Hydromagnetic Impermanence of rotating visco-elastic Rivlin-Ericksen nano fluid layer heated from below

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Abstract

Hydromagnetic impermanence of rotating visco-elastic Rivlin-Ericksen nanofluid layer heat from below is observed for more realistic boundary conditions. By applying Perturbation method, Normal mode technique, the dispersion relation has been derived. The impressions of the different physical parameters of the system namely Lewis number, modified diffusivity ratio, nano particle Rayleigh number, magnetic field and rotation on the stationary deportation have been investigated both analytically and graphically. The Lewis number, modified diffusivity ratio and nano particle Rayleigh number and rotation are found to have destabilizing impression, whereas magnetic field has a stabilizing impression for stationary deportation.

Keywords-
Nanofluid; Rivlin-Ericksen visco-elastic fluid; Normal mode analysis; Rayleigh number; Lewis number; modified diffusivity ratio; magnetic field, rotation.

1. Introduction

The thermal instability of a Newtonian fluid explained by Chandrasekhar [1] under the assumptions of hydromagnetics and hydrodynamics. The instability depends on the depth of layer, it is experimentally discussed by Chandra [2] and found that there is a contradiction between the theory and experiment for the onset of deportation in fluids heated from below. Bhatia and Steiner [3] investigated the thermal instability of a Maxwellian visco-elastic fluid in the presence of magnetic field. A large number of researchers, in recent years has centred on the study nanofluids on considering the applications in various industrial fields such as automotive, energy supply sector, pharmaceuticals. Choi [4] was the first person who coined the term nanofluid. Nanofluid is a colloidal mixture of nanoparticles which are below 100nm. Some nitride ceramics, oxide ceramics and several metals such as aluminium and copper have been used in nanofluids as nanoparticles. Veronis [5] investigated the problem of thermohaline deportation in a layer or fluid heated from below and subjected to a stable salinity gradient. With the growing importance of non-Newtonian fluids in various industrial field, many researchers have paid their attention towards such fields. The Rivlin-Ericksen [6] is one such fluid. Rana and Kumar [7] discussed the onset of deportation in a horizontal layer uniformly heated for rotating incompressible Rivlin-Ericksen permeated with suspended particles. Rayleigh-Bènard deportation in visco-elastic Rivlin-ericksen nanofluid in the presence of suspended particles has been studied by S.K.Pundir, D.Kapil and R.Pundir [8]. Hydromagnetic instability of visco-elastic Walter's (modal B) nanofluid layer heated from below has been investigated by D. Kapil et al. [9] and found that magnetic field has a stabilizing effect for stationary deportation. Sharma [10] has discussed the thermal instability of a layer of visco-elastic fluid acted on by a uniform rotation and resulted that rotation has destabilizing effect as well as stabilizing effects under certain conditions. Chand and Rana [11] have studied the effect of rotation on thermal deportation in nanofluid layer saturating a Darcy-Brinkman porous medium. Effect of rotation on hydromagnetic instability of visco-elastic Walter's (modal B) nanofluid layer heated from below has been studied by S.K.Pundir et al. [12] and resulted that rotation has destabilizing impression on the stationary deportation. Rana [13] has studied hydromagnetic thermosolutal instability of Rivlin-Ericksen rotating fluid permeated with suspended particles and variable gravity field in porous medium.

In the present paper, We have discussed hydromagnetic stability of rotating visco-elastic Rivlin-Ericksen nanofluid layer heated from below.

2. Mathematical Formulation

Suppose the horizontal layers of Rivlin-Ericksen visco-elastic nanofluid of thickness d^* and of infinite length is bounded by $z = 0$ and $z = d^*$ and which is heated from below. The fluid layer is acting in upward direction under gravity force g (0, 0,-g). Let T_0 and φ_0 are the temperature and volumetric fraction of nano particles at $z = 0$ and T_1, φ_1 are temperature and volumetric fraction at $z = d^*$ respectively.

The governing equation for visco-elastic Rivlin-Ericksen nanofluid

$$\nabla \boldsymbol{q}_f = 0 \tag{1}$$

$$\rho \frac{d\boldsymbol{q}_f}{dt} = -\nabla \mathrm{p} + \rho \mathrm{g} + \left(\mu + \mu' \frac{\partial}{\partial t}\right) \nabla^2 \boldsymbol{q}_f + \frac{\mu_e}{4\pi} (\boldsymbol{H}\nabla)\boldsymbol{H} + 2\rho\left(\boldsymbol{q}_f \times \Omega\right) \tag{2}$$

where $\frac{d}{dt} = \frac{\partial}{\partial t} + (\boldsymbol{q}_f . \nabla)$ stands for deportation derivative, $\boldsymbol{q}_f$(u, v, w) is the velocity vector, p is the hydrostatic pressure, μ and μ' are the viscosity and kinematic visco-elasticity respectively and μ_e is the fluid magnetic permeability and H is the magnetic field and fluid is acted upon by a uniform rotation $\Omega(0,0,\Omega)$. The density ρ of nanofluid can be written as

$$\rho = \varphi\, \rho_p + (1 - \varphi)\rho_f \tag{3}$$

where φ is the volume fraction of nano particles, ρ_p and ρ_f are the densities of nano particles and base fluid respectively.

