INFLUENCE OF NONLINER CONVECTION AND THERMOPHORESIS ON HEAT AND MASS TRANSFER FROM A ROTATING CONE TO FLUID FLOW IN POROUS MEDIUM

Mallikarjuna BANDARU[1], Mohammad Mehdi Rashidi[2,3], Hariprasad Raju S[4]

1. Department of Mathematics, BMS college of engineering, Bangalore, India-560019.
2. Shanghai Key Lab of Vehicle Aerodynamics and Vehicle Thermal Management Systems, Tongji University, Address: 4800 Cao An Rd., Jiading, Shanghai 201804, China.
3. ENN-Tongji Clean Energy Institute of advanced studies, Shanghai, China.
4. Department of Mathematics, Sri Venkateswara University, Tirupati, India-517501.
*Corresponding Author Email: mm_rashidi@sawtc.com

In this paper, we study the effects of Thermophoresis and nonlinear convection on mixed convective flow of viscous incompressible rotating fluid due to rapidly rotating cone in a porous medium, whose surface temperature and concentration are higher than the temperature and concentration of its surrounding fluid. The governing equations for the conservation of mass, momentum, energy and concentration are transformed, using similarity transformations and the solutions are obtained by employing shooting method that uses Runge-Kutta method and Newton Raphson method. A comparison of the present results with previously published work for special cases shows a good agreement. The effects of temperature and concentration, ratio of angular velocities, relative temperature difference parameter, thermophoretic coefficients on velocity, temperature and concentration profiles as well as tangential and circumferential skin friction coefficients, Nusselt number and Sherwood number results are discussed in detail. The results indicate that the temperature is more influential compared to concentration. Also, the wall thermophoretic deposition velocity changes according to different values of pertinent parameter. Applications of the study arise in aerosol technology, space technology, astrophysics and geophysics, which related to temperature-concentration-dependent density.

KEYWORDS: *Convection; Thermophoresis; Rotating flow; Rotating cone.*

Introduction

Transport process of the mixed convective heat and mass transfer through fluid saturated porous medium play an important role in enormous practical applications in modern industry and engineering fields, such as geothermal energy technology, design of building component, solar power collectors, food industries, oil recovery modeling, thermal insulating systems, nuclear reactors, electronic equipment and compact heat exchangers. These applications can be found to date in the recent books Nield and Bejan et al [1] and Ingham and Pop [2]. Recently, Rashidi [3]–[5] studied the combined free and forced convection flow past a different geometries embedded in a porous medium.

Mixed convective heat and mass transfer over a rotating vertical cone embedded in a fluid saturated porous medium is an important phenomenon for spin stabilized missiles, geothermal reservoirs, rotating heat exchanger and containers of nuclear waste disposal. Earlier, Hering and Grosh [6] investigated combined convection about a rotating vertical cone. They reported the results of buoyancy parameter which gives rise to three convective regions, as purely forced, purely free and combined convection flows. Himasekhar et al [7] studied analytically heat transfer and buoyancy-induced flow around a rotating vertical cone. Saravanan [8] theoretically investigated the effect of magnetic field on the onset of convection in a fluid saturated anisotropic rotating porous medium. Mohiddin et al [9] studied numerically the unsteady free convective heat and mass transfer in a Walters-B viscoelastic flow over a vertical cone. Rashidi et al [10-11] studied analytically the convective heat transfer of magnetized micropolar fluid and viscous dissipative fluid of slip flow induced by rotating disc. Chamkha and Ahmed [12] investigated unsteady MHD double diffusive convective flow in a rotating sphere at different wall conditions. Chamkha and Rashad [13] studied chemical reaction and cross diffusion effects on heat and mass transfer flow over a rotating vertical cone. Mallikarjuna et al [14] studied chemical reaction and thermophoretic effect on convective flow of a viscous fluid over a rotating cone.

Combined heat and mass transfer flow of rotating flow in a porous media has been growing interest the last several decades due to its practical applications in engineering and industrial applications. Salah et al [15] reported the exact solutions of unsteady MHD convective rotating flow of second grade fluid in a porous medium. Bhadauria et al [16] investigated nonlinear thermal instability in a rotating flow. They studied the stability of the system and presented stream lines for different slow times as a function of modulation amplitude. Rashad [17] and Mallikarjuna and Bhuvanavijaya [18] studied the effects of variable properties on unsteady and steady mixed convective flow of a rotating flow on a stretching sheet and vertical plate in a porous medium.

Boussinesq approximation is applicable in cases with a moderate influence of temperature and concentration gradients on the fluid density. Therefore, the density is considered as constant everywhere except in the buoyancy force term. Since the temperature and concentration difference between ambient fluid and cone surface was appreciably large, the mathematical model developed by using a linear density temperature and concentration relation becomes more inaccurate. The heat produced by the viscous dissipation and thermal stratification are also another reasons for the density temperature concentration relationship to become non-linear. The applications related to temperature-concentration-dependent density relation is of immense important in industrial and geothermal engineering, for instance, design of thermal system, cooling transpiration, cooling of electric components, turbine blades, drying of the surfaces, areas of reactor safety, solar collectors, combustion, metallic foams and sponges. In view of the above applications, the authors envisage to investigate the effect of nonlinear convection and thermophoretic on heat and mass transfer flow of rotating fluid over a rotating vertical cone in a fluid saturated Darcy porous medium [22, 23].

