mass Transport in the Presence of Hall, Ion Slip and Thermo Diffusion in Radiative Second Grade Material: Application of Micromachines. Aruna *et al.,* [13] have analyzed an unsteady MHD flow of a second-grade fluid passing through a porous medium in the presence of radiation absorption exhibits Hall and ion slip effects. Raghunath and Mohanaramana [14] have discussed Hall, Soret, and rotational effects on unsteady MHD rotating flow of a second-grade fluid through a porous medium in the presence of chemical reaction and aligned magnetic field. Raghunath *et al.,* [15] have discussed Hall and ion slip radiative flow of chemically reactive second grade through porous saturated space via perturbation approach. From their result, it can be seen that temperature distribution and thermal boundary layer reduce with an increase of dimensionless thermal free convection parameter, dimensionless mass free convection parameter, and Prandtl number.

When heat and mass transfer occurs simultaneously in a moving fluid, the energy flux caused by a concentration gradient is termed as diffusion thermo effect, whereas mass fluxes can also be created by temperature gradients which is known as a thermal diffusion effect. These effects are studied as second-order phenomena and may have significant applications in areas like petrology, hydrology, and geosciences. Ramachandra *et al.,* [16] have possessed Effects of Hall Current, Activation Energy and Diffusion Thermo of MHD Darcy-Forchheimer Casson Nanofluid Flow in the Presence of Brownian Motion and Thermophoresis. Srinivasacharya and RamReddy [17] considered the problem of the steady MHD mixed convection heat and mass transfer of micropolar fluid through non-Darcy porous medium over a semi-infinite vertical plate with Soret and Dufour effects. Influence of the Soret and Dufour numbers on mixed convection flow and heat and mass transfer of non-Newtonian fluid in a porous medium over a vertical plate was analyzed by Mahdy [18]. Hayat and

Nawaz [19] investigated analytically the effects of the Hall and ion slip on the mixed convection heat and mass transfer of second-grade fluid with Soret and Dufour effects. Rani and Kim [20] studied numerically the laminar flow of an incompressible viscous fluid past an isothermal vertical cylinder with Soret and Dufour effects. The effects of chemical reaction and Soret and Dufour on the mixed convection heat and mass transfer of viscous fluid over a stretching surface in the presence of thermal radiation were analyzed by Pal and Mondal [21]. Sharma *et al.,* [22] studied the mixed convective flow, heat and mass transfer of viscous fluid in a porous medium past a radiative vertical plate with chemical reaction, and Soret and Dufour effects.

The Brownian motion (BM) is a motion of random particles and plays a vital role in the area of science and biology. The BM is produced due to the continuous bombardment of the molecules in the surrounding medium. This sort of motion is the result of the collision with nearby liquids/gaseous molecules. The mini/microscopic particles suspended in liquids or gases are impacted by the molecules of the fluid covering the particles. Sui *et al.,* [23] studied the transportation of mass, collective motion, and BM. Mendoza-Gonzalez *et al.,* [24] explained the continuous martingales and BM along with the continuity of nanoparticles and transformation of mass. Saffman and Delbruck [25] described the impacts of BM over chemical reactions in the thin sheet of a viscous fluid along with the chemical reactions. Michaelides [26] discussed the nanoparticle suspension during the movement of the liquid. Berla *et al.,* [27] discussed the role of BM, especially in the field of biology. The relation between BM and thermal conductivity is so strong, and by using this fact, Jang and Choi [28] proved that the main cause of BM is the increase in thermal conductivity.

Thermophoresis is the change in position/migration of the large structure molecules to a macroscopic temperature gradient. The phenomenon is observed due to the exhibition of different responses of particles. Raghunath *et al.,* [29] have studied Diffusion Thermo and Chemical Reaction Effects on Magnetohydrodynamic Jeffrey Nanofluid over an Inclined Vertical Plate in the Presence of Radiation Absorption and Constant Heat Source. Raghunath [30] has studied Study of Heat and Mass Transfer of an Unsteady Magnetohydrodynamic Nanofluid Flow Past a Vertical Porous Plate in the Presence of Chemical Reaction, Radiation and Soret Effects. . Raghunath *et al.,* [31] have discussed Unsteady MHD fluid flow past an inclined vertical porous plate in the presence of chemical reaction with aligned magnetic field, radiation, and Soret effects. Raghunath *et al.,* [32] have possessed Characteristics of MHD Casson fluid flow past an inclined vertical porous plate. Raghunath *et al.,* [33] have expressed Effects of Radiation Absorption and Aligned Magnetic Field on MHD Cassion Fluid Past an Inclined Vertical Porous Plate in Porous Media.

The aforementioned studies and open literature survey bear witness effects of Activation energy, Diffusion thermo and Thermal Diffusion on two-dimensional laminar and incompressible steady flow of thermally radiant Williamson nanofluid through vertical cone with porous material in the presence of thermal radiation has been presented. The highly non-linear partial differential equations are simplified by using suitable similarity transformation equations and the reduced equations are solved numerically with the help of the conventional fourth-order Runge Kutta method along with the shooting procedure. Discussion on the results is deliberated through graphs and tables for some pertinent parameters of interest. Moreover, a comparison of the numerical results was checked and the validity of the method with published works was made; it shows nice agreement.

2. Flow Governing Equations

The steady, laminar, and incompressible flow of Casson fluid over stretching surface considered as cone with porous material. The boundary surface of geometries is imposed with convective conditions. Brownian motion and thermophoresis influences are also considered. The stretching velocity of the surface is taken as $u_w = xu/L^2$, whereas the suction/injection velocity is taken as v_w. The surface temperature is taken as $T_w = T_\infty + ax^{r1}$, where a and r_1 represent the constant and wall thermal factor, respectively. The concentration near the surface is taken as $C_w = C_\infty + ax^{r2}$, where r_2 represents the nanofluid concentration parameter. The half angle of the cone is taken by α, with radius r. The physical model of the geometry is shown in Figure 1(a).