The equation of motion for visco-elastic Rivlin-Ericksen nanofluid is given as:

$$\rho \frac{d\boldsymbol{q}_f}{dt} = -\nabla \mathrm{p} + \left(\varphi\, \rho_p + (1-\varphi)\{\rho\left(1 - \alpha(T - T_0)\right)\}\right)\mathrm{g} + \left(\mu + \mu' \frac{\partial}{\partial t}\right) \nabla^2 \boldsymbol{q}_f + \frac{\mu_e}{4\pi} (\mathbf{H}.\nabla)\mathbf{H} + 2\rho\left(\boldsymbol{q}_f \times \Omega\right) \tag{4}$$

where α is the coefficient of thermal expansion.

The continuity equation for the nano particles is

$$\frac{\partial \varphi}{\partial t} + \boldsymbol{q}_f \nabla \varphi = D_B \nabla^2 \varphi + \frac{D_T}{T_1} \nabla^2 T \tag{5}$$

where D_B is the Brownian diffusion coefficient and D_T is the Thermoporetic diffusion coefficient of the nano particles.

The energy equation in nanofluid is

$$\rho_c \left(\frac{\partial T}{\partial t} + \boldsymbol{q}_f \nabla T\right) = k\nabla^2 \mathrm{T} + (\rho_c)_p (D_B \nabla\varphi . \nabla T + \frac{D_T}{T_1} \nabla T . \nabla T) \tag{6}$$

Where $\rho_c$the heat capacity of fluid is, $(\rho_c)_p$ is the heat capacity of nano particles and k is the thermal conductivity.
The Maxwell equation being

$$\frac{\partial \boldsymbol{H}}{\partial t} + \left(\boldsymbol{q}_f \nabla\right)\boldsymbol{H} = (\boldsymbol{H}\, \nabla)\boldsymbol{q}_f + \eta\, \nabla^2 \mathbf{H} \tag{7}$$

$$\nabla \mathbf{H} = 0 \tag{8}$$

where η is the fluid electrical resistivity.

Introducing non-dimensional variables as:

$(x', y', z') = \left(\frac{x,\ y,\ z}{d^*}\right),$

$\boldsymbol{q}_{f'}(u', v', w') = \boldsymbol{q}_f\left(\frac{u,\ v,\ w}{k}\right) d^*,\ t' = \frac{tk}{d^{*2}},$

$p' = \frac{p}{\rho k^2}\, d^{*2},\ \varphi' = \frac{\varphi - \varphi_0}{\varphi_1 - \varphi_0},$

$T' = \frac{T - T_0}{T_0 - T_1},$

where $\frac{k}{\rho_c}$ = k is the thermal diffusivity of the fluid.

Equations (1), (4), (5), (6), (7) and (8), in non-dimensional form can be written as:

$$\nabla \boldsymbol{q}_f = 0 \tag{9}$$

$$\frac{1}{p_{r_1}}\frac{\partial \boldsymbol{q}_f}{\partial t} = -\nabla \mathrm{p} + (1 + \mathrm{nF})\nabla^2 \boldsymbol{q}_f - \mathrm{R_m}\hat{\mathrm{e}}_\mathrm{z} - \mathrm{R_n}\varphi\hat{\mathrm{e}}_\mathrm{z} - \mathrm{R_a}\mathrm{T}\hat{\mathrm{e}}_\mathrm{z} + \mathrm{Q}\,\frac{p_{r_1}}{p_{r_2}}\,(\boldsymbol{H}.\nabla)\boldsymbol{H} + \frac{2d^{*2}\rho}{\boldsymbol{\mu}}\left(\boldsymbol{q}_f \times \Omega\right) \tag{10}$$

$$\frac{\partial \varphi}{\partial t} + \boldsymbol{q}_f \nabla \varphi = \frac{1}{L_e}\nabla^2 \varphi + \frac{N_A}{L_e}\nabla^2 T \tag{11}$$

$$\frac{\partial T}{\partial t} + \boldsymbol{q}_f\, \nabla T = \nabla^2 \mathrm{T} + \frac{\mathrm{N_B}}{L_e}\nabla\varphi . \nabla T + \frac{N_A N_B}{L_e}\,\nabla T\,.\nabla T \tag{12}$$

$$\frac{\partial H}{\partial t} + \left(\boldsymbol{q}_f\, \nabla\right)\boldsymbol{H} = (\boldsymbol{H}\, \nabla)\boldsymbol{q}_f + \frac{p_{r_1}}{p_{r_2}}\,\nabla^2 \boldsymbol{H} \tag{13}$$

$$\nabla \boldsymbol{H} = 0 \tag{14}$$

[The dashes (`) have been dropped for simplicity]

Here non-dimensional parameters are:

Lewis number $L_e = \frac{k}{D_B}$, Prandtl number $p_{r_1} = \frac{\mu}{\rho k}$, Magnetic Prandtl number $p_{r_2} = \frac{\mu}{\rho\eta}$, Rayleigh number $\mathrm{R_a} = \frac{\rho g \alpha d^{*3}}{\mu k}(\mathrm{T_0} - \mathrm{T_1})$,Basic- density Rayleigh number $\mathrm{R_m} = \frac{[\rho_p \varphi_0 + \rho\,(1 - \varphi_0)]g\, d^{*3}}{\mu k}$, Nano particle Rayleigh number $\mathrm{R_n} = \frac{(\rho_p - \rho)(\varphi_1 - \varphi_0)g\, d^{*3}}{\mu k}$, Kinematic visco-elasticity parameter $\mathrm{F} = \frac{\mu'}{\rho d^{*2}}$, Modified diffusivity ratio $N_A = \frac{D_T}{D_{\boldsymbol{B}}\mathrm{T_1}(\varphi_1 - \varphi_0)}(\mathrm{T_0} - \mathrm{T_1})$, Modified particle density increment $N_{\boldsymbol{B}} = \frac{(\rho_c)_p\,(\varphi_1 - \varphi_0)}{(\rho_c)_f}$, Chandrasekhar number $\mathrm{Q} = \frac{\mu_e H_0^2\, d^{*2}}{4\pi\nu\rho\eta}$, Taylor number $T_A = \left(\frac{2d^{*2}\Omega}{\boldsymbol{\upsilon}}\right)^2$