Problem formulation

We consider steady, two-dimensional, incompressible rotating Newtonian fluid over a vertical rotating cone in a fluid saturated porous medium. The physical configuration and coordination of the system is given in Fig. 1. We consider the rectangular curvilinear coordinate system. We assume the velocity components u, v and w along tangential (x-axis), azimuthal or circumferential (y-axis), and normal (z-axis) directions, respectively. The cone surface is maintained with variable temperature and concentration, which are greater than free stream fluid temperature and concentration. All the fluid and porous medium properties are assumed to be constant. We assume that the fluid and the porous medium are to be locally thermodynamic equilibrium with solid matrix. Using the above assumptions, Boussinesq and boundary layer approximations; the governing equations for conservation of mass, momentum, energy and species are as follows:

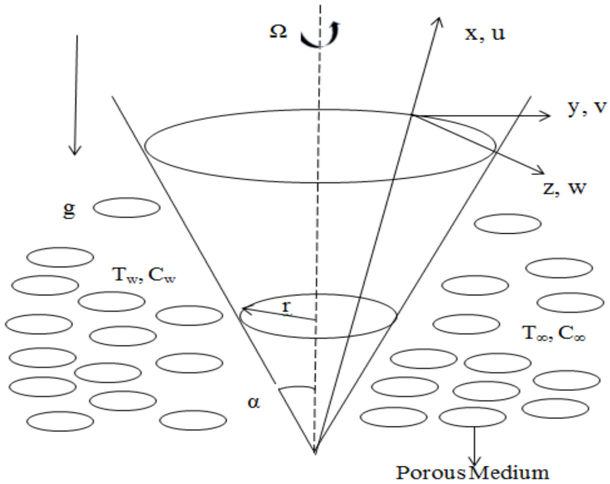

Fig. 1: Physical Configuration and Coordinate System.

$$\frac{\partial u}{\partial x}+\frac{\partial w}{\partial z}+\frac{u}{x}=0 \tag{1}$$

$$u\frac{\partial u}{\partial x}+w\frac{\partial u}{\partial z}-\frac{v^2}{x}=-\frac{v_e^2}{x}+\upsilon\frac{\partial^2 u}{\partial z^2}-\frac{\upsilon}{K}u+g\cos(\alpha)\left[\beta_0\left(T-T_\infty\right)+\beta_1\left(T-T_\infty\right)^2+\beta_2\left(C-C_\infty\right)+\beta_3\left(C-C_\infty\right)^2\right] \tag{2}$$

$$u\frac{\partial v}{\partial x}+w\frac{\partial v}{\partial z}+\frac{uv}{x}=\upsilon\frac{\partial^2 v}{\partial z^2}-\frac{\upsilon}{K}v \tag{3}$$

$$\left(u\frac{\partial T}{\partial x}+w\frac{\partial T}{\partial z}\right)=\frac{k_e}{\rho c_p}\frac{\partial^2 T}{\partial z^2} \tag{4}$$

$$u\frac{\partial C}{\partial x}+w\frac{\partial C}{\partial z}+\frac{\partial}{\partial z}\left(Cv_t\right)=D\frac{\partial^2 C}{\partial z^2} \tag{5}$$

The corresponding boundary conditions are

$$\begin{aligned}&u=0,\, v=r\Omega_1,\, w=0,\, T=T_w(x),\;\; C=C_w(x) \quad \text{at} \;\; z=0\\ &u=0,\, v=0,\, T=T_\infty,\, C=C_\infty \qquad\qquad\qquad \text{as} \;\; z\to\infty\end{aligned} \tag{6}$$

where $r = x\sin(\alpha)$ is the radius of the cone, Ω_1, Ω_2 are the angular velocities of the cone and free stream, respectively, $\beta_o, \beta_1, \beta_2, \beta_3$ are thermal and solutal diffusivities, ρ is the fluid density, μ is the dynamic viscosity, c_p is the specific heat at constant pressure, g is the acceleration due to gravity. Also α represents the cone apex half angle, K is the permeability of the porous medium, k_e is the effective thermal conductivity and D is the molecular diffusivity.

The thermophoretic velocity v_t which appear in Eq. (5) recommended by Talbot et al [19] as

$$v_t=-k\upsilon\frac{\partial T}{\partial z} \tag{7}$$

where k is the thermophoretic coefficient, whose values range from 0.2 and 1.2 and $k\upsilon$ is the thermophoretic diffusivity.

Non-Dimentionalisation

Now we introduce the following non-dimensional variables to get the non-dimensional governing equations

$$\eta=\left(\frac{\Omega\sin(\alpha)}{\upsilon}\right)^{1/2}z,\, u=x\Omega\sin(\alpha)F(\eta),\, v=x\Omega\sin(\alpha)G(\eta),\;\; w=\left(\upsilon\Omega\sin(\alpha)\right)^{1/2}H\left(\eta\right),$$

$$\theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty},\;\; \phi(\eta)=\frac{C-C_\infty}{C_w-C_\infty},T_w(x)-T_\infty=\frac{\left(T_L-T_\infty\right)x}{L},\;\; C_w(x)-C_\infty=\frac{\left(C_L-C_\infty\right)x}{L} \tag{8}$$

where L being the cone slant height and T_L being the cone surface temperature and C_L being the cone surface concentration at the base(x=L). Using equations (7) and (8), the equations (1) – (6) reduces to

$$F=-\frac{1}{2}H' \tag{9}$$

$$H'''-HH''-Da^{-1}H+\frac{1}{2}H'^2-2\left(G^2-\left(1-\lambda\right)^2\right)-2g_s\left[\left(\theta+\alpha_1\theta^2\right)+N\left(\phi+\alpha_2\phi^2\right)\right]=0 \tag{10}$$

$$G'' - HG' + H'G - Da^{-1}G = 0 \tag{11}$$

$$\theta'' - \Pr\left(H\theta' - \frac{1}{2}H'\theta \right) = 0 \tag{12}$$

$$\phi'' + Sc\left(\frac{1}{2}H'\phi - H\phi' \right) + \frac{N_t ScK}{\theta N_t + 1}\left(\phi'\theta' + \phi\theta'' - \frac{N_t \phi \theta'^2}{\theta N_t + 1} \right) = 0 \tag{13}$$