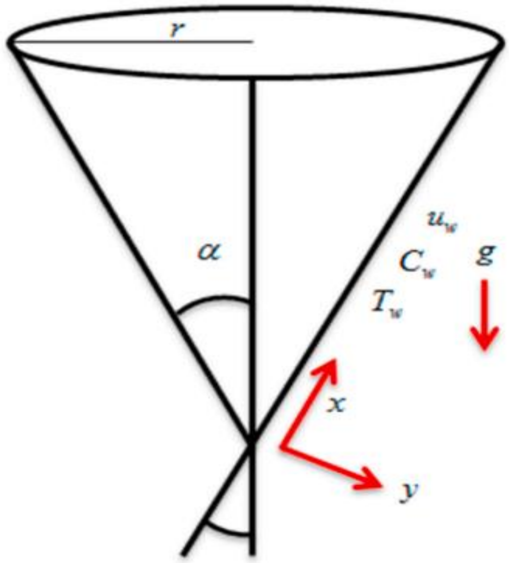

Fig. 1(a). Physical configuration of the problem

By considering the works of Raghunath *et al.,* [34] and by employing the Boussinesq approximation the governing equations describing steady-state conservation of mass, momentum, energy as well as conservation of nanoparticles for nanofluids in the presence of thermal radiation, activation energy and other important take the following form:

$$\frac{\partial}{\partial x}(ru) + \frac{\partial}{\partial y}(rv) = 0 \tag{1}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \upsilon\left(1+\frac{1}{\beta}\right)\frac{\partial^2 u}{\partial x^2} - \sqrt{2}\upsilon\Gamma\frac{\partial u}{\partial y}\frac{\partial^2 u}{\partial y^2} + g\big[(1-C_\infty)_{\rho f_\infty}\beta(T-T_\infty) - \left(\rho_p - \rho_{f_\infty}\right)(C - C_\infty)\big]Cos\gamma \tag{2}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \tau\left(D_B\frac{\partial T}{\partial y}\frac{\partial C}{\partial y} + \frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right) - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y} + \frac{D_m k_T}{c_s c_p}\frac{\partial^2 C}{\partial y^2} \tag{3}$$

$$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_B\frac{\partial^2 C}{\partial y^2} + \left(\frac{D_T}{T_\infty}\right)\frac{\partial T^2}{\partial y^2} - k^2{}_r\left(\frac{T}{T_\infty}\right)e^{(-E_{a/kT})}(C - C_\infty) \tag{4}$$

For this flow, corresponding boundary conditions are

$$u = u_w, v = -v_w, -k^*\frac{\partial T}{\partial y} = h_1(T_w - T), D_B\frac{\partial T}{\partial y} + \frac{D_T}{T_\infty}\frac{\partial T}{\partial y} = 0 at y = 0$$
$$u \to 0, T \to T_\infty, C \to C_\infty as y \to \infty \tag{5}$$

where u and v are the velocity components in their respective directions, β_T is the coefficient of volumetric thermal expansion, β_C is the volumetric concentration expansion, υ is the kinematic viscosity, ρ is the density, L is the characteristics length, τ is the extra stress tensor, Γ is the positive time constant, D_B and D_T are the diffusion coefficients of Brownian and thermophoresis, respectively, αis the thermal conductivity, T is the temperature, C is the concentration. E is the nondimensional activation energy, δ is the temperature difference parameter. The subscripts w and ∞ represent conditions near the wall and ambient from the wall, respectively.

The radiative heat flux q_r (using Roseland approximation followed [24]) is defined as

$$q_r = -\frac{4\sigma^*}{3K^*}\left(\frac{\partial T^4}{\partial y}\right) \tag{6}$$

We assume that the temperature variances inside the flow are such that the term T^4 can be represented as linear function of temperature. This is accomplished by expanding T^4 in a Taylor series about a free stream temperature T_∞ as follows:

$$T^4 = T_\infty^4 + 4T_\infty^3(T - T_\infty) + 6T_\infty^2(T - T_\infty)^2 + \ldots\ldots\ldots.. \tag{7}$$

After neglecting higher-order terms in the above equation beyond the first degree term in $(T - T_\infty)$, we get

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4 \tag{8}$$

Thus substituting Eq. (8) in Eq. (6), we get

$$q_r = -\frac{16T_\infty^3\sigma^*}{3K^*}\left(\frac{\partial T}{\partial y}\right) \tag{9}$$

Using (9), Eq. (3) can be written as

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial y^2} + \tau\left(D_B\frac{\partial C}{\partial y}\frac{\partial T}{\partial y} + \frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right) + \frac{1}{\rho C_p}\frac{16T_\infty^3\sigma^*}{\partial K^*}\left(\frac{\partial^2 T}{\partial y^2}\right) + \frac{D_m k_T}{c_s c_p}\frac{\partial^2 C}{\partial y^2} \tag{10}$$

The following similarity variables are introduced for solving governing Eq. (2), (6) and (4) as

$$\eta = \frac{y}{L}, u = \frac{xD}{L}f'(\eta), v = \frac{\upsilon(1+m)}{L}f(\eta), \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \varphi(\eta) = \frac{C - C_\infty}{C_w - C_\infty} \tag{11}$$