We assume that temperature and volumetric fraction of nano particles are constant on boundaries. Thus the dimensionless boundaries conditions are

$$w = 0,\ T = 1,\ \varphi = 0\ \ at\ \ z = 0 \tag{15}$$

and $w = 0,\ T = 0,\ \varphi = 1\ \ at\ \ z = 1$ (16)

2.1) Basic States and its solution

The basic state of nanofluid is supposed to be time independent of time and can be written as

$q_f{}'(u,v,w) = 0,\ p' = p(z),\ T' = T_b(z),\ \varphi' = \varphi_b(z),$ Equations (9) to (12) using boundary conditions (15) and (16) give solution as:

$$T_b = 1 - z \text{ and } \varphi_b = z \tag{17}$$

2.2) Perturbation solution

The stability of the system can be studied by introducing small perturbations to primary flow, and written as

$$q_f{}'(u,v,w) = 0 + q_f{}''(u,v,w),\ T' = T_b + T'', \varphi' = \varphi_b + \varphi'',\ p' = p_b + p'', \text{ with } T_b = 1 - z \text{ and } \varphi_b = \mathrm{z} \tag{18}$$

Using equation (18) in equation (9) to (12) and linearize by neglecting the product of the prime quantities, we obtain the following equations:

$$\nabla \boldsymbol{q}_f = 0 \tag{19}$$

$$\frac{1}{p_{r_1}}\frac{\partial w}{\partial t}\hat{\mathrm{e}}_\mathrm{z} = (1+\mathrm{nF})\hat{\mathrm{e}}_\mathrm{z}\frac{\partial^2 w}{\partial z^2} - \mathrm{R_n}\varphi\hat{\mathrm{e}}_\mathrm{z} + \mathrm{R_a}\mathrm{T}\hat{\mathrm{e}}_\mathrm{z} + \mathrm{Q}\ \frac{p_{r_1}}{p_{r_2}}\frac{\partial \mathbf{H}}{\partial \mathrm{z}}\hat{\mathrm{e}}_\mathrm{z} + \frac{2{d^*}^2\rho\Omega \mathrm{w}\hat{\mathrm{e}}_\mathrm{z}}{\boldsymbol{\mu}} \tag{20}$$

$$\frac{\partial\varphi}{\partial t} + w = \frac{1}{L_e}\nabla^2\varphi + \frac{N_A}{L_e}\nabla^2 T \tag{21}$$

$$\frac{\partial T}{\partial t} - w = \nabla^2\mathrm{T} + \frac{\mathrm{N_B}}{L_e}\left(\frac{\partial \mathrm{T}}{\partial \mathrm{z}} - \frac{\partial\varphi}{\partial \mathrm{z}}\right) - 2\frac{N_A N_B}{L_e}\frac{\partial \mathrm{T}}{\partial \mathrm{z}} \tag{22}$$

$$\frac{\partial \boldsymbol{H}}{\partial t} = \frac{\partial w}{\partial z}\hat{\mathrm{e}}_\mathrm{z} + \frac{p_{r_1}}{p_{r_2}}\nabla^2\boldsymbol{H} \tag{23}$$

$$\nabla \mathbf{H} = 0 \tag{24}$$

The dashes (′′) have been dropped for simplicity.

Since R_m is just a measure of basic static pressure gradient so it is not involved in these and subsequent equations. Now by operating Eq. (20) with $\hat{\mathrm{e}}_\mathrm{z}$.curl curl, we get:

$$\frac{1}{p_{r_1}}\frac{\partial}{\partial t}\nabla^2 w - (1+\mathrm{nF})\nabla^4 w - \frac{2{d^*}^2\rho\Omega}{\boldsymbol{\mu}}\nabla^2 w = \mathrm{R_a}\nabla_\mathrm{H}^2\mathrm{T} - \mathrm{R_n}\nabla_\mathrm{H}^2\varphi - \mathrm{Q}\ \frac{\partial^2 w}{\partial z^2} \tag{25}$$

where $\nabla_\mathrm{H}^2 = \frac{\partial^2}{\partial \mathrm{x}^2} + \frac{\partial^2}{\partial \mathrm{y}^2}$ is the two dimensional Laplacian operator on horizontal plane.

3. Normal mode observation

On analysing the disturbances in to normal modes and assuming that the perturbed quantities are of the form:

$$[W, \mathrm{T}, \varphi] = [W(z), T(z), \varphi(z)] \exp(ik_x x + ik_y y + nt) \tag{26}$$

Where k_x and k_y are wave numbers in x and y directions respectively, while n is growth rate of disturbances.