Boundary conditions

$$\begin{aligned} &H = 0,\ \ H' = 0,\ \ G = \lambda,\ \ \ \theta = 1,\ \ \ \phi = 1 \ \ \text{at } \eta = 0 \\ &H' = 0,\ \ G = 1 - \lambda,\ \ \ \theta = 0,\ \ \ \phi = 0 \ \ \ \ \text{as } \eta \to \infty \end{aligned} \tag{14}$$

where $Da^{-1} = \dfrac{\upsilon}{K\Omega \sin\alpha}$ is the inverse of Darcy number, $Gr = \dfrac{g\beta_T (T_\omega - T_\infty) L^3 \cos\alpha}{\upsilon^2}$ is the Grashof number, $N = \dfrac{\beta_c (C_w - C_\infty)}{\beta_t (T_w - T_\infty)}$ is the buoyancy ratio, $\alpha_1 = \dfrac{\beta_1}{\beta_0}(T_w - T\infty)$, $\alpha_2 = \dfrac{\beta_3}{\beta_2}(C_w - C_\infty)$ $\mathrm{Re} = \dfrac{\Omega L^2 \sin\alpha}{\upsilon}$ is the local Reynolds number, $g_s = \dfrac{Gr}{\mathrm{Re}^2}$ is the mixed convection parameter, $\Pr = \dfrac{\mu C_p}{k_e}$ is the Prandtl number, $Sc = \dfrac{\upsilon}{D}$ is the Schmidt number, $N_t = \dfrac{T_w - T_\infty}{T_\infty}$, is the temperature difference parameter, Ω_1 and Ω_2 are the angular velocities of the cone and free stream fluid respectively, $\Omega_1 + \Omega_2 = \Omega$ and $\lambda = \dfrac{\Omega_1}{\Omega}$.

Skin-Friction, Nusselt Number and Sherwood Number

The physical parameters of interest, local skin friction coefficients in x and y-directions, local Nusselt number, local Sherwood number and wall thermophoretic deposition velocity in non-dimensional form are given by

$$C_{fx}\mathrm{Re}^{1/2} = -H''(0), \quad 2^{-1}\mathrm{Re}^{1/2} C_{fy} = -G'(0), \quad \mathrm{Re}^{-1/2} Nu_x = -\theta'(0), \quad \mathrm{Re}^{-1/2} Sh_x = -\phi'(0),$$

$$V_t = \left(\frac{-k\ N_t}{N_t + 1} \right)\theta'(0) \tag{15}$$

Numerical Method of Solution

The set of equations (9) – (13) with boundary conditions (14) are solved by using shooting method that uses Runge-Kutta method and Newton-Raphson method (Srinivasacharya et al [20]). At first Eqs. (9) – (13) are converted into a system of differential equations of first order, by assuming

$H = X_1,\ G = X_4,\ \theta = X_6,\ \phi = X_8,$ We get

$$H' = X_2,\ H'' = X_3,\ G' = X_5,\ \theta' = X_7,\ \phi' = X_9 \tag{16}$$

$$H''' = X_1 X_3 - \frac{1}{2}X_2^2 + Da^{-1}X_2 + 2\left(X_4{}^2 - (1-\lambda)^2 \right) + 2g_s\left[X_6 + \alpha_1 X_6{}^2 + N\left(X_8 + \alpha_2 X_8^2 \right) \right] \tag{17}$$

$$G'' = X_1 X_5 - X_2 X_4 + Da^{-1}X_4 \tag{18}$$

$$\theta'' = \Pr\left(X_1 X_7 - \frac{1}{2} X_2 X_6 \right) \tag{19}$$

$$\phi'' = Sc\left(X_1 X_9 - \frac{1}{2} X_2 X_8 \right) - \frac{NtSck}{X_6 Nt + 1}\left(X_7 X_9 + X_8 \Pr\left(X_1 X_7 - \frac{1}{2} X_2 X_6 \right) - \frac{Nt X_8 X_7^{\,2}}{X_6 Nt + 1} \right) \tag{20}$$

with Boundary conditions

$$X_1(0) = 0, X_2(0) = 0, X_4(0) = \lambda, X_6(0) = 1, X_8(0) = 1,$$
$$X_2(\infty) = 0, X_4(\infty) = 1 - \lambda, X_6(\infty) = 0, X_8(\infty) = 0 \tag{21}$$

We assume the initial conditions for $X_3(0), X_5(0), X_7(0)$ which are not given at z = 0 (initial conditions) and then the Eqs. (16) – (21) are integrated using fourth order Runge-Kutta method from $\eta = 0$ to $\eta_{\max}$ over successive step lengths $\Delta\eta$, where $\eta_{\max}$ is η at ∞ and chosen large enough so that the solution shows little further change for η larger than $\eta_{\max}$. We employed ODE45 solver in MATLAB® to solve these nine first ordered coupled nonlinear ordinary differential equations. The accuracy of the assumed values for $X_3(0), X_5(0), X_7(0)$ is then checked by comparing the calculated values of X_2, X_4, X_6, X_8 at $\eta = \eta_{\max}$ with their given value at $\eta = \eta_{\max}$. If a difference exists, another set of initial values for $X_3(0), X_5(0), X_7(0)$ are assumed and the process is repeated. In principle, a trial and error-method can be used to determine these initial values, but it is tedious.

Alternatively, we used Newton-Raphson method to accurately find the initial values of $X_3(0), X_5(0), X_7(0)$ and then integrate equations (16) – (20) by using fourth order Runge-Kutta method. This process is continued until the agreement between the calculated and the given condition at $\eta = \eta_{\max}$ is within the specified degree of accuracy 10^{-5}.