Substituting Eq. (11) into Eq. (2), (3) and (4), we get the following system of non-linear ordinary differential equations

$$f'''\left(1 + \frac{1}{\beta}\right) + (1+m)ff'' - f'^2 + Gr\theta Cos\alpha + Gc\varphi Cos\alpha - Mf' = 0 \tag{12}$$

$$\theta''(1+R) + Pr[(1+m)f\theta' - r_1 f'\theta + (N_b\theta'\varphi' + N_t\theta'^2) + D_u\varphi'] = 0 \tag{13}$$

$$\varphi'' + Sc\left[(1+m)f\varphi' - r_2 f'\varphi - \sigma[1+\delta\theta]^n\, exp\left[\frac{-E}{1+\delta\theta}\right]\varphi\right] + \left(\frac{N_t}{N_b}\right)\theta'' = 0 \tag{14}$$

The corresponding boundary conditions (5) become

$$f(0) = S, f'(0) = 1, f'(\infty) = 0, \theta'(0) = B_i(\theta(0) - 1),$$
$$\theta(\infty) = 0, \varphi'(0) = -\frac{Nt}{Nb}\theta'(0), \varphi(\infty) = 0. \tag{15}$$

where prime denotes differentiation with respect to η, and the significant thermophysical parameters indicating the flow dynamics are defined by

$Pr = \frac{\alpha}{\mu C_p}$ is the Prandtl number,

$N_b = \frac{\tau D_B(C_W - C_\infty)}{\upsilon}$ is the Brownian motion parameter,

$N_t = \frac{\tau D_T(T_W - T_\infty)}{\upsilon T_\infty}$ is the thermophoresis parameter,

$B_i = \frac{Lh_1}{k}$is the Biot number,

$E = \frac{E_a}{kT_\infty}$is the non-dimensional activation energy,

$\delta = \frac{(T_W - T_\infty)}{T_\infty}$ Is the temperature difference parameter,

$\sigma = \frac{k_r^2}{a}$is the non-dimensional reaction rate,

$Grx = \frac{gL^2\beta_T(T_W - T_\infty)}{\upsilon u_W}$ Is the thermal Grashof number,

$Grc = \frac{gL^2\beta_T(C_W - C_\infty)}{\upsilon u_W}$ is the concentration Grashof number,

$R = \frac{14\sigma^* T_\infty^3}{3kK^*}$ is the thermal Radiation parameter,

$Du = \frac{D_M k_T(C_W - C_\infty)}{C_S C_p \upsilon \alpha^2 (T_W - T_\infty)}$ is the Diffusion thermo parameter.

The quantities we are interested to study are the skin friction coefficient C_f, the local Nusselt number N_{ux} and the local Sherwood number S_{hx}. The quantities are defined as:

$$C_f = \frac{\tau_w}{\rho u_w^2} = \frac{\mu\left[\frac{\partial u}{\partial y} + \frac{\Gamma}{\sqrt{2}}\left(\frac{\partial u}{\partial y}\right)^2\right]_{y=0}}{\rho\left(\frac{x\upsilon}{L^2}\right)} = f''(0) + \frac{W}{2}f''^2(0) \tag{16}$$

$$Nu_x = \frac{xq_W}{k(T_W - T_\infty)} = \frac{-x\left(\frac{\partial T}{\partial y}\right)_{y=0}}{k(T_W - T_\infty)} = -\theta'(0), \tag{17}$$

$$Sh_x = \frac{xj_w}{D_B(C_w - C_\infty)} = \frac{-x\left(\frac{\partial C}{\partial y}\right)_{y=o}}{D_B(C_w - C_\infty)} = -\varphi'(0). \tag{18}$$

3. Numerical Solution

As Eq. (12)–(14) are strongly non-linear, it is difficult or maybe impossible to find the closed form solutions. Accordingly, these boundary value problems are solved numerically by using the conventional fourth-order RK integration scheme along with the shooting technique. The first task to carry out the computation is to convert the boundary value problem to an initial value problem. The first task to carry out the computation is to convert the boundary value problem to an initial value problem.

Let by using the following notations:

$$\boldsymbol{f = y_1, f' = y_2, f'' = y_3, f''' = y_3', \theta = y_4, \theta' = y_5, \theta'' = y_5', \varphi = y_6, \varphi' = y_7, \varphi'' = y_7'}. \tag{19}$$

By using the above variables, the system of first-order ODEs is

$$y_1' = y_2, \tag{20}$$

$$y_2' = y_3, \tag{21}$$

$$y_3' = \frac{1}{\left(1+\frac{1}{\beta}\right)}\left(y_2^2 - (1+m)y_1y_3 - GrCos\alpha y_4 - GcCos\alpha y_6 + Ky_2\right), \tag{22}$$

$$y_4' = y_5, \tag{23}$$

$$y_5' = \frac{1}{1+R_d}\left(-Pr(1+m)\,y_1y_5 + r_1y_2y_4 - Pr\,N_b\left(y_5y_7 + \frac{Nt}{Nb}(y_5)^2\right) - Pr \quad Duy_7\right), \tag{24}$$

$$y_6' = y_7, \tag{25}$$

$$y_7' = -S_c\left[(1+m)y_1y_7 + r_2y_2 + \sigma[1+\delta y_4]^n\, exp\left[\frac{-E}{1+\delta y_4}\right]y_6\right] - \left(\frac{N_b}{N_t}\right)y_5' \tag{26}$$

