

# Effect of Rotation on Thermosolutal Convection in Visco-elastic Nanofluid with Porous Medium

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**Abstract:** In this paper, we studied the rotation effect on the thermosolutal convection in visco-elastic nanofluid in the presence of porous medium using Walters` (model B`). To solve the conservation equation, we used the normal mode technique and Galerkin weighted residual method. For stationary convection, the onset criterion derived analytically and experiential that visco-elastic nanofluid behaves as a regular Newtonian nanofluid. The effect of rotation, thermo-nanofluid Lewis number, thermosolutal Lewis number and solutal Rayleigh number analyze analytically and graphically.

**Keywords-** Nanofluid; thermosolutal instability; Walters` (model B`); porous medium; rotation.

## 1. Introduction

The problem of thermosolutal convection in porous medium has motivated during the last few decades, because it has various applications in soil science, oceanography, engineering, astrophysics etc. The thermal instability for Newtonian fluid with hydrodynamic and hydromagnetic assumptions was discussed by Chandrasekhar [2]. Kuznetsov and Nield [6] investigated theoretically the expression for thermal Rayleigh number, the condition for oscillatory motions derived and the instability of nanofluids using conservation equation. The nanofluid was firstly used by Choi [4] in regular fluid with nanometer sized particles for the colloidal suspension. The nanoparticles size is less than 100 nm in a base fluid, in nanofluids, for instance water, engine oils, ethanol are commonly used as base fluids. The materials of nanoparticles may be in use as nitrides (AlN, SiN), metal carbides (SiC), oxide ceramics ( $Al_2O_3$ , CuO) or metals (Cu, Al). Kuznetsov and Nield was studied to the convection in a binary nanofluid layer in porous medium. The thermosolutal and thermal instability problems for Walters` (model B`) with elastico-viscous fluid in a porous medium studied by Rana and Sharma [9]. Gupta et al. studied the effect of horizontal magnetic field on nanofluid convection [5]. Pundir et al. studied on the onset of thermosolutal convection of an elastico-viscous nanofluid in porous medium in presence of magnetic field [8]. Sharma and Gupta studied double diffusive nanofluid convection in porous medium with rotation using Darcy-Brinkman model [10]. The effect of rotation on nanofluid convection in porous was studied by Chand and Rana [3]. We are investigate the effect of rotation on thermosolutal convection of visco-elastic nanofluid presence of porous medium using Walters` (model B`). The coriolis force term is added in the momentum equation due to the presence of rotation so we introduce a non-dimensional rotation parameter Taylor number. The problem is analized with normal mode technique and Galerkin weighted residual method. The effect of rotation, thermo-nanofluid Lewis number, thermosolutal Lewis number and solutal Rayleigh number analyze graphically.

## 2. Mathematical Model

Here we regard a rotating horizontal layer with thickness  $d$  and angular velocity  $\Omega$  of Walters' (model B') elastico-viscous nanofluid situated between the plates  $z = 0$  and  $z = d$ . The fluid layer is heated from lower layer and working upwards direction with a gravity force  $\mathbf{g} = (0, 0, -g)$ . Temperature  $T_D$ , concentration  $C_D$  and volumetric fraction  $\varphi_D$  of nanoparticle, at the lower boundary and upper boundary are taken to be  $T_1$  and  $T_0$ ,  $C_1$  and  $C_0$ ,  $\varphi_1$  and  $\varphi_0$  respectively, with  $T_1 > T_0$ ,  $C_1 > C_0$  and  $\varphi_0 > \varphi_1$ . The governing equation for Walters' (model B') elastico-viscous nanofluid in porous medium as given by Yadav et al. [11] and Nield and Kuznetsov [7] are:

$$\nabla \mathbf{q}_D = 0 \quad (1)$$

$$\frac{\rho}{\varepsilon} \frac{\partial \mathbf{q}_D}{\partial t} = -\nabla p + (\varphi_D \rho_p + (1 - \varphi_D) \{ \rho (1 - \alpha_T (T_D - T_0) - \alpha_C (C_D - C_0)) \}) \mathbf{g} - \frac{1}{k} \left( \mu - \mu' \frac{\partial}{\partial t} \right) \mathbf{q}_D + \mu \nabla^2 \mathbf{q}_D + \frac{2\rho}{\varepsilon} (\mathbf{q}_D \times \Omega) \quad (2)$$

where  $\mathbf{q}_D, p, \mu, \mu', \mathbf{g}, k, \rho, \varepsilon, \varphi_D, \alpha_C$ , and  $\alpha_T$  denoted by the Darcy velocity, hydrostatic pressure, viscosity, viscoelasticity, acceleration attainable to gravity, medium permeability, density, porosity, volume fraction of nanoparticles, solute concentration and coefficient of thermal expansion respectively.

For the nanofluid, the equation of thermal energy is given as:

$$(\rho_c)_m \frac{\partial T_D}{\partial t} + \rho_c \mathbf{q}_D \cdot \nabla T_D = k_m \nabla^2 T_D + \varepsilon (\rho_c)_p \left[ D_B \nabla \varphi_D \cdot \nabla T_D + \frac{D_T}{T_0} \nabla T_D \cdot \nabla T_D \right] + \rho_c D_{TC} \nabla^2 C_D \quad (3)$$

where  $D_{TC}$  is a Dufour diffusivity,  $k_m$  is thermal conductivity,  $(\rho_c)_p$  is the heat capacity of nanoparticles and  $(\rho_c)_m$  is heat capacity of the fluid in porous medium.

For the nanoparticles, the continuity equation given by Biongiorno [1] as:

$$\frac{\partial \varphi_D}{\partial t} + \frac{\mathbf{q}_D}{\varepsilon} \cdot \nabla \varphi_D = D_B \nabla^2 \varphi_D + \frac{D_T}{T_0} \nabla^2 T_D \quad (4)$$

where  $D_B$  and  $D_T$  are the Brownian diffusion coefficient and the thermoporetic diffusion coefficient, respectively.

The equation of conservation of solute concentration is given as:

$$\frac{\partial C_D}{\partial t} + \frac{1}{\varepsilon} \mathbf{q}_D \cdot \nabla C_D = D_S \nabla^2 C_D + D_{CT} \nabla^2 T_D \quad (5)$$

where  $D_{CT}$  and  $D_S$  are Soret type diffusivity and the solute diffusivity of porous medium.

The boundary conditions are given as:

$$q = 0, \quad T_D = T_1, \quad \varphi_D = \varphi_1, \quad C_D = C_1 \text{ at } z = 0 \quad (6)$$

$$q = 0, \quad T_D = T_0, \quad \varphi_D = \varphi_0, \quad C_D = C_0 \text{ at } z = d \quad (7)$$

We establish nondimensional variables as:

$$(x^*, y^*, z^*) = \frac{(x, y, z)}{d}, \quad \mathbf{q}^* = \mathbf{q}_D \frac{d}{\alpha_m}, \quad t^* = \frac{t \alpha_m}{\sigma d^2}, \quad p^* = \frac{pk}{\mu \alpha_m}, \quad \phi^* = \frac{\varphi_D - \varphi_1}{\varphi_0 - \varphi_1},$$

$$T^* = \frac{T_D - T_0}{T_1 - T_0}, \quad C^* = \frac{C_D - C_0}{C_1 - C_0},$$

$$\text{where } \alpha_m = \frac{k_m}{\rho_c}, \quad \sigma = \frac{(\rho_c)_m}{\rho_c}.$$