Code Validation

In the absence of mass transfer with thermophoresis, and inverse Darcy parameter and without rotating fluid for linear convection, the nonlinear ordinary differential equations (16) – (20) with corresponding boundary conditions (21) exactly coincides with those of Hering and Grosh [6] and Himasekhar et al [7]. The comparison results found very good agreement with earlier existing results as shown in table 2 and table 3.

Table-2: The values of $-H''(0), -G'(0)$ and $-\theta'(0)$ for different values of $g_s = \dfrac{Gr}{\mathrm{Re}^2}$, for Pr = 0.7, $\alpha_1 = 0, \alpha_2 = 0$, Da^{-1}=0, $\lambda = 1$, and N = 0 (in the absence of concentration equation without rotating flow)

	-H″(0)	**-G′(0)**	**-θ′(0)**

Gr/Re^2	**Hering and Grosh [6]**	**Present work**	**Hering and Grosh [6]**	**Present work**	**Hering and Grosh [6]**	**Present work**
0	1.0205	1.0203	0.61592	0.61583	0.42852	0.42842
1.0	2.2078	2.2075	0.85076	0.85080	0.61202	0.61213
100	46.052	46.0523	2.4738	2.47382	1.7946	1.79459

Table-3: The values of $-H''(0)$, $-G'(0)$ and $-\theta'(0)$ for different values of Pr for $g_s = \frac{Gr}{\mathrm{Re}^2} = 0.1$, $Da^{-1}=0$, $\alpha_1 = 0, \alpha_2 = 0$, $\lambda = 1$, and N = 0 (in the absence of concentration equation without rotating flow)

Pr	**$-H''(0)$**		**$-G'(0)$**		**$-\theta'(0)$**	
	Himasekhar et.al [7]	**Present work**	**Himasekhar et.al [7]**	**Present work**	**Himasekhar et.al [7]**	**Present work**
1.0	1.1282	1.12824	0.6437	0.64374	0.5457	0.54573
2.0	1.1120	1.11203	0.6335	0.63347	0.7450	0.74502
10	1.0702	1.07018	0.6202	0.62021	1.4106	1.41066

Results and Discussion

In order to discuss the results, the computational calculations are presented in the form of non-dimensional velocity, temperature and concentration profiles, as well as skin-friction, local rate of heat and mass transfer and wall thermophoretic velocity. In this problem we considered the fluid as air (Pr = 0.72) and the species is hydrogen (Sc = 0.22) and mixed convective parameter $g_s = 1$ represents the equal influence of free and forced convection, is responsible for the flow. The effects of the angular velocity ratio, nonlinear temperature, concentration and thermophoretic coefficients are shown in Figs. 2-20 for various values of fluid and physical properties.

Figures 2-5 show the effects of the nonlinear temperature (α_1) and concentration (α_2) on tangential and circumferential velocity, temperature and concentration profiles, respectively. Increasing nonlinear temperature parameter α_1 (α_2 is fixed) serves to enhance the tangential flow velocity (Fig. 2), i.e. accelerates the flow. This effect is accentuated close to the cone where a peak in velocity arises.

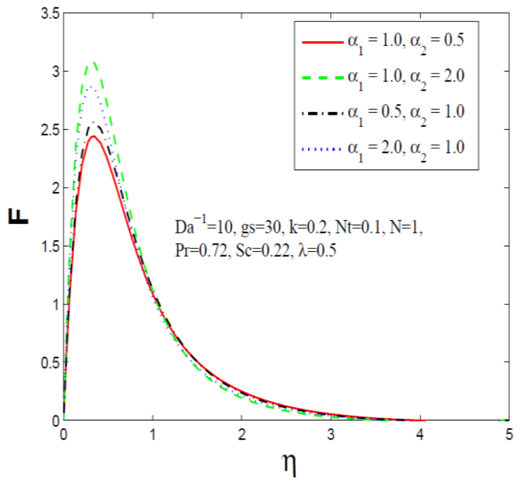

Fig 2: Tangential velocity profile (F) for different values of α_1 and α_2.

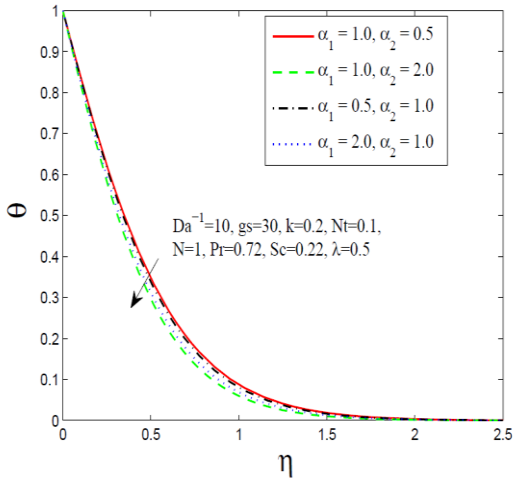

Fig 4: Temperature profile (θ) graph for different values of α_1 and α_2.

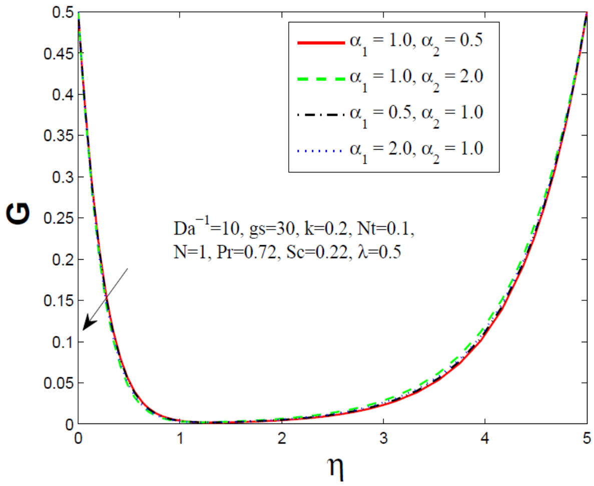

Fig 3: Circumferential velocity profile (G) for different values of α_1 and α_2.