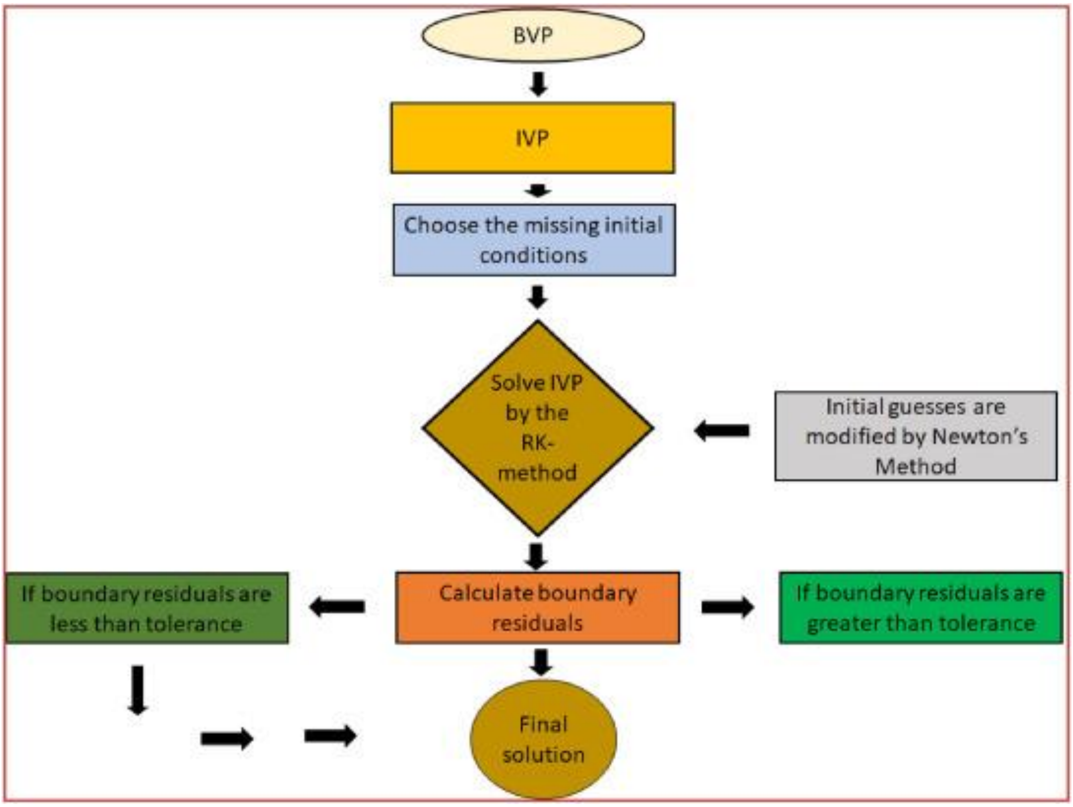

Fig. 1(b). Flow chart for numerical scheme

4. Code Validation

We checked the accuracy of current outcomes with previous literature in the limited case and obtained a fantastic agreement. Table 3 displays a comparison of numeric outcome for Sherwood values of the Diffusion thermo parameter with the published result of Raghunath *et al.,* [34] with an outstanding agreement.

5. Results and Discussion

The set of nonlinear equations with appropriate boundary conditions are solved numerically by Runge Kutta method along with the shooting procedure. To analyze the variation in velocity, thermal, and concentration distributions, Figure 3-7 are displayed. Also, the skin friction factor, Nusselt number, and Sherwood number are displayed through Tables 2 and 3. For the present analysis, the values of fixed parameters are taken as Pr = 1.0, Rd=0.5, Sc = 0.5, K=1.5, r_1 = 1.0, r_2 = 1.0, S = 1.0, Grx = 0.5, E=0.5, δ=0.2, γ = 0.6, Grc = 0.5, Nb = 0.5, Nt = 0.3, Du=1.0 and α = 45^0.

In Figure 3 and 4 the effects of the thermal Grashof Gr and mass Grashof Gc numbers on the resultant velocity are displayed. As the Grashof number is a ratio of the buoyancy force to the viscous force and it appears due to the natural convection flow, so an increase in the tangential velocity as well as the transverse velocity of the fluid. It happens because of the fact that higher the Grashof number implies higher the buoyancy force which means higher the movement of the flow.

Figure 5-8 depict the influence of the thermal and solutal Grashof number on the temperature and the concentration profile respectively. An increase in the both thermal and solutal Grashof number means a decrease in the viscous force which reduces the temperature and the concentration of the fluid.

The temperature and concentration profiles for different values of Brownian motion parameter (Nb) is summarized in Figure 9 and 10. It is investigated that an increases in (Nb), the temperature is extends as shown in Figure 9, whereas the concentration profiles depreciates in Figure 10. This is because of the Brownian motion is the random motion of suspended nanoparticles in the base fluid and is more influenced by its fast moving atoms or molecules in the base fluid. It is mentioned that Brownian motion is related to the size of nanoparticles and are often in the form of agglomerates. Clearly, it can be concluded that Brownian motion parameter has significant influence on the both temperature and concentration.

The Variation of non-dimensional temperature and concentration distributions for different values of thermophoretic parameter (Nt) is depicted in Figure 11 and 12. It is noticed from these Figure 11 and 12 that both temperature and concentration profiles boosted in the boundary layer region for the accrual values of thermophoretic parameter (Nt). This is because of the fact that as the values of (Nt) increases the hydrodynamic boundary layer thickness is reduced. This is from the reality that particles near the hot surface create thermophoretic force; this force enhances the temperature and concentration of the fluid in the fluid region.

Figure 13 depicts the temperature for the contribution of Diffusion thermo parameter Du. Temperature enhancement is noticed for higher Du values. The effect of thermal radiation parameter (Rd) on temperature profile is shown in Figure 14. It is acknowledged that, the thermal boundary layer thickness is enlarged with improving values of radiation parameter (Rd) in the entire boundary layer region of fluid. This is due to the fact that imposing thermal radiation into the flow warmer the fluid, which causes an increment in the temperature.