Dropping the star (\*) for simplification. Equations (1) and equation (5) to (10) reduce in non-dimensional form:

$$\nabla \mathbf{q} = 0 \quad (8)$$

$$0 = -\nabla p - \left( 1 - F \frac{\partial}{\partial t} \right) \mathbf{q} + Pl \nabla^2 \mathbf{q} - R_m \hat{k} - R_n \phi \hat{k} + R_D T \hat{k} + \frac{R_S}{L_S} C \hat{k} + \sqrt{Ta} (\mathbf{q} \times \hat{k}) \quad (9)$$

$$\frac{\partial T}{\partial t} + \mathbf{q} \cdot \nabla T = \nabla^2 T + \frac{N_B}{Ln} \nabla \varphi \cdot \nabla T + \frac{N_D N_B}{Ln} \nabla T \cdot \nabla T + S_{TC} \nabla^2 C \quad (10)$$

$$\frac{1}{\sigma} \frac{\partial \varphi}{\partial t} + \frac{1}{\varepsilon} \mathbf{q} \cdot \nabla \varphi = \frac{1}{Ln} \nabla^2 \varphi + \frac{N_D}{Ln} \nabla^2 T \quad (11)$$

$$\frac{1}{\sigma} \frac{\partial C}{\partial t} + \frac{1}{\varepsilon} \mathbf{q} \cdot \nabla C = \frac{1}{Ls} \nabla^2 C + S_{CT} \nabla^2 T \quad (12)$$

where the dimensionless parameters are:

Thermosolutal Lewis number  $Ls = \frac{\alpha_m}{D_S}$ , Thermonanofluid Lewis number  $Ln = \frac{\alpha_m}{D_B}$ , Kinematic viscoelastic

parameter  $F = \frac{\mu' \alpha_m}{\mu \sigma d^2}$ , Density Rayleigh number  $R_m = \frac{\rho_p \varphi_1 + \rho(1-\varphi_1) g k d}{\mu \alpha_m}$ , Nanoparticle Rayleigh number  $R_n =$

$\frac{(\rho_p - \rho)(\varphi_0 - \varphi_1) g k d}{\mu \alpha_m}$ , Thermal Rayleigh Darcy number  $R_D = \frac{\rho \alpha_T (T_1 - T_0) g k d}{\mu \alpha_m}$ , Solutal Rayleigh number  $R_s =$

$\frac{\rho \alpha_C (C_1 - C_0) g k d}{\mu D_S}$ , Dimensionless medium permeability  $Pl = \frac{k}{d^2}$ , Modified diffusivity ratio  $N_D = \frac{D_T (T_1 - T_0)}{D_B T_0 (\varphi_0 - \varphi_1)}$ ,

Modified particle density increment  $N_B = \frac{(\rho_c)_p (\varphi_1 - \varphi_0)}{\rho_c}$ , Soret parameter  $S_{CT} = \frac{D_{CT} (T_1 - T_0)}{\alpha_m (C_1 - C_0)}$  Dufour parameter

$S_{TC} = \frac{D_{TC} (C_1 - C_0)}{\alpha_m (T_1 - T_0)}$ , Taylor number  $Ta = \left( \frac{2 \Omega d^2 \rho}{\varepsilon \mu} \right)^2$ .

The dimensionless boundary conditions are:

$$w = 0, \quad T = 1, \quad \varphi = 1, \quad C = 0 \quad \text{at } z = 0 \quad (13)$$

$$w = 0, \quad T = 0, \quad \varphi = 0, \quad C = 1 \quad \text{at } z = 1 \quad (14)$$

### 3.1 Basic states and its solutions

The basic state of nanofluid is assumed and does not depend on time and describes as:

$$\mathbf{q}(u, v, w) = 0, \quad p = p(z), \quad T = T_i(z), \quad \varphi = \varphi_i(z), \quad C = C_i(z)$$

The basic variable represented by subscript  $i$ .