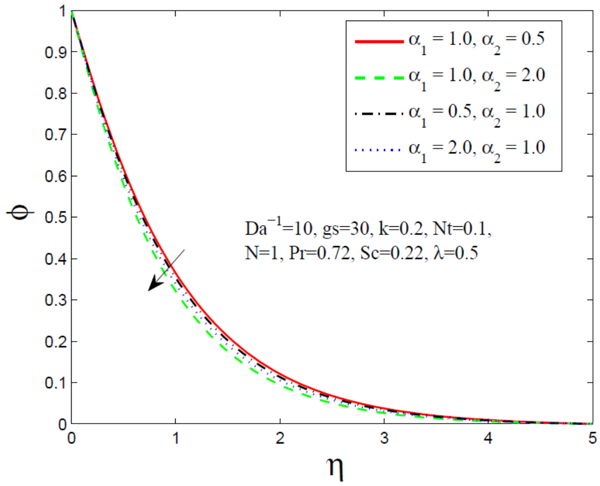

Fig 5: Concentration profile (ϕ) for different values of α_1 and α_2.

The influence of nonlinear concentration parameter α_2 (α_1 is fixed) on tangential velocity reported similar behavior to that of α_1. Thus, hydrodynamic boundary layer thickness is increased near to the surface for different values of α_1 and α_2. From the Fig. 3, we notice that increasing α_1 leads to depreciate the circumferential velocity profile near to the cone surface until getting to certain point and then enhanced when α_2 is fixed. The similar results are reported for different values of α_2 when α_1 is fixed. The effects of nonlinear temperature and concentration parameter on the boundary layer flow are represented in figures 4 and 5. It is noticed from these figures that temperature and concentration profiles are decreased with increasing values of α_1 and α_2. It is important to note that the influence of nonlinear concentration parameter α_2 on velocity, temperature and concentration profiles seems to be more prominent compared with that of nonlinear temperature parameter α_1.

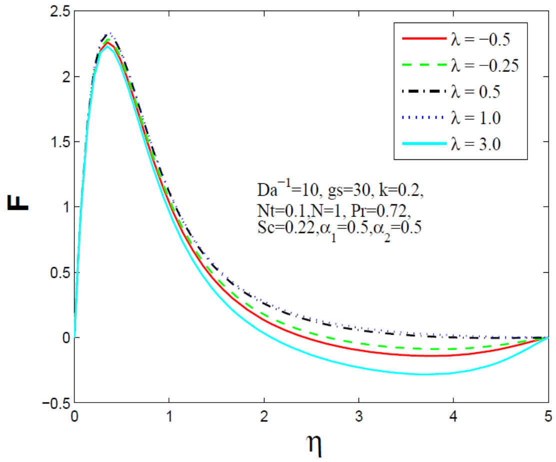

Fig 6: Tangential velocity profile (F) for different values of λ.

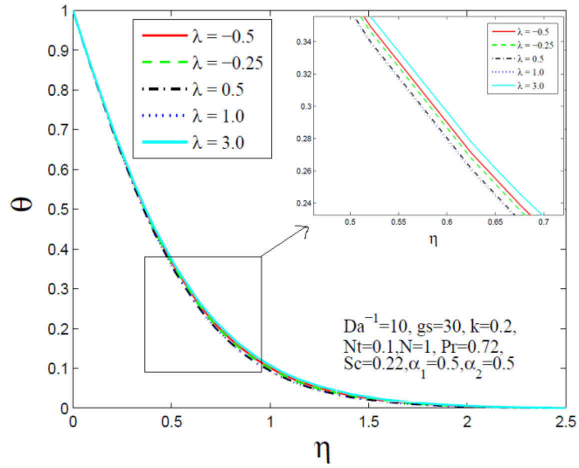

Fig 8: Temperature profile (θ) for different values of λ.

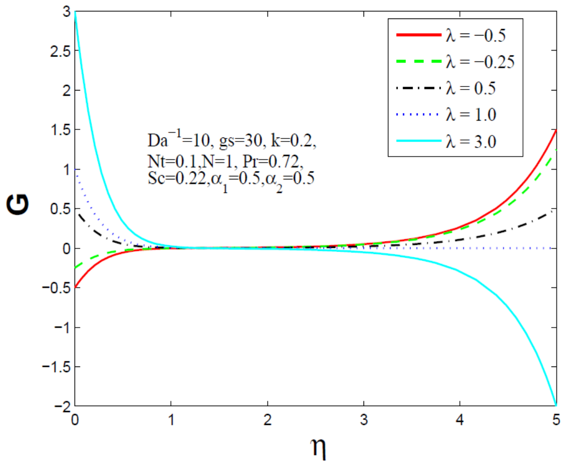

Fig 7: Circumferential velocity profile (G) graph for different values of λ.