Figure 15 is drawn to show the effects of dimensionless activation energy E on concentration distribution. From the figure, it is revealed that E is dwindling function of increasing values of E with low temperature results in smaller reaction rate constant and eventually slow chemical reaction is observed. This increases the concentration's solute. Figure 16 shows the effect of the chemical reaction rate δ on the solute concentration. It can be observed that an increase in either results in diminishes of concentration profiles as we had shown Figure 16. This is due to the fact that an increase in either results in an increase in the factor of

$$[1+\delta\theta]^n \, exp\left[\frac{-E}{1+\delta\theta}\right]$$

and this results in the favor of destructive chemical reaction due to which concentration decreases. The influence that the Casson component (β) has on the velocity outline is seen in 17. It has come to our attention that as it grows, the velocity and the thickness of the boundary layer decrease. Therefore, the magnitude of the velocity is more significant in Casson fluid as contrasted to viscous fluids since the Casson fluid is less dense.

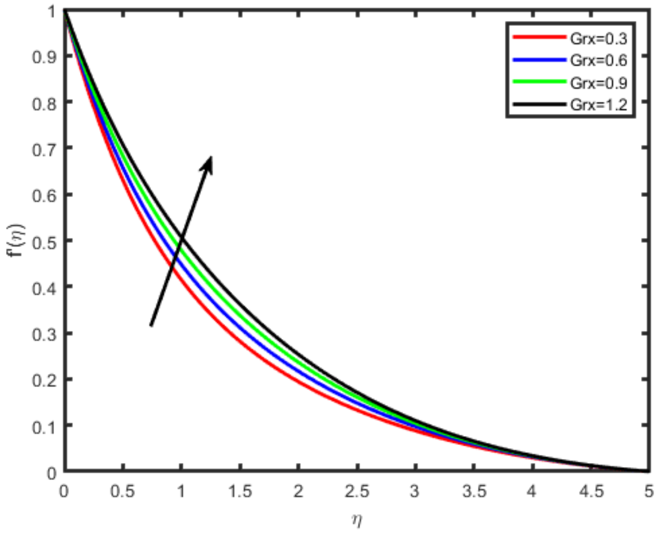

Fig. 3. Effect of Gr on Velocity profile

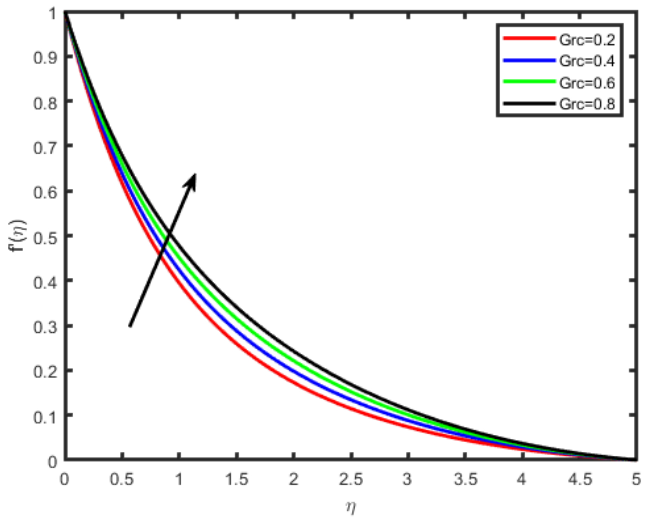

Fig. 4. Effect of Gc on Velocity profile