The equations (8) to (12) with boundary conditions (13) and (14) gives the solution:

$$T_i = 1 - z, \quad C_i = 1 - z \quad \text{and} \quad \varphi_i = z. \quad (15)$$

### 3.2 Perturbation solutions

We introduced small perturbations on the basic state for the investigate the stability of the system and write

$$\mathbf{q}^* = 0 + \mathbf{q}'(u, v, w), \quad T^* = (1 - z) + T', \quad C^* = (1 - z) + C', \quad \varphi^* = z + \varphi', \quad p^* = p_i + p' \quad (16)$$

Using equation (16) in equations (8) to (12) and linearise by disuse the multiplication of the prime quantities, and after dipping the dash ( ' ), we get the subsequent equations:

$$\nabla \mathbf{q} = 0 \quad (17)$$

$$0 = -\nabla p - \left( 1 - F \frac{\partial}{\partial t} \right) \mathbf{q} + Pl \nabla^2 \mathbf{q} - R_n \varphi \hat{k} + R_D T \hat{k} + \frac{R_s}{Ls} C \hat{k} + \sqrt{Ta} (\mathbf{q} \times \hat{k}) \quad (18)$$

$$\frac{\partial T}{\partial t} - w = \nabla^2 T + \frac{N_B}{Ln} \left( \frac{\partial T}{\partial z} - \frac{\partial \varphi}{\partial z} \right) - 2 \frac{N_D N_B}{Ln} \frac{\partial T}{\partial z} + S_{TC} \nabla^2 C \quad (19)$$

$$\frac{1}{\sigma} \frac{\partial \varphi}{\partial t} + \frac{1}{\varepsilon} w = \frac{1}{Ln} \nabla^2 \varphi + \frac{N_D}{Ln} \nabla^2 T \quad (20)$$

$$\frac{1}{\sigma} \frac{\partial C}{\partial t} - \frac{1}{\varepsilon} w = \frac{1}{Ls} \nabla^2 C + S_{CT} \nabla^2 T \quad (21)$$

and boundary conditions are:

$$w = 0, \quad T = 0, \quad \varphi = 0, \quad C = 0 \quad \text{at } z = 0 \quad \text{and } z = 1. \quad (22)$$

$R_m$  is not involved in these because  $R_m$  is presently a estimate of basic static pressure gradient. So by operating equation (18) with  $\hat{k} \cdot \text{curl} \cdot \text{curl}$ , we get:

$$\left[-\left(1-F\frac{\partial}{\partial t}\right)+Pl\right]\nabla^2 w + R_D \nabla_H^2 T - R_n \nabla_H^2 \varphi + \frac{R_s}{L_s} \nabla_H^2 C + Ta \frac{\partial^2 w}{\partial z^2} = 0 \quad (23)$$

$$\text{where } \nabla_H^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \quad \text{and } \nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

#### 4. Normal mode analysis

The disturbances analyzing by normal mode analysis as follow:

$$[w, T, C, \varphi] = [W(z), \Theta(z), \Gamma(z), \phi(z)] \exp(ik_x x + ik_y y + nt) \quad (24)$$

where  $n$  is the growth rate and  $k_x$  and  $k_y$  are the wave number along  $x$  and  $y$  directions, respectively.

Using equation (24) in equations(27) to (29) and equation (23), we get;

$$[-(1-nF)+Pl](D^2-a^2)+TaD^2]W - R_D a^2 \Theta - \frac{R_s}{L_s} a^2 \Gamma + a^2 R_n \phi = 0 \quad (25)$$

$$W + \left[(D^2-a^2)-n+\varepsilon \frac{N_B}{Ln} D - 2\varepsilon \frac{N_D N_B}{Ln} D\right] \Theta + S_{TC}(D^2-a^2) \Gamma - \frac{N_B}{Ln} D \phi = 0 \quad (26)$$

$$\frac{W}{\varepsilon} - \frac{N_D}{Ln} (D^2-a^2) \Theta + \left[\frac{n}{\sigma} - \frac{D^2-a^2}{Ln}\right] \phi = 0 \quad (27)$$

$$\frac{W}{\varepsilon} + S_{CT}(D^2-a^2) \Theta + \left(\frac{D^2-a^2}{L_s} - \frac{n}{\sigma}\right) \Gamma = 0 \quad (28)$$

where  $D = \frac{d}{dz}$  and  $a^2 = k_x^2 + k_y^2$  is the dimensionless ensuing wave number and the boundary conditions in view of normal mode are:

$$W = D^2 W = \Gamma = \Theta = \phi = 0 \quad \text{at } z = 0 \quad \text{and } z = 1 \quad (29)$$