Using eq. (26), eq. (21), (22), and (25) become:

$$W - \frac{N_A}{L_e}(D^2 - a^2)T - \left[\frac{1}{L_e}(D^2 - a^2) - n\right]\varphi = 0 \tag{27}$$

$$W + \left[(D^2 - a^2) - n + \frac{N_B}{L_e}D - \frac{2N_A N_B}{L_e}D\right]T - \frac{N_B}{L_e}D\varphi = 0 \tag{28}$$

$$\left[(D^2 - a^2)\frac{n}{p_{r_1}} - (1 + nF)(D^2 - a^2)^2 + QD^2 - \left(\frac{2d^{*2}\Omega}{v}\right)(D^2 - a^2)\right]W + a^2 R_a T - a^2 R_n \varphi = 0 \tag{29}$$

Where $D = \frac{d}{dz}$ and $a = \sqrt{k_x{}^2 + k_y{}^2}$ is the dimensionless the resultant wave number. The boundary conditions of the problem in view of normal mode are written as

$$W = 0, D^2W = 0,\ T = 0, \varphi = 0 \text{ at } z = 0 \text{ and } W = 0, D^2W = 0,\ T = 0,\ \varphi = 0 \text{ at } z = 1 \tag{30}$$

4. Linear Stability Observation

Consider the solution in the form w, T, φ is given as:

$w = w_0 \sin \pi z, T = T_0 \sin \pi z, \varphi = \varphi_0 \sin \pi z$

Equations (27),(28) and (29) reduced as

$$\left[\frac{n}{p_{r_1}}J + (1 + nF)J^2 + Q(J - a^2) - \sqrt{T_A}\,J\right]w_0 - a^2 R_a T_0 + a^2 R_n \varphi_0 = 0 \tag{31}$$

$$w_0 + \frac{N_A}{L_e}JT_0 + \left[\frac{1}{L_e}J + n\right]\varphi_0 = 0 \tag{32}$$

$$w_0 - (J + n)T_0 = 0 \tag{33}$$

From equation (32) & (33), we get

$$\left[(J + n) + \frac{N_A}{L_e}J\right]T_0 + \left(\frac{1}{L_e}J + n\right)\varphi_0 = 0 \tag{34}$$

From equation (31),(33) & (34), we get

$$R_a = \frac{1}{a^2}\left[\left\{(1 + nF)J + \frac{n}{p_{r_1}}\right\}J + Q(J - a^2) - \sqrt{T_A}\,J\right](J + n) - \frac{\left\{(J + n) + \frac{N_a}{L_e}J\right\}}{\frac{1}{L_e}J + n}R_n \tag{35}$$

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

For neutral stability, the real part of n is zero. Hence, on putting $n = i\,\omega$, (ω is the real and dimensionless frequency of oscillation) in eq.(35), we get:

$$R_a = \Delta_1 + i\,\omega\,\Delta_2 \tag{36}$$

where

$$\Delta_1 = \frac{J}{a^2}\left[J^2 + Q(J - a^2) - \frac{\omega^2}{p_{r_1}} + \omega^2 FJ - \sqrt{T_A}\,J\right] - \frac{1}{\left\{\left(\frac{J}{L_e}\right)^2 + \omega^2\right\}}\left[\frac{J^2}{L_e{}^2}(L_e + N_a) + \omega^2\right]R_n \tag{37}$$

and imaginary part

$$\Delta_2 = \frac{1}{a^2}\left[\left\{1 + JF + \frac{1}{p_{r_1}}\right\}J^2 + Q(J - a^2) - \sqrt{T_A}\,J\right] - \frac{\left[\frac{J}{L_e} - J\left(1 + \frac{N_A}{L_e}\right)\right]}{\left\{\left(\frac{J}{L_e}\right)^2 + \omega^2\right\}}R_n \tag{38}$$

R_a will be real since it is a physical quantity Hence, it follow from Eq.(36) that either $\omega = 0$ (exchange of stability, steady state) or $\Delta_2 = 0$ ($\omega \neq 0$ over stability or oscillatory onset).

5. Stationary Deportation

When the stability occurs in as stationary convection, the marginal state will be characterized by $\omega = 0$. the Eq. (38) reduces as:

$$(R_a)_s = \frac{(\pi^2 + a^2)}{a^2}\left[(\pi^2 + a^2)^2 + \pi^2 Q - \sqrt{T_A}(\pi^2 + a^2)\right] - (L_e + N_A)R_n \tag{39}$$

Here R_a is independent of both the prandtl numbers and the parameters containing the Brownian effects and the thermophoretic effects and presented in the thermal energy equation and the conversation equation for nano particles.

Take $x = \frac{a^2}{\pi^2}$ in Eq. (39), then we have

$$(R_a)_s = \frac{\pi^2(1+x)}{x}\left[\pi^2(1 + x)^2 + Q - \sqrt{T_A}(1 + x)\right] - (L_e + N_A)R_n \tag{40}$$

To study the effects of Lewis number $\mathrm{L_e}$, modified diffusivity ratio $\mathrm{N_A}$, and nano particles Rayleigh number $\mathrm{R_n}$, magnetic field and rotation on stationary convection. We examine the nature of

$\frac{\partial \mathrm{R_a}}{\partial \mathrm{L_e}}$, $\frac{\partial \mathrm{R_a}}{\partial \mathrm{N_A}}$, $\frac{\partial \mathrm{R_a}}{\partial \mathrm{R_n}}$, $\frac{\partial \mathrm{R_a}}{\partial \mathrm{Q}}$, $\frac{\partial \mathrm{R_a}}{\partial \mathrm{T}_A}$, analytically.

From eq. (40)

$\frac{\partial R_a}{\partial L_e} < 0$, $\frac{\partial R_a}{\partial N_A} < 0$, $\frac{\partial R_a}{\partial R_n} < 0$, $\frac{\partial R_a}{\partial Q} > 0$, $\frac{\partial R_a}{\partial T_A} < 0$

It implies that for stationary convection Lewis number, modified diffusivity ratio, and nano particle Rayleigh number and rotation have destabilizing effect whenever magnetic field has stabilizing effect on the fluid layer.

6. Results and discussion

Hydromagnetic Instability of rotating visco-elastic Rivlin-Ericksen nanofluid layer heated from below is observed under realistic boundary conditions.

