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Thermosolutal Instability of Couple Stress Rivlin Ericksen Ferromagnetic Fluid with Rotation, Magnetic and Variable Gravity Field in Porous Medium

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ABSTRACT

In this paper thermosolutal instability of a couple stress Rivlin-Ericksen ferromagnetic fluid layer with rotation, magnetic and variable gravity field in porous medium is studied. Using normal mode analysis technique the dispersion relation has been obtained and solved analytically. For stationary convention, it is found that couple stress, magnetic field and permeability of medium have stabilizing effect on thermal instability under certain conditions. Rotation has stabilizing effect if $\lambda > 0$ and destabilizing effect if $\lambda < 0$. Solute gradients has stabilizing effect either $\lambda > 0$ or $\lambda < 0$. The presence of solute gradient, viscoelastic parameter, rotation and magnetic field introduces oscillatory modes, stability in the system and principle of exchange of stability is not satisfied if $\lambda < 0$ and system may be stable or unstable if $\lambda > 0$.

Keywords: Thermal instability, solute gradient, Couple-stress fluid, Rivlin-Ericksen fluid, Ferromagnetic fluid, Magnetisation.

INTRODUCTION

Thermosolutal convection is a challenge in oceanography, limnology, and engineering. It arises when a layer of fluid with a dissolved solute (such as salt) is heated from below. The study of thermosolutal convection is sparked by its intriguing intricacies as a double diffusion phenomenon, as well as its direct application to geophysics and astronomy. Because the conditions in which convective motion in double diffusive convection is significant are frequently far distant from those in which a single component fluid and rigid boundaries are considered, it is preferable to examine a fluid acted on by a solute gradient and free boundaries. (Veronis, 1965) looked into thermohaline convection in a layer of a fluid heated from below and exposed to a constant salinity gradient. (Stokes, 1966) developed and popularised the couple stress fluid theory. (Chandrasekhar, 1981) first proposed the concept of thermal instability in a fluid layer heated from below. Under rotation with vertical temperature and concentration gradients, (Goel et al., 1999) investigated the hydromagnetic stability of an unbounded couple stress binary fluid mixture. (Sharma and Sharma, 2001) explore a couple of stress fluids heated from below in a porous media. The impact of a magnetic field and rotation on a couple stress fluid heated from below in a porous media was explored by (Sunil et al., 2002). In the presence of magnetic field and Hall Currents Thermal instability of a couple stress fluid has been studied by (Vishnoi and Jawla, 2013). (Kumar and Mohan, 2017) studied the convection of rotatory couple stress fluid in porous medium and found that stable solute gradient and rotation have stabilizing effects whereas medium permeability and couple-stress parameter have both stabilizing and destabilizing effects. (Kumar et al., 2014, 2015, 2016) investigated the influence of rotation and magnetic field on thermal convection on a couple stress fluid in a porous media. The effect of uniform vertical magnetic field on thermosolutal convection in a layer of an electrically conducting couple stress fluid heated and soluted from below has been investigated by (Singh and Kumar, 2011) and discovered stable solute gradient, magnetic field and couple stress have stabilizing effect, Solute gradient and magnetic field introduces oscillatory modes in the system. On applying uniform vertical rotation and uniform vertical magnetic field (Kumar, 2012) has studied thermosolutal convection in a couple stress fluid layer heated and soluted from below and found stable solute gradient and rotation has stabilizing effect. (Kumar et al., 2017) investigate the start of double diffusive convection in a pair stress fluid saturated with a porous material under the influence of a magnetic field, rotation, and suspended particles. (Kumar et al., 2009) investigated thermosolutal instability of a couple stress spinning fluid in the presence of a magnetic field and discovered that oscillatory modes are introduced owing to the existence of rotation, a magnetic field, and a solute gradient. Thermosolutal instability of rivlin-ericksen rotating fluid in porous medium has been studied by (Sharma et al, 1998) and found that solute gradient and rotation have stabilizing effects on the system. (Aggarwal, 2010) has studied the thermosolutal convection in Rivlin-Ericksenelastico-viscous fluid in porous medium on applying effects of rotation and suspended particles and found that suspended particles and permeability have destabilizing effect while solute gradient and rotation have stabilizing effect. Combined effect of suspended particles and rotation on thermosolutal convection in a Rivlin-Ericksen viscoelastic fluid saturating a Darcy-Brinkman porous medium is studied by (Rana and Thakur, 2013). (Kumar and Mohan, 2014) have investigated thermosolutal convective Instability through porous medium. On applying the effects of suspended particles, rotation, magnetic field and variable gravity field (Makhija and Aggarwal, 2014) have studied the thermosolutal convection in Rivlin-Ericksen fluid in porous medium and found that due to presence of all these effects oscillatory modes added in to the system.