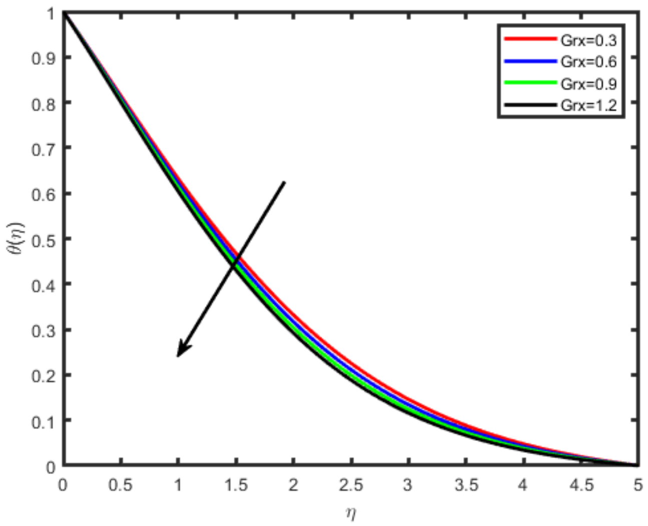

Fig. 5. Effect of Gr on Temperature profile

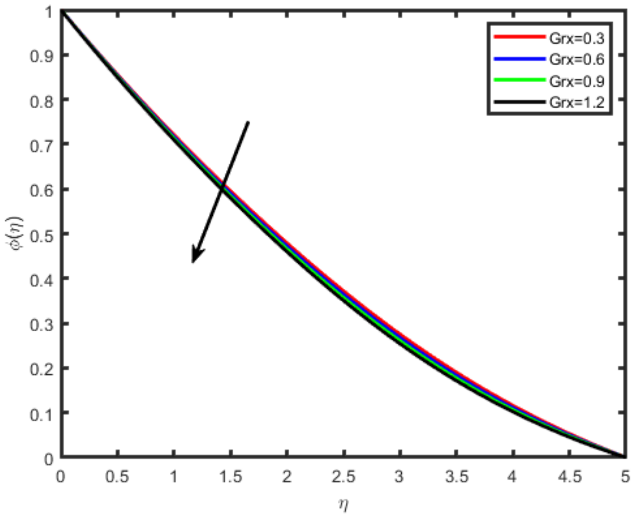

Fig. 6. Effect of Gr on Concentration profile

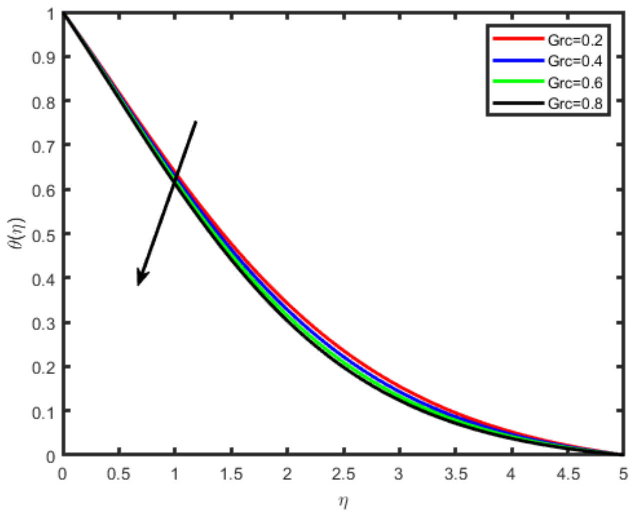

Fig. 7. Effect of Gc on Temperature profile

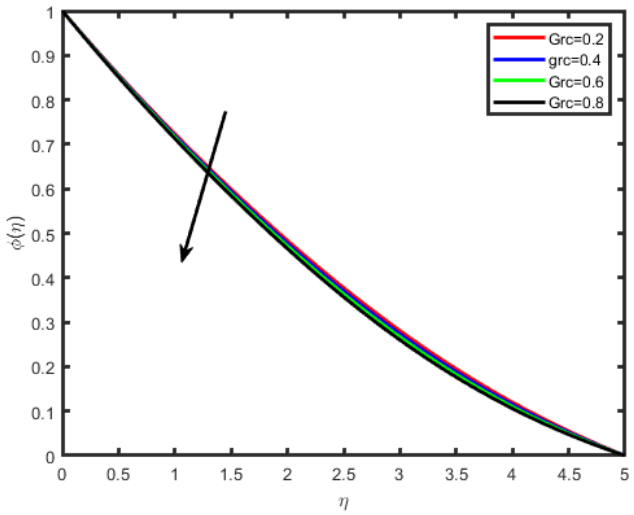

Fig. 8. Effect of Gc on Concentration profile

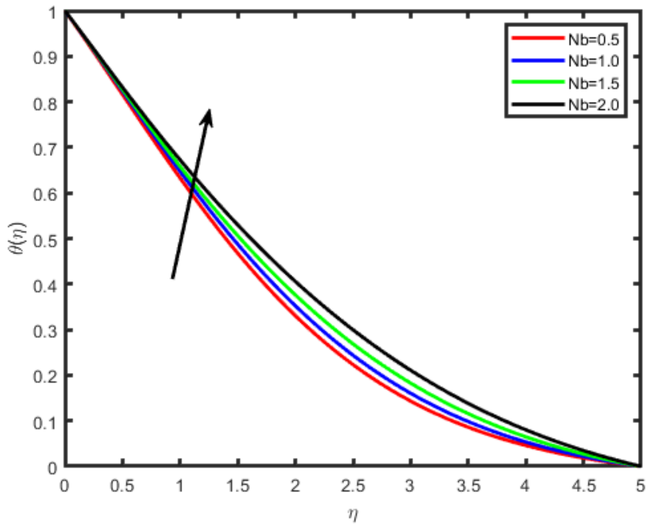

Fig. 9. Effect of Nb on Temperature profile

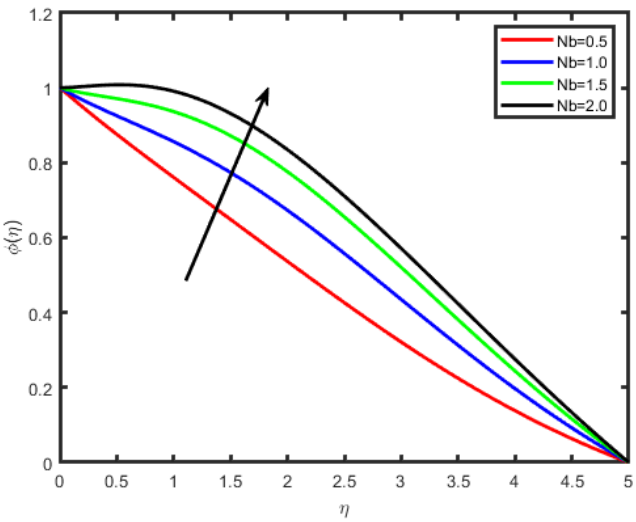

Fig. 10. Effect of Nb on Concentration profile

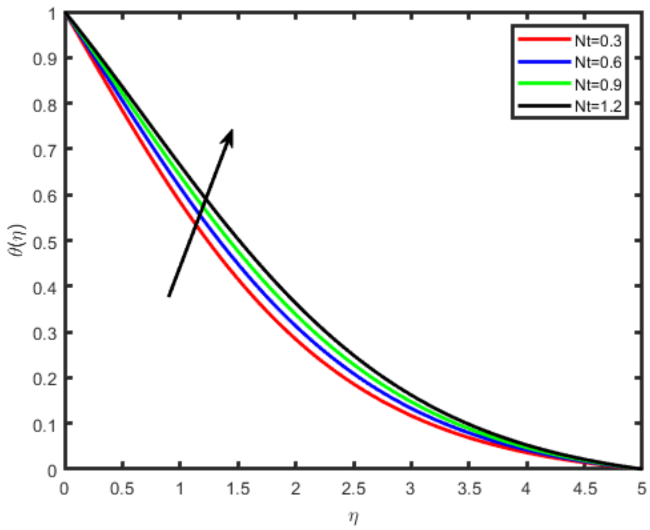

Fig. 11. Effect of Nt on Temperature profile

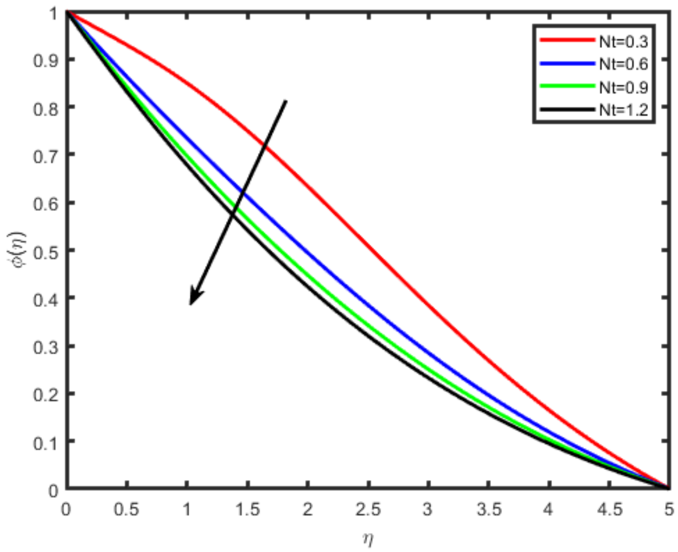

Fig. 12. Effect of Nt on Concentration profile

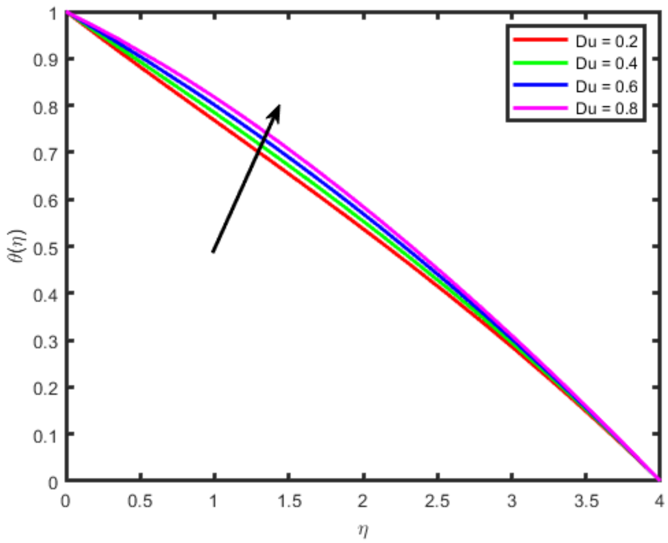

Fig. 13. Effect of Du on Temperature profile

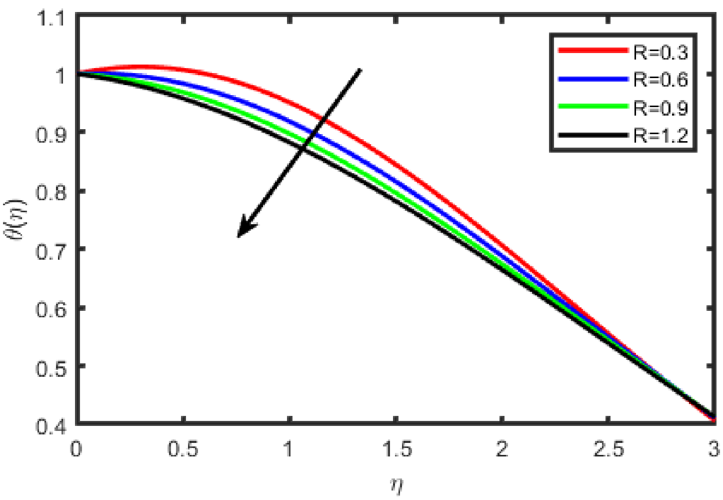

Fig. 14. Effect of Rd on Temperature profile

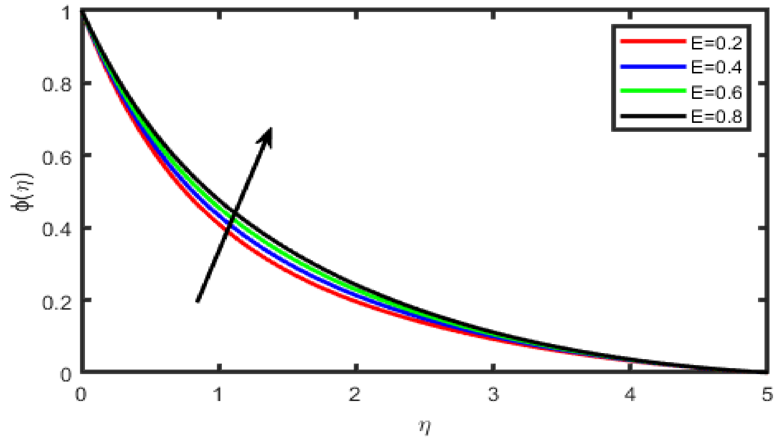

Fig. 15. Effect of E on Concentration profile

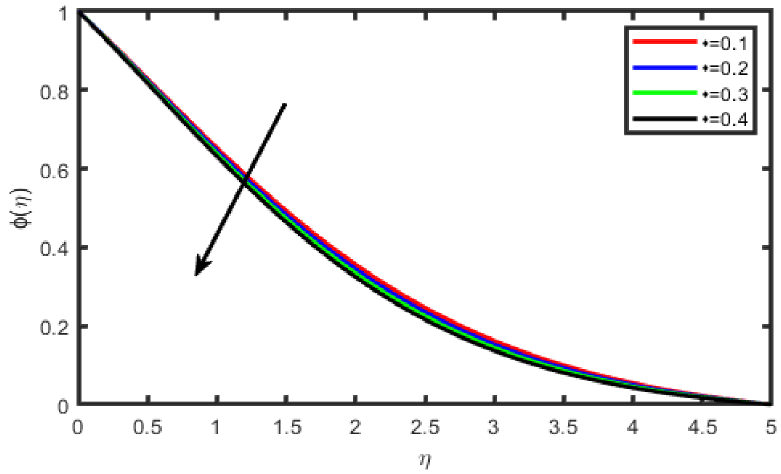

Fig. 16. Effect of δ on Concentration profile

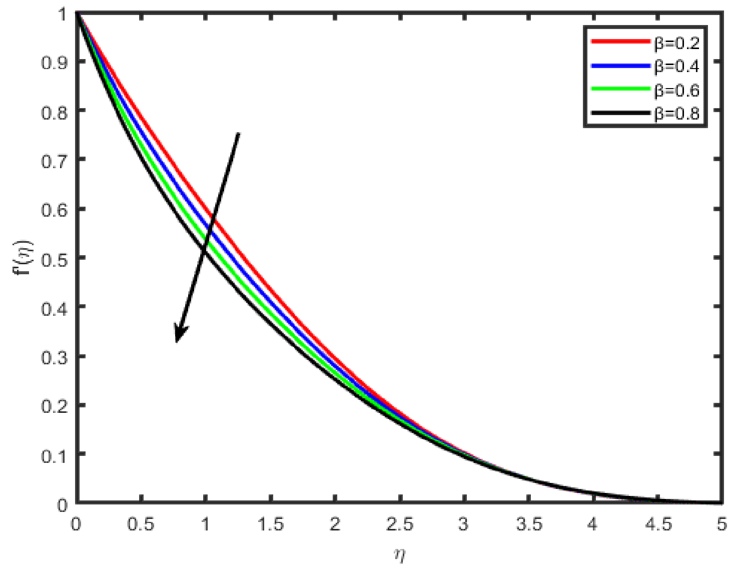

Fig. 17. Effect of β ofn Velocity profile