Figure 1 represents the variation of stationary Rayleigh number with Lewis number L_e for different values of R_n . The stationary Rayleigh number R_a is plotted against Lewis number for fixed values of $N_A = 5, Q = 5, T_A = 1. L_e = 100, 50, 30$ and $R_n = 50, 20, 10$. The Rayleigh number decreases with increases in Lewis number, which shows that Lewis number has destabilizing impression on the stationary deportation.

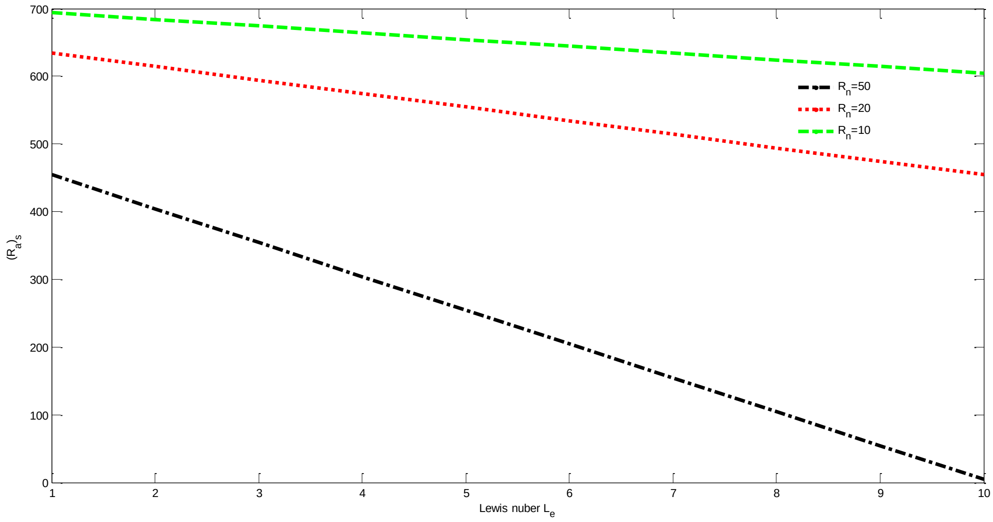

Fig.1: Variations of stationary Rayleigh number with Lewis number

Figure 2 represents the variation of stationary Rayleigh number with Lewis number L_e for different values of T_A . The stationary Rayleigh number R_a is plotted against Lewis number for fixed values of $N_A = 5,\ Q = 5, L_e = 100. T_A = 10, 20, 30$ and $R_n = 50, 20, 10$. The Rayleigh number decreases with increases in Lewis number, which shows that Lewis number has destabilizing impression on the stationary deportation.

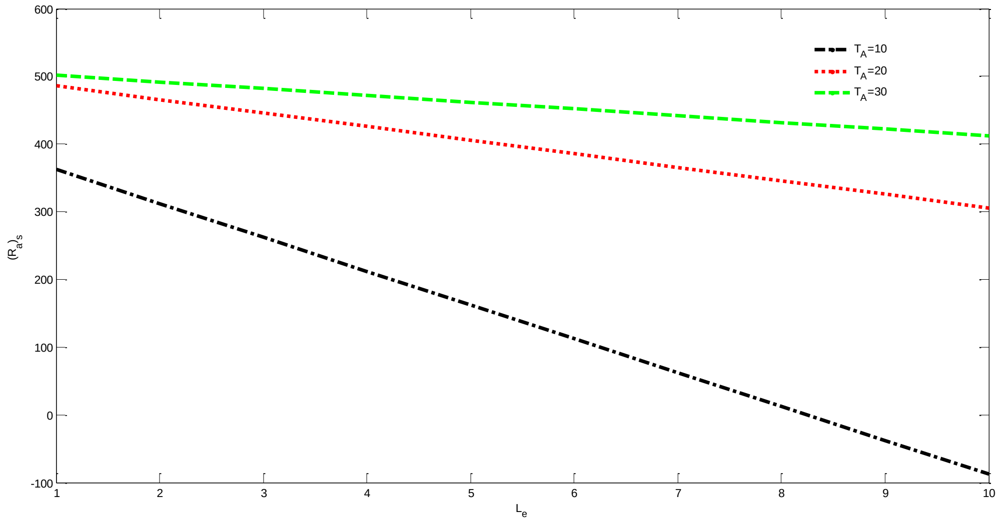

Fig.2: Variations of stationary Rayleigh number with Lewis number

Figure 3 represents the variation of stationary Rayleigh number with modified diffusivity ratio number N_A for different values of Q . The stationary Rayleigh number R_a is plotted against modified diffusivity ratio number for fixed values of $L_e = 5,\ R_n = 10, N_A = 100$ and $T_A = 1, 2, 3, Q = 5,10,15$. The Rayleigh number decreases with increases in modified diffusivity ratio number which shows that modified diffusivity ratio number has destabilizing effect on the stationary deportation.