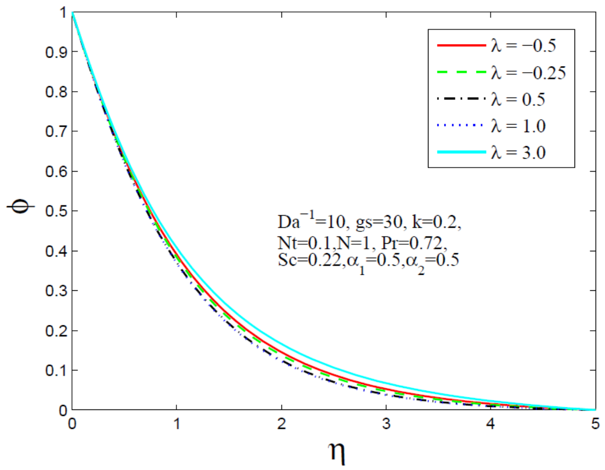

Fig 9: Concentration profile (ϕ) for different values of λ.

Figures 6 – 9 are plotted to see the variation of the ratio of angular velocities λ. The value $\lambda = 0$ represents the fluid is rotating and cone is at rest while the fluid and cone are rotating with same angular velocities in the same direction for $\lambda = 0.5$. From fig. 6 we observed that for $\lambda > 0.5$, the tangential velocity decreases and the opposite behavior exist for $\lambda < 0.5$. It should be noted that for certain values of physical parameters, these results are opposite to the finding by Nadeem and Saleem [21] for unsteady flow of non-Newtonian nanofluid. We observed from Fig. 7 that, circumferential velocity increases for larger values of λ for both cases of $\lambda < 0.5$ and $\lambda > 0.5$ near to the cone surface, $(0 < \eta < 1.2)$ when η range is $1.2 < \eta < 5$, the circumferential velocity profile reported opposite results. It is noticed from figs. 8 and 9 that, temperature and concentration profiles are decreased as λ increases for the case of $\lambda < 0.5$, however these results are reported opposite for the case $\lambda > 0.5$.

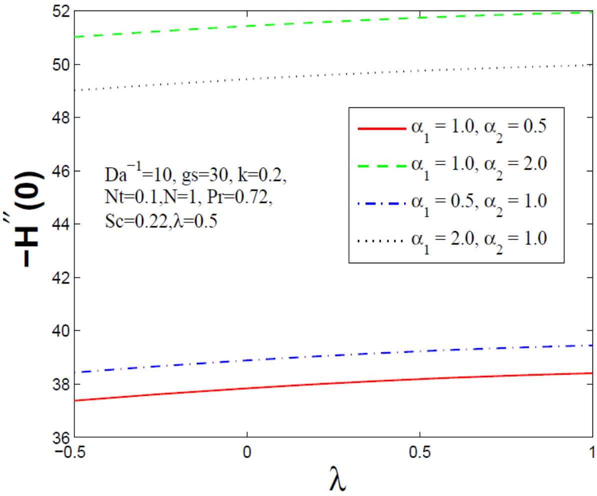

Fig 10: Tangential skin friction coefficient (C_{fx}) for different values of α_1 and α_2.

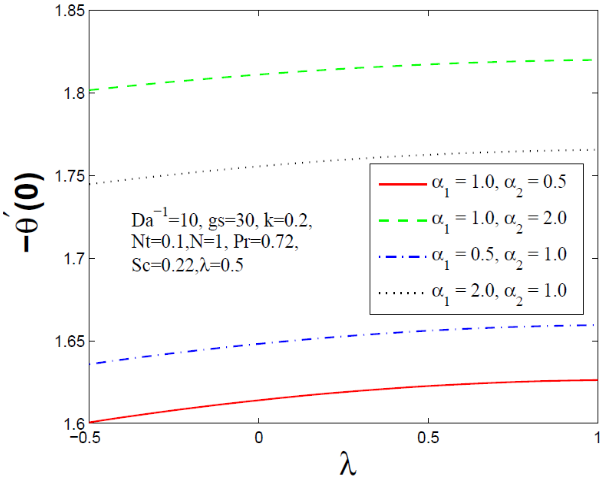

Fig 12: Nusselt number $-\theta''(0)$ for different values of α_1 and α_2.

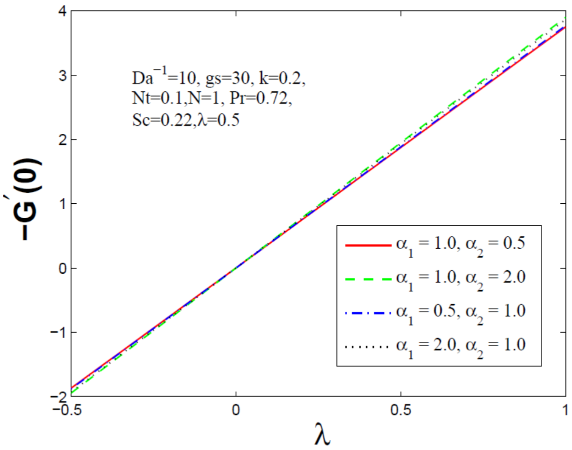

Fig 11: Circumferential skin friction coefficient(C_{fy})for different values of α_1 and α_2.

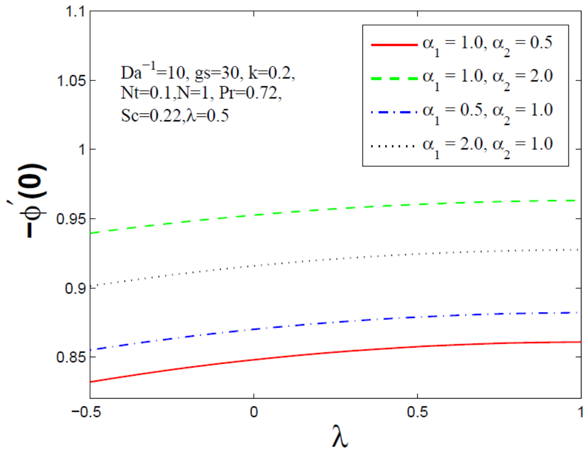

Fig 13: Sherwood number ($-\phi''(0)$) for different values of α_1 and α_2.