The thermosolutal convection in a ferromagnetic fluid was studied by (Sunil et al., 2004). (Sunil et al.,2004) discussed the effect of rotation on a ferromagnetic fluid heated and soluted from below saturating a porous medium. Also, the effect of the magnetic field dependent viscosity on the thermosolutal convection in a ferromagnetic fluid saturating a porous medium was studied by (Sunil et al., 2005). The effect of rotation on the double-diffusive convection in a magnetized ferrofluid with internal angular momentum was studied by (Sunil et al., 2011). (Sunil et al., 2005) studied the effect of the magnetic-field dependent viscosity on the thermosolutal convection of a rotating ferromagnetic fluid saturating a porous medium. The magneto-rotational convection for ferromagnetic fluids in the presence of compressibility and heat source via a porous medium was studied with the aid of using the results of (Sharma et al., 2014). (Pundiret. Al, 2021) discussed the effect of magnetic field, rotation and magnetization on the thermosolutal instability of a ferromagnetic fluid in the presence of a variable gravity field. On applying the effects of rotation and variable gravity field (Pulkit et al., 2020) have studied the thermosolutal instability of couple stress ferromagnetic fluid. Effect of rotation, magnetic field, suspended particles with various conditions on Thermal instability of couple stress RivlinEricksen ferromagnetic fluid with variable gravity field in porous medium have been studied by (Rahul and Sharma, 2021). (Rahul et al., 2021) investigated the effect of suspended particles, couple stress and permeability of the medium on the thermal instability of a couple stress Rivlin-Ericksen ferromagnetic fluid with varying gravity field through a porous medium and found that suspended particles, couple stress and permeability have conditional destabilizing and stabilizing effect. Oscillatory modes are not allowed and the principle of exchange of stability is satisfied.

To view the scope of thermosolutal convection of a couple-stress Rivlin-Ericksen ferromagnetic fluid in porous medium in food processing, geophysics, soil sciences, ground water hydrology and astrophysics we have investigated here the thermosolutal convection of couple stress rivlin-ericksen ferromagnetic fluid with variable gravity, rotation and magnetic field through a porous medium.

MATHEMATICAL FORMULATION AND DISPERSION RELATION

Here we have consider a thin layer of infinite in compressible, electrically non conducting couple stress Rivlin-Ericksen ferromagnetic fluid bounded between two infinite horizontal planes situated at z=0 & z=d. A uniform rotation Ω (0, 0,Ω), a uniform magnetic field

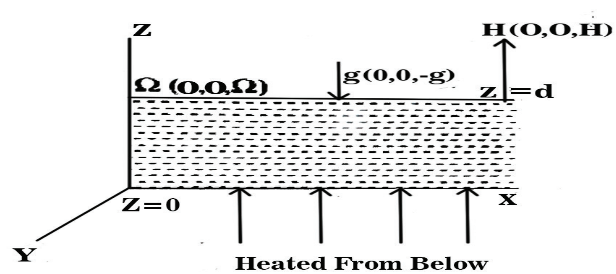


Fig. 1

H (0, 0, H) & variable gravity field g (0, 0,-g) are applied along the vertical direction which istaken as Z axis on considered layer.where $g = \lambda g_o$, g_o is the value of gat z=0, whichis alwayspositive. λ can be positiveor negativeas gravity increase or decreasesupwards from its value at z=0 (g_o).

The considered fluid layer is heated from below so that the uniform temperature gradient $\beta = \left(\left|\frac{dT}{dz}\right|\right)$ is maintained.

A ferromagnetic fluid reacts so quickly to a magnetic torque that we can simulate the following conditions to maintain,

$$M \times H = 0 \qquad \ldots(1)$$

Where *M* represents magnetization and *H* represents the magnetic field intensity.