The numerical values of C_f for dissimilar values of embedded parameters through cone is displayed in Table 1. From the tabular values, it is concluded that the higher thermal Grashof number increase the skin friction, while the greater values of solutal Grashof number, wall suction parameter, and Williamson parameter reduces the skin friction. The numerical values of Nu and Sh for different values of embedded factors is displayed in Table 2. From the tabular values, it is concluded that the higher Brownian motion and Diffusion thermo parameters increases the Nusselt number, while reduces the Sherwood number. Higher thermophoresis parameter and thermal radiation diminishes the Nusselt and Sherwood numbers, whereas the reversal behavior has observed in the case of activation energy. To verify the validity and accuracy of the present analysis, the Sherwood number the results for the mass transfer were compared with those reported by Raghunath *et al.,* [34]. The comparison in the above cases is found to be in excellent agreement, as shown in Table 3.

Table 1
Numerical values of C_f for different values of embedded factors through cone and wedge by taking $\alpha = 45^0$

Grx	Grc	S	E	β	C_f
0.3					-4.6957
0.6					-4.4097
0.9					-4.1847
	0.2				-4.5834
	0.4				-4.7943
	0.6				-5.0943
		0.2			-4.5937
		0.4			-4.8843
		0.6			-5.0043
			0.2		-0.5439
			0.4		-0.4983
			0.8		-0.3043
				0.2	-0.7623
				0.4	-0.6195
				0.6	-0.5347

Table 2
Numerical values N_u and S_h for different values of embedded factors through cone by taking $\alpha=45^0$