Figs 10 and 11 show the effect of nonlinear convection parameters α_1 and α_2 on tangential and circumferential skin friction coefficients. From these figures we notice that tangential and circumferential skin friction coefficients are increased for larger values of α_1 and α_2. The influence of nonlinear parameters α_1 and α_2 on local rate of heat and mass transfer are given in figures 12 and 13, respectively. It is seen from these figures that, increasing α_1 and α_2, local rate of heat transfer (Nusselt number) and mass transfer (Sherwood number) results are increased which similar to that of skin friction coefficients as shown in figures 10 and 11. It is to be noted that influence of α_1 produces more dominant results compared to the results of α_2.

In order to discuss the influence of thermophoresis on particle deposition onto a rotating vertical cone surface, the tangential and circumferential skin friction coefficients and Nusselt number and Sherwood number are shown in figures 14 – 17, respectively, for representative relative temperature difference parameter (N_t) and thermophoretic coefficient (k). It is observed from these figures that tangential and skin friction coefficients and Nusselt number results are increased for

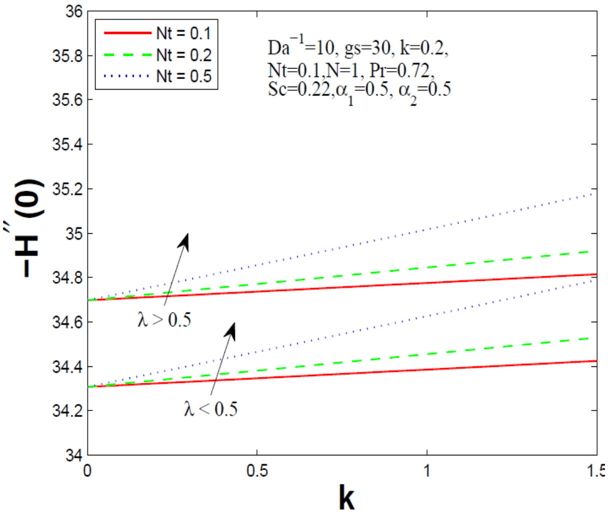

Fig 14: Tangential skin friction coefficients (C_{fx}) for different values of Nt.

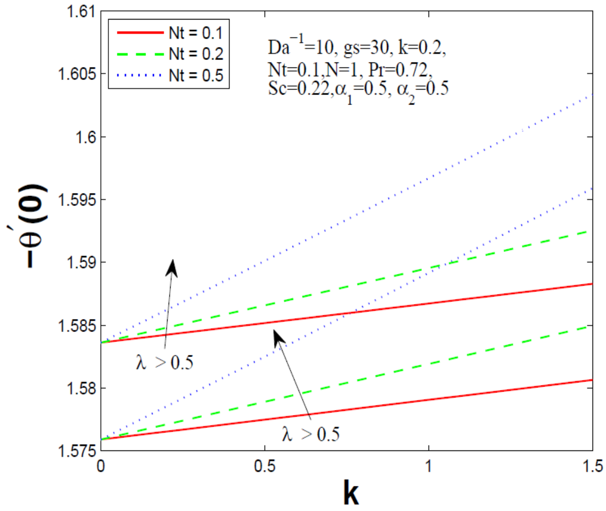

Fig 16: Nusselt number ($-\theta''(0)$) for different values of Nt.

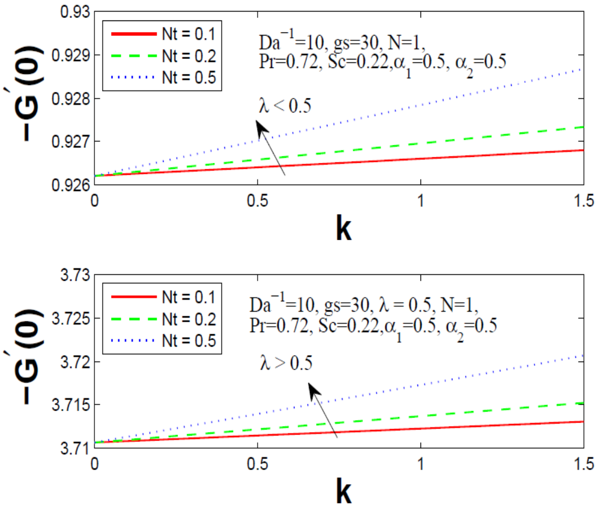

Fig 15: Circumferential skin friction coefficient (C_{fy}) for different values of Nt.

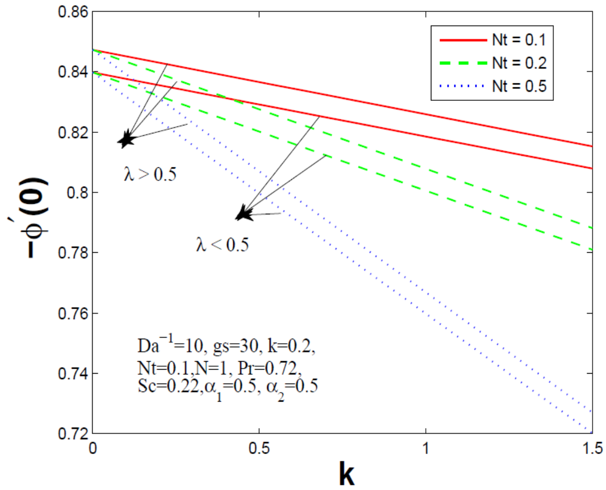

Fig 17: Sherwood number ($-\phi''(0)$) for different values of Nt.

increasing values of N_t and k for both cases of $\lambda > 0.5$ and $\lambda < 0.5$, but the opposite results are reported on Sherwood number, i.e., the Sherwood number results are decreased with increasing values of N_t and k as shown in fig. 17. It is worth to mention that these results are more pronounced for $\lambda > 0.5$ compared to $\lambda < 0.5$.