The Maxwell's equation is also satisfied by ferromagnetic fluid. Here we examine electrically non conducting fluid, therefore the displacement current is negligible. Maxwell's equation becomes,

$$\nabla \cdot B = 0, \nabla \times H = 0 \qquad \ldots(2)$$

The magnetic field intensity H, magnetization M and magnetic induction B are correlated in Chu formulation of electrodynamics such that,

$$B = \mu_0 (H + M) \qquad \ldots(3)$$

Let us assume that magnetization is depend on the amplitude of magnetic field, temperature and salinity. Let us also assume that magnetization is aligned with magnetic field so that,

$$M = \frac{H}{H} M\left(H, T, C\right) \qquad \ldots(4)$$

Let us take Pressure, Density, solute concentration, Temperature, Coefficient of thermal expansion, an analogous solvent expansion coefficient, Kinematic viscosity, kinematic viscous elasticity, couple stress viscosity, medium porosity, medium permeability, magnetic permeability, thermal diffusivity, Solute diffusivity, resistivity and velocity of fluid are denoted by $p, \rho, C, T, \alpha, \alpha', \nu, \nu', \mu', \varepsilon, K_1, \mu_e, \kappa_T, \kappa_S, \eta$ and $q = (u_1, u_2, u_3)$ respectively.

In presence of rotation and magnetic field, the equation of motion, continuity, heat conduction and solute concentrationof couple stress RivlinEricksen ferromagnetic fluid through porous medium are

$$\frac{1}{\varepsilon}\left[\frac{\partial q}{\partial t} + \frac{1}{\varepsilon}\left(q \cdot \nabla\right) q\right] = -\frac{1}{\rho_0}\nabla P + G\left(1 + \frac{\delta\rho}{\rho_0}\right) + \frac{1}{\rho_0} M \nabla H + \left(\nu - \frac{\mu}{\rho_0}\nabla^2\right)\nabla^2 q$$
$$-\frac{1}{K_1}\left(\nu + \nu' \frac{\partial q}{\partial t}\right) + \frac{2}{\varepsilon}\left(q \times \Omega\right) + \frac{\mu_e}{4\pi\rho_0}\left[\left(\nabla \times H\right) \times H\right] \qquad \ldots(5)$$

$$\nabla \cdot q = 0 \qquad \ldots(6)$$

$$\frac{\partial T}{\partial t} + \left(q \cdot \nabla\right) T = \kappa_T \nabla^2 T \qquad \ldots(7)$$

$$\frac{\partial C}{\partial t} + \left(q \cdot \nabla\right) C = \kappa_S \nabla^2 C \qquad \ldots(8)$$

The Maxwell's equation of electromagnetism is,

$$\varepsilon \frac{\partial H}{\partial t} = \left(H \cdot \nabla\right) q + \varepsilon \eta \nabla^2 H \qquad \ldots(9)$$

$$\nabla \cdot H = 0 \qquad \ldots(10)$$

The equation of state is

$$\rho = \rho_0 \left[1 - \alpha(T - T_0) + \alpha' (C - C_0)\right] \qquad \ldots(11)$$

Where T_0 and ρ_0 represents the value of temperature and density at $z = 0$ respectively.

∇H denotes the magnetic field gradient.

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

$$H = |H|, B = |B|, M = |M|$$

In general, to complete the system a state equation is needed, which satisfy M in two thermodynamic variables H and T. In present paper we consider magnetization is independent of magnetic field and depend on temperature only. Therefore,

$$M = M(T)$$

As the first approximation, we consider that

$$M = M_0 [1 - \gamma(T - T_0)] \qquad \ldots(12)$$

Where M_0 is the magnetization at $T = T_0$ *and*

$$\gamma = \frac{1}{M_0}\left(\frac{\partial M}{\partial T}\right)_H$$

To decompose the disturbances we use Normal Mode method. We suppose that perturbation is in following form,

$(u_3, \theta, \zeta, \xi, \gamma', hz) = [W(z), \Theta(z), Z(z), X(z), L(z), V(z)] \cdot \exp(i\, k_x x + i k_y y + nt$ …(13)

Where k_x and k_y are wave number in X and Y direction and k is the resultant disturbances wave number such that,

$$k = \sqrt{\left[(k_x)^2 + (k_y)^2\right]}$$

n is the frequency of any arbitrary disturbances which is a complex constant.