K	Rd	E	Nt	Nb	Du	Nu_z	Sh_z
1.5	0.5	0.5	0.3	0.5	1.0	1.9873	0.7575
1.0						1.0544	0.7464
1.5						0.8855	0.9823
	0.3					0.9835	0.8728
	0.6					0.9421	0.7547
		0.2				0.8765	0.8286
		0.4				0.9875	0.7821
			0.6			1.3457	0.9878
			0.9			1.2978	0.8836
				1.0		1.1836	0.9857
				1.5		1.4872	0.7844
					0.2	0.7945	0.42943
					0.4	0.7943	0.4043

Table 3
Comparison of present Sherwood number with the published Sherwood number results of Raghunath *et al.,* [34] when $E=\delta=S=r_1=r_2=Grx=Grc=0$

Du	S_h Raghunath *et al.,* [34]	S_h Present values
0.2	0.47452142	0.47984874
0.4	0.44521478	0.44083271
0.6	0.42852147	0.47974245

6. Conclusions

The following is a condensed version of the conclusions that may be drawn from the numerical results:

i. The reducing impact of Casson parameter on velocity distribution is higher. While an increasing conduct is witnessed in the velocity of the nanofluid flow via thermal and solutal Grashof numbers.
ii. An increase in thermal radiation parameter results in an increase in temperature field.
iii. With increasing values of (Nb) temperature profiles optimized, whereas, concentration profiles declines in the entire fluid regime.
iv. The resultant temperature profiles are enhances with increases Du values.

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