#### 5. Linear stability analysis

The eigen functions  $f_i(z)$  corresponding to the eigen values problem (35) to (38) are  $f_j = \sin(\pi z)$ . the corresponding solutions are:

$$W = W_0 \sin(\pi z), \quad \Theta = \Theta_0 \sin(\pi z), \quad \Gamma = \Gamma_0 \sin(\pi z), \quad \phi = \phi_0 \sin(\pi z) \quad (30)$$

The linear system has a solutions if and only if

$$R_D = \frac{1}{J^2 \sigma \varepsilon + n \varepsilon L_s - S_{TC} J^2 L_s \sigma} \left[ \frac{(-(1-nF)+Pl)J^2 + \pi^2 Ta}{a^2} \varepsilon (J^2 + n)(J^2 \sigma + n L_s) - S_{CT} S_{TC} J^4 L_s \sigma \right) + R_s \sigma (\varepsilon S_{CT} J^2 - (J^2 + n)) - \frac{R_n \sigma}{(J^2 \sigma + n L_n)} \left( ((J^2 + n) L_n + J^2 N_D \varepsilon) (J^2 \sigma + n L_s) + S_{TC} J^4 L_s \sigma (L_n S_{CT} \varepsilon + N_D) \right) \right] \quad (31)$$

where  $J^2 = \pi^2 + a^2$ .

#### 6. The stationary convection

The stationary convection will be characterized by  $n = 0$  in equation (31), and reduce it to

$$R_D = \frac{1}{(\varepsilon - S_{TC} L_s)} \left[ \frac{J^2 (-J^2 Pl + \pi^2 Ta) \varepsilon}{a^2} (1 - S_{CT} S_{TC} L_s) + R_s (\varepsilon S_{CT} - 1) - R_n \left( (L_n + N_D \varepsilon) + S_{TC} L_s (L_n S_{CT} + N_D) \right) \right] \quad (32)$$

the thermal Darcy Rayleigh number reveal by equation (32) which is a function of  $a, S_{CT}, S_{TC}, Le, N_D, R_s, R_n, Ln$ . Since elasto-viscous parameter  $F$  vanish with  $n$ , so the Walters' (model B') elasto-viscous nanofluid react similar to usual Newtonian nanofluid, In the nonappearance of the Dufour and Soret parameters equation (32) reduces to

$$R_D = \left[ \frac{(\pi^2 + a^2)(-\pi^2 + a^2)Pl + \pi^2 Ta}{a^2} - \frac{R_s}{\varepsilon} - R_n \left( \frac{Ln}{\varepsilon} + N_D \right) \right] \quad (33)$$

Here, take  $x = \frac{a^2}{\pi^2}$ , in equation (43), then we get

$$R_D = \pi^2 \left[ \frac{Ta(1+x)}{x} - \frac{Pl(1+x)^2}{x} \right] - \frac{R_s}{\varepsilon} - R_n \left( \frac{Ln}{\varepsilon} + N_D \right) \quad (34)$$

## 7. Results and Discussion

The equation (34) express for stationary thermal Rayleigh Darcy number compute as a function of solute Rayleigh number, nanoparticle Rayleigh number, modified diffusivity ratio, thermo-nanofluid Lewis number, Taylor number, medium permeability, porosity, and dimensionless wave number.

We observe the nature of  $\frac{\partial R_D}{\partial Ta}$ ,  $\frac{\partial R_D}{\partial N_D}$ ,  $\frac{\partial R_D}{\partial R_n}$ ,  $\frac{\partial R_D}{\partial R_s}$ ,  $\frac{\partial R_D}{\partial Pl}$  and  $\frac{\partial R_D}{\partial Ln}$  analytically. Equation (34) gives

$$\frac{\partial R_D}{\partial Ta} > 0 \text{ and } \frac{\partial R_D}{\partial R_s} < 0, \frac{\partial R_D}{\partial N_D} < 0, \frac{\partial R_D}{\partial Pl} < 0, \frac{\partial R_D}{\partial R_n} < 0, \frac{\partial R_D}{\partial Ln} < 0.$$

This implies that for stationary convection, Taylor number have stabilizing effect whenever Solute Rayleigh number, thermo-nanofluid Lewis number, modified diffusivity ratio, nanoparticle Rayleigh number and medium permeability have destabilizing effect on the system.