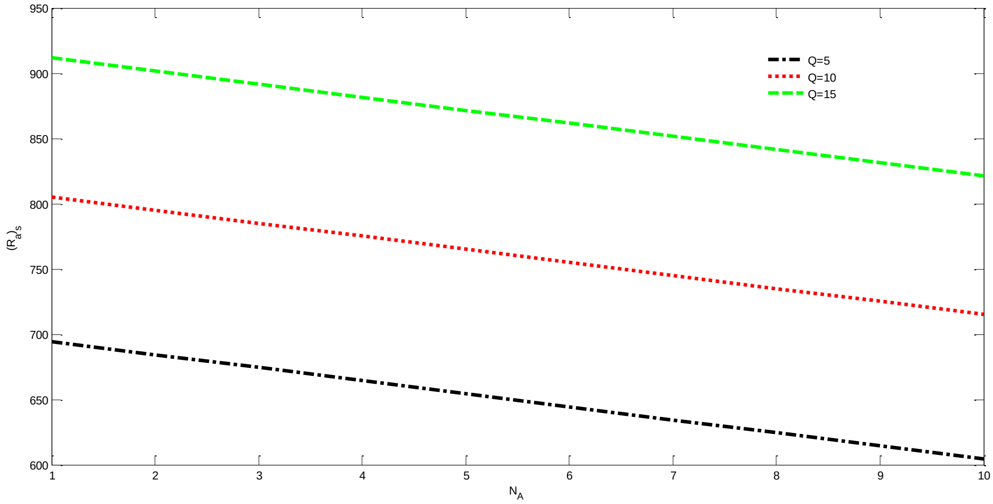

Fig.3: Variations of stationary Rayleigh number with modified diffusivity ratio number

Figure 4 represents the variation of stationary Rayleigh number with modified diffusivity ratio number N_A for different values of L_e . The stationary Rayleigh number R_a is plotted against modified diffusivity ratio number for fixed values of $T_A = 1$, $R_n = 100, N_A = 10$ and $L_e = 10, 20, 30, Q = 50,100,150$. The Rayleigh number decreases with increases in modified diffusivity ratio number which shows that modified diffusivity ratio number has destabilizing effect on the stationary deportation.

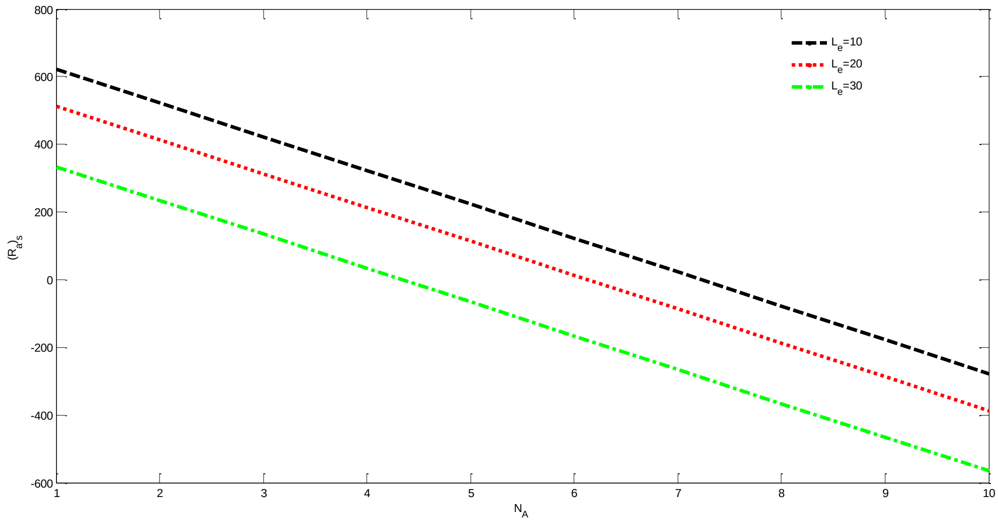

Fig.4: Variations of stationary Rayleigh number with modified diffusivity ratio number

Figure 5 represents the variation of stationary Rayleigh number with nanoparticle Rayleigh number R_n for different values of Q . The stationary Rayleigh number R_a is plotted against nanoparticle Rayleigh number for fixed values of $N_A = 100$, $R_n = 10, L_e = 10$ and $L_e = 10, 20, 30, Q = 50,100,150$. The Rayleigh number decreases with increases in nanoparticle Rayleigh number which shows that nanoparticle Rayleigh number has destabilizing effect on the stationary deportation.

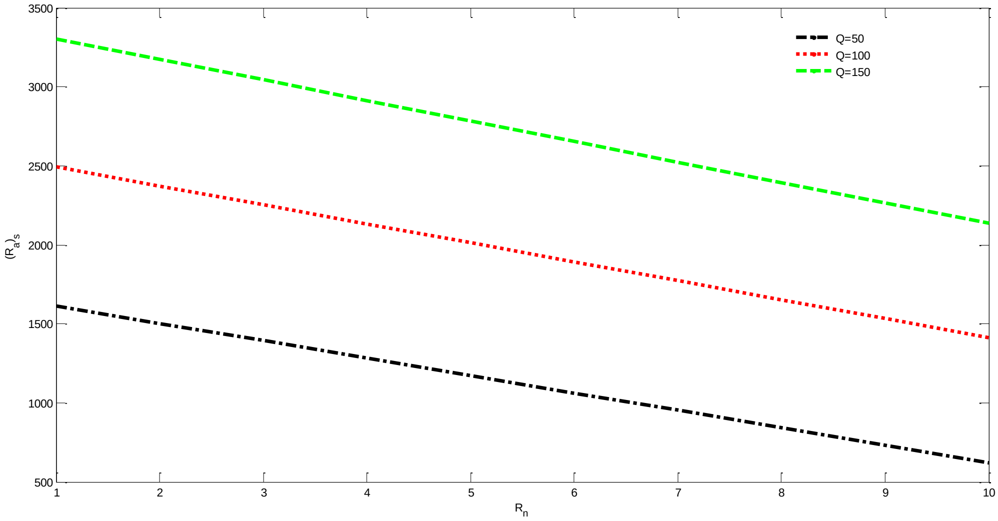

Fig.5: Variations of stationary Rayleigh number with modified nanoparticle Rayleigh number

Figure 6 represents the variation of stationary Rayleigh number with Q for different values of L_e . The stationary Rayleigh number R_a is plotted against Q for fixed values of $N_A = 100, T = 1, R_n = 10$ and $L_e = 10,20,30$, $Q = 50,100,150$ The Rayleigh number increases with increases in Q, which shows that Q has stabilizing effect on the stationary deportation.