Figures 18 and 19 display non-dimensional wall thermophoretic velocity (V_{tw}) for different values of nonlinear parameters α_1, α_2 and ratio of angular velocities (λ). From these figures we say that the wall thermophoretic velocity decreases for increasing values of α_1 and α_2. It is also observed from these figures that increasing λ leads to decrease the wall thermophoretic velocity deposition.

Variation of wall thermophoretic velocity $\left(V_{tw}\right)$ for various values of N_t and k is shown in Fig. 20. This figure shows the usual decreasing effect of N_t and thermophoretic coefficient on wall thermophoretic velocity $\left(V_{tw}\right)$.

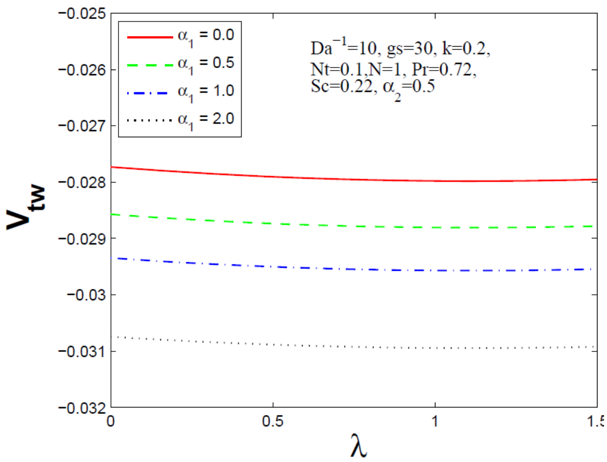

Fig 18: Wall thermophoretic velocity (V_{tw}) for different values of α_1.

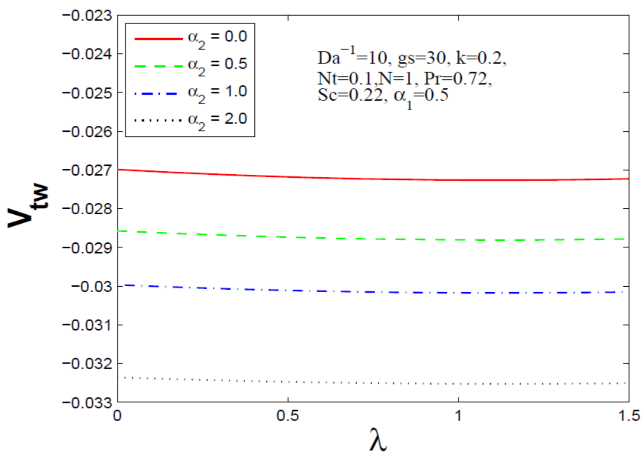

Fig 19: Wall thermophoretic velocity (V_{tw}) for different values of α_2.

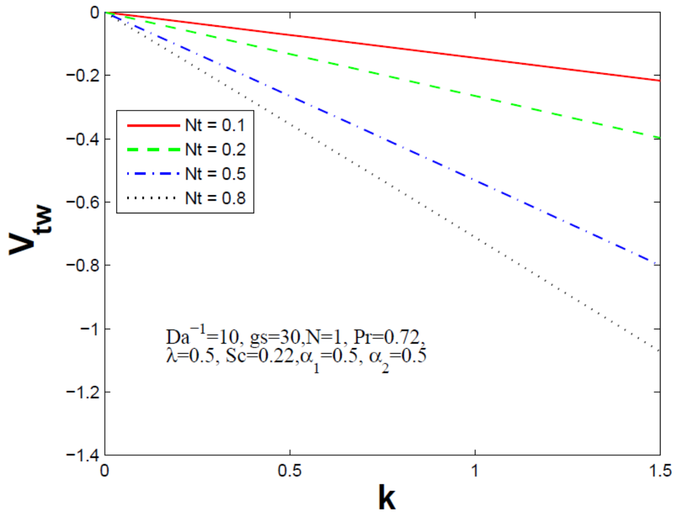

Fig 20: Wall thermophoretic velocity (V_{tw}) for different values of Nt.

Conclusion

Effects of nonlinear convection and thermophoretic on heat and mass transfer flow of a Newtonian incompressible rotating fluid over a rotating vertical cone have been analyzed. In order to determine velocity, temperature and concentration profiles as well as skin friction coefficients, Nusselt number and Sherwood number, we used similarity transformations and numerical method (shooting method). The effects of nonlinear convection parameter, ratio of angular velocities, relative temperature difference parameter and thermophoretic coefficient are examined. These results are reported in the form of graphs. The major conclusions of the present investigation are given as follows: Increasing nonlinear temperature and concentration parameters leads to enhance the tangential velocity profiles but circumferential velocity, temperature and concentration profiles are decreased. The tangential and circumferential skin friction coefficients, Nusselt number and Sherwood numbers results are increased for larger values of nonlinear temperature and concentration parameter. Tangential velocity, temperature and concentration profiles are decreased with increasing values of ratio of angular velocity λ for $\lambda<0.5$. For $\lambda>0.5$ the opposite results are reported. But circumferential velocity profiles produces opposite to that of tangential velocity profile for larger values of λ. The tangential and circumferential skin friction coefficients, Nusselt number and results are decreased for larger values of relative temperature difference parameter and thermophoretic coefficient. But opposite results are produced on Sherwood number. The wall thermophoretic velocity decreases with increasing of nonlinear temperature and concentration, temperature difference parameter, thermophoretic coefficient and ratio of angular velocity.

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