Figure 1 represents the Rayleigh Darcy number increase with Taylor number and for different values of solute Rayleigh number  $R_s = 100, 200, 300$  with the constant values of  $N_D = 1$ ,  $Pl = 5$ ,  $R_n = 1$ ,  $Ln = 1000$ ,  $\varepsilon = 0.6$ . The Rayleigh number  $R_D$  increase with the Taylor number  $Ta$ , which implise that on the stationary convection Taylor number has stabilizing effect.

Figure 2 represents the Rayleigh Darcy number decrease with medium permeability and for different values of nanoparticle Lewis number  $Ln = 1000, 4000, 7000$  with the constant values of  $N_D = 1$ ,  $Ta = 100$ ,  $R_n = 1$ ,  $R_s = 100$ ,  $\varepsilon = 0.6$ . The Rayleigh number  $R_D$  decrease with the medium permeability  $Pl$ , which implise that on the stationary convection medium permeability has destabilizing effect.

Figure 3 represents the Rayleigh Darcy number decrease with solute Rayleigh number and for different values of Taylor number  $Ta = 100, 300, 600$  with the constant values of  $N_D = 1$ ,  $Pl = 5$ ,  $R_n = 1$ ,  $Ln = 1000$ ,  $\varepsilon = 0.6$ . The Rayleigh number  $R_D$  decrease with the solute Rayleigh  $R_s$ , which implise that on the stationary convection solute Rayleigh has destabilizing effect.

Figure 4 represents the Rayleigh Darcy number decrease with nanoparticle Rayleigh number and for different values of diffusive ratio  $N_D = 1, 5, 10$  with the constant values of  $Ta = 100$ ,  $R_s = 100$ ,  $Pl = 5$ ,  $Ln = 200$ ,  $\varepsilon = 0.6$ . The Rayleigh number  $R_D$  decrease with the nanoparticle Rayleigh number  $R_n$ , which implise that on the stationary convection nanoparticle Rayleigh number has destabilizing effect.

Figure 5 represents the Rayleigh Darcy number decrease with diffusive ratio and for different values of medium permeability  $Pl = 1, 5, 10$  with the constant values of  $Ta = 100$ ,  $R_s = 100$ ,  $R_n = 1$ ,  $Ln = 200$ ,  $\varepsilon = 0.6$ . The Rayleigh number  $R_D$  decrease with the diffusive ratio  $N_D$ , which implise that on the stationary convection diffusive ratio has destabilizing effect.

Figure 6 represents the Rayleigh Darcy number decrease with nanoparticle Lewis number and for different values of nanoparticle Rayleigh number  $R_n = 1, 2, 3$  with the constant values of  $Ta = 100$ ,  $R_s = 100$ ,  $Pl = 1$ ,  $N_D = 1$ ,  $\varepsilon = 0.6$ . The Rayleigh number  $R_D$  decrease with the nanoparticle Lewis number  $R_n$ , which implise that on the stationary convection nanoparticle Lewis number has destabilizing effect.