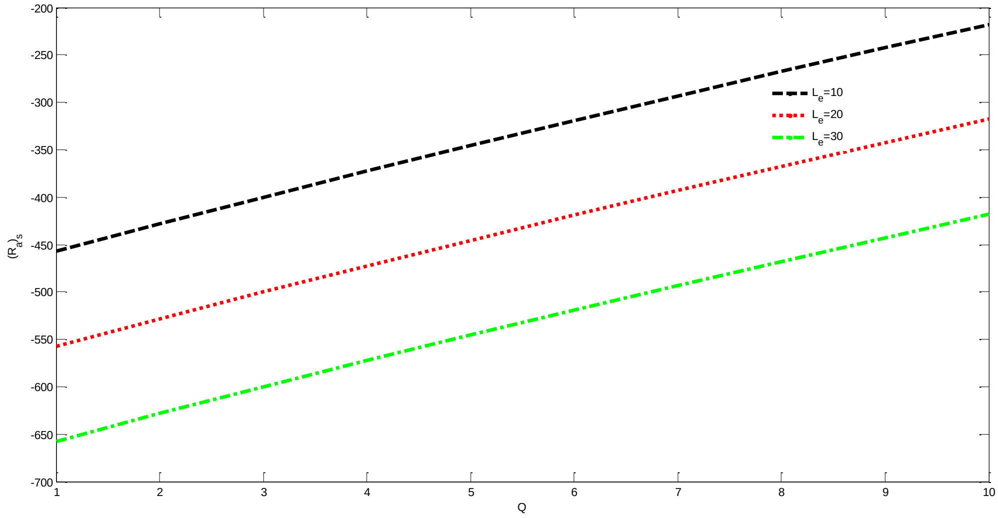

Fig.6: Variations of stationary Rayleigh number with Q

Figure 7 represents the variation of stationary Rayleigh number with for different values of T_A . The stationary Rayleigh number R_a is plotted against T_A for fixed values of $N_A = 100$, $Q = 5, L_e = 50,100,150$ and $R_n = 1,2,3$, $T_A = 10,15,20$ The Rayleigh number decreases with increases in T_A, which shows that T_A has destabilizing effect on the stationary deportation.

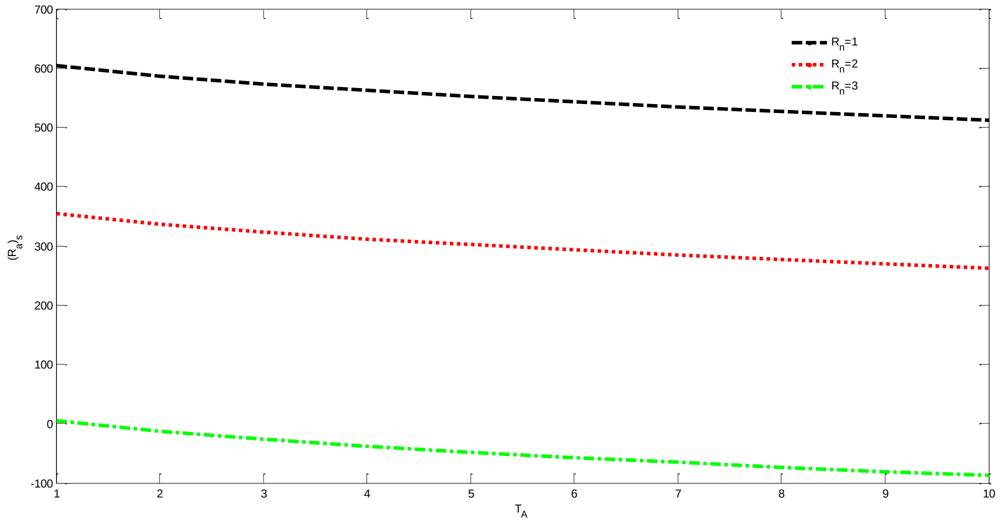

Fig.7: Variations of stationary Rayleigh number with T_A

Figure 8 represents the variation of stationary Rayleigh number with for different values of T_A . The stationary Rayleigh number R_a is plotted against T_A for values of $N_A = 5$, $Q = 5, L_e = 1,5,10$ and $R_n = 5,10,20$, $T_A = 100$ The Rayleigh number decreases with increases in T_A, which shows that T_A has destabilizing effect on the stationary deportation.