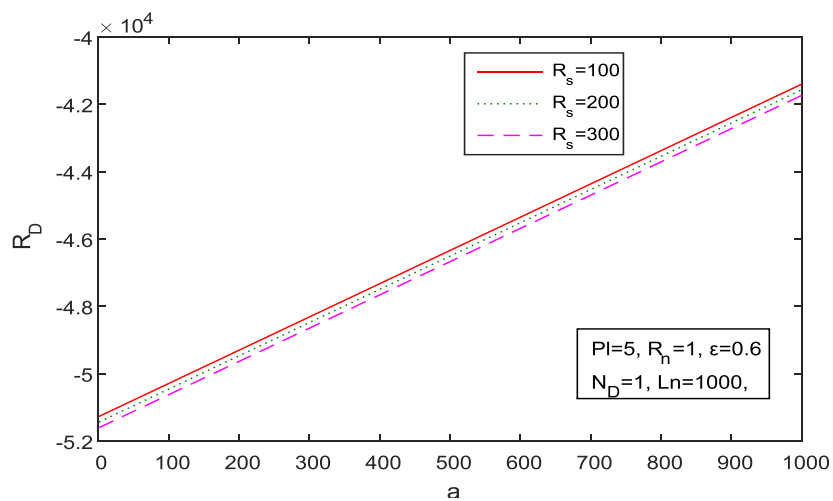


Figure: 1

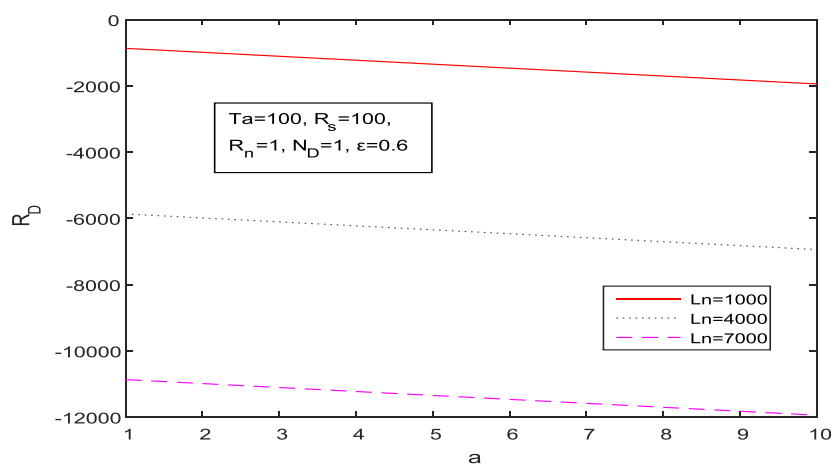


Figure: 2

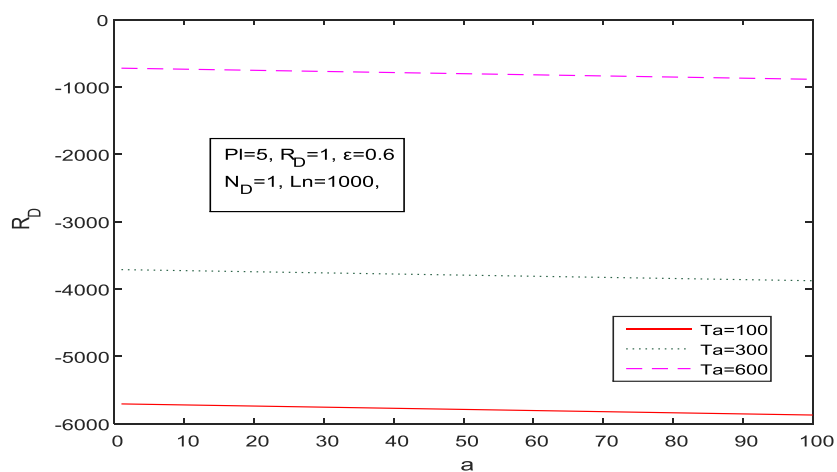


Figure: 3

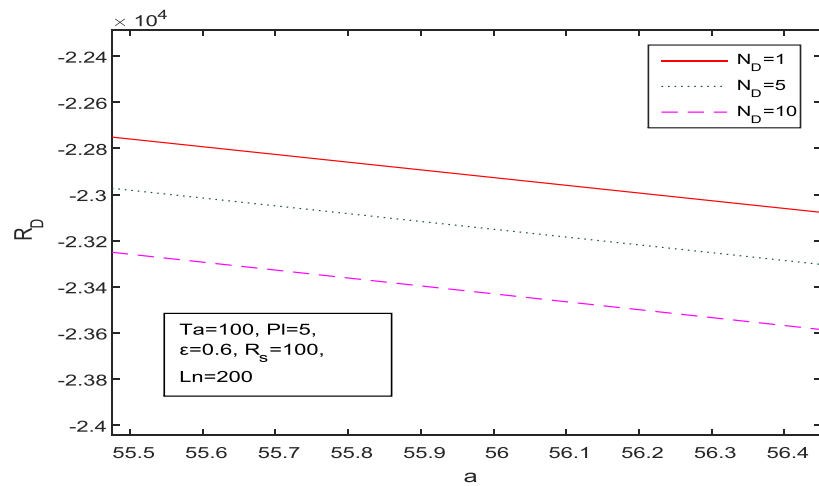


Figure: 4

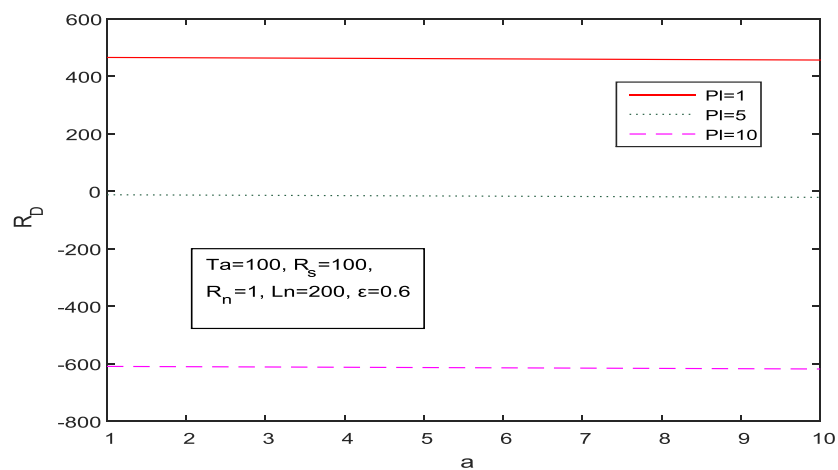


Figure: 5

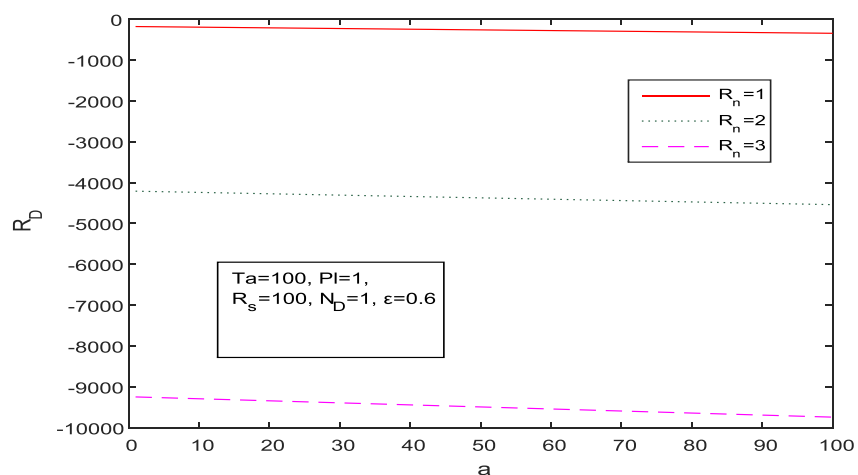


Figure: 6

## 8. Conclusion

The effect of rotation on thermosolutal convection of visco-elastic nanofluid with porous medium using Walters' (Model B') is investigated by using linear stability analysis. We drawn the main conclusion are following as:

- (i) Due to rotation, Taylor number has stabilizing effect for stationary convection.
  - (ii) Solute Rayleigh number, thermo-nanofluid Lewis number, modified diffusivity ratio, nanoparticle Rayleigh number and medium permeability have destabilizing effect for stationary convection.
- The Walters` (model B`) elastico-viscous nanofluid react similar to regular Newtonian nanofluid for stationary convection.

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