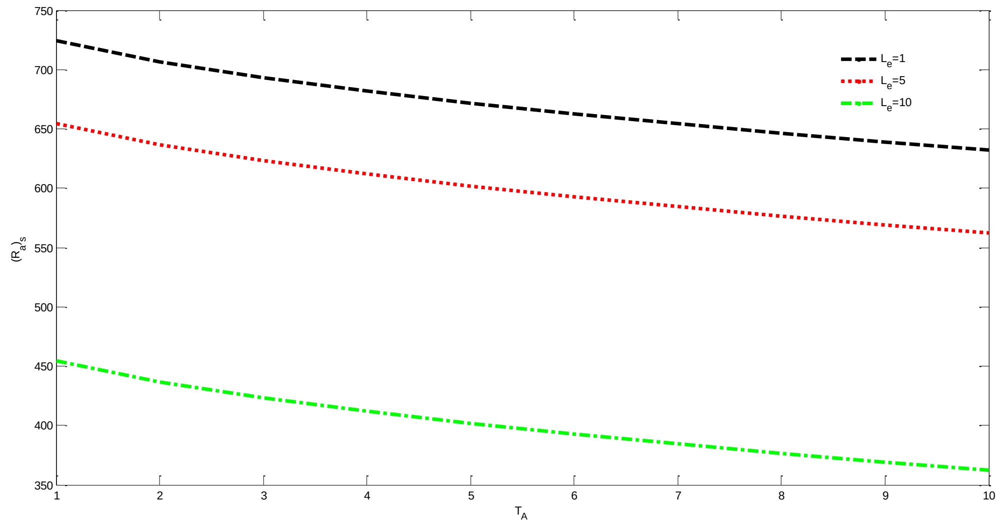

Fig.8: Variations of stationary Rayleigh number with T_A

7. CONCLUSIONS

Hydromagnetic Instability of rotating visco-elastic Rivlin-Ericksen nanofluid layer heated from below is investigated by using linear instability analysis. The main conclusions from the analysis of this paper are as follows:

(1) For the stationary convection rotation has destabilizing effect on the system.

(2) For the stationary convection magnetic field has stabilizing effect on the system.

(3) Lewis number, modified diffusivity ratio and nano particle Rayleigh number have destabilizing effect on the stationary convection.

8. NOMENCLATURE

a	dimensionless resultant wave number
d^*	Thickness of nanofluid layer
D_B	Brownian diffusion coefficient
N_B	Modified particle-density increment
D_T	Thermophoretic diffusion coefficient
ρ	Density of nanofluid
g	acceleration due to gravity
η	Fluid electrical resistivity
n	growth rate of disturbances
k_1	Medium permeability
q_f	Velocity vector
R_a	Rayleigh number
R_m	Density Rayleigh number
R_n	Nano particle Rayleigh number
T	Temperature
T_1	Reference temperature
t	time
P_{r_1}	Prandtl number
P_{r_2}	Magnetic Prandtl number
H	magnetic field
L_e	Lewis number
N_A	Modified diffusivity ratio
T_A	Taylor number

Greek symbols

α	Thermal expansion coefficient
μ	Viscosity
ε	Porosity
μ_e	Magnetic permeability
μ'	Kinematic visco-elasticity
$(\rho_c)_p$	Heat capacity of nanoparticles
$(\rho_c)_f$	Heat capacity of base fluid
φ	volume fraction nanoparticle
ρ_p	density of nanoparticles
ρ_f	density of base fluid
k	Thermal diffusivity
ω	dimensionless frequency
Q	Chandrasekhar number

Superscripts

`	non-dimensionless variables
$''$	perturbed quantities

9. REFERENCES:

[1] S. Chandrasekhar, "Hydrodynamic and Hydromagnetic stability", Dover Publication, Newyork, (1981)

[2] K.Chndra, "Theory and experiment for the onset of convection in fluids", Proc. Roy.Soc. London, A164, (1938), pp.231-242.

[3] J.M.Steiner, P.K.Bhtia, "Thermal instability in a visco-elastic fluid layer in hydromagnetics", J.Math. Anal.Appl., 41, (1973), pp.271-289

[4] S. Choi, "Enhancing thermal conductivity of fluids with nanoparticles", In: D. A. Siginer and H.P. Wang (eds), Developments and applications of non-Newtonian Flows, ASMEFED 231/MD, 66, (1995),pp. 99-105.

[5] G.Veronis, “On finite amplitude instability in thermohaline convection” J.Marine Res., 23, (1967), pp. 1-17.

[6] R.S.Rivlin , J.L.Ericksen,“Stress deformation relations for isotropic material” Journal of rational mechanics and analysis,4,(1955),pp.323-334.

[7] G.C.Rana , S.Kumar, “Thermal instability of Rivlin- Ericksen elastico-viscous rotating fluid permitted with suspended particles and variable gravity field in porous medium”, Studia Geotechnica et Mechanica,32,(2010),pp.39-54.

[8] S.K.Pundir, D.Kapil, R.Pundir, “Rayleigh-Bènard convection in visco-elastic Rivlin-Ericksen nanofluid in presence of suspended particles in porous medium”, compliance Journal,11(10),(2020),pp. 67-78.

[9] D. Kapil, S. Kumar, “Hydromagnetic stability of visco-elastic welter’s (modal B’) nanofluid layer heated from below”,IJEDR,ISSN2321-9939,8(2),(2020),pp.170-178.

[10] R.C.Sharma, “Effect of rotation on thermal instability of a visco-elastic fluid”,Acta. Physica Hung.40, (1976), pp. 11-17.

[11] R.Chand, G.C.Rana, “On the onset of thermal convection in rotating nanofluid layer saturating a Darcy-Brinkman porous medium”, Int. J. Heat Mass Transfer, 55,(2012),pp. 5417-5424.

[12] S.K.Pundir, D.Kapil, R.Pundir, “Effect of rotation on hydromagnetic instability of visco-elastic welter’s (modal B’) nanofluid layer heated from below”, compliance Journal,12(1),(2020),pp.187-199.

[13] G.C.Rana, “Hydromagnetic thermosolutal instability of Rivlin-Ericksen rotating fluid permeated with suspended particles and variable gravity field in porous medium”, Acta. Univ. Sapientiae, Mathematica, 6(1),(2014),pp.24-45.