Now by using relation (13) we obtain non dimensional form

$$\left(D^2 - a^2\right)\begin{bmatrix} \frac{\sigma}{\varepsilon} + F\left(D^2 - a^2\right)^2 \\ -\left(D^2 - a^2\right) + \frac{(1+\sigma F_1)}{P_t} \end{bmatrix} W + \frac{\alpha a^2 \lambda d^2}{v}\left(g_o - \frac{\gamma M_0 \nabla H}{\rho_0 \alpha \lambda}\right)\theta$$
$$- \frac{\lambda g_0 \alpha' a^2 d^2}{v} L + \frac{2}{\varepsilon v}\Omega d^3 DZ - \frac{\mu_e H d}{4\pi\rho_0 v}\left(D^2 - a^2\right) DV = 0 \qquad \ldots(14)$$

$$\begin{bmatrix} \frac{\sigma}{\varepsilon} + F\left(D^2 - a^2\right)^2 \\ -\left(D^2 - a^2\right) + \frac{\left(1 + \sigma \frac{F_1}{P_t}\right)}{P_t} \end{bmatrix} Z = \frac{2\Omega d}{\varepsilon v} DW + \frac{\mu_e H d}{4\pi\rho_0 v} DX \qquad \ldots(15)$$

$$\varepsilon\left[\left(D^2 - a^a\right) - \sigma P_2\right] X = -\frac{Hd}{\eta} DZ \qquad \ldots(16)$$

$$\varepsilon\left[\left(D^2 - a^a\right) - \sigma P_2\right] V = -\frac{Hd}{\eta} DW \qquad \ldots(17)$$

$$\left[\left(D^2 - a^a\right) - \sigma P_1\right] \Theta = -\frac{\beta d^2}{\kappa_T} W \qquad \ldots(18)$$

$$\left[\left(D^2 - a^a\right) - \sigma P_3\right] L = -\frac{\beta' d^2}{\kappa_S} W \qquad \ldots(19)$$

Where we have represent the coordinates x, y and z in new units of length d, time t and (d^2/κ_T). Let $a = kd$, $\sigma = nd^2/v$, $F = \frac{\mu}{\rho_\theta d^2 v}$, $F_1 = \frac{v'}{d^2}$, $F_1 =$, $P_t = K_1/d^2$, $P_1 = v/\kappa_T$, $P_2 = v/\eta$, $P_3 = v/\kappa_S$ $x^* = x/d$, $y^* = y/d$, $z^* = z/d$, $D^* = dD$ and dropping * for convenience.

Where P1 and Pt denotes prandlt number and dimensionless medium permeability.

Now eliminate Θ, X, V, L and Z from (14) with the help of (15), (16), (17), (18) and (19), then we get Stability governing equation

$$\lambda a^2 Rf \frac{1}{\left(D^2-a^2\right)-\sigma P_1} W$$

$$= (D^2-a^2)\begin{bmatrix} \frac{\sigma}{\varepsilon}+F\left(D^2-a^2\right)^2 \\ -\left(D^2-a^2\right)+\frac{\left(1+\sigma F_1\right)}{P_t} \end{bmatrix} W + \lambda a^2 S \frac{1}{\left(D^2-a^2\right)-\sigma P_3} W$$

$$+\frac{T_A}{\varepsilon^2}\left[\frac{1}{\left[\left[\begin{Bmatrix} \frac{1}{\varepsilon}+F\left(D^2+a^2\right)^2-\left(D^2-a^2\right)+\frac{\left(1+\sigma F_1\right)}{P_t} \\ +\frac{QD^2}{\varepsilon\left(D^2-a^2-\sigma P_2\right)} \end{Bmatrix}\right]\right]}\right] D^2 W + \frac{Q}{\varepsilon\left(\left(D^2-a^2\right)-\sigma P_2\right)}\left(D^2-a^2\right) D^2 W$$

(20)

Where

$$R_f = \frac{\alpha\beta d^4}{\nu\kappa_T}\left[g_0 - \frac{\gamma M_0 \nabla H}{\rho_0 \alpha\lambda}\right] = \frac{\alpha\beta d^4 g_0}{\nu\kappa_T}\left[1-\frac{\gamma M_0 \nabla H}{\rho_0\alpha\lambda g_0}\right] = R\left[1-\frac{\gamma M_0 \nabla H}{\rho_0\alpha\lambda g_0}\right]$$

R_f is the Rayleigh number for ferromagnetic fluid.R is the Rayleigh number for fluid.

$T_A = \left(\frac{2\Omega d^2}{\nu}\right)^2$ is the modified Taylor number. $Q = \frac{\mu_e H^2 d^2}{4\pi\rho_0 \nu\eta}$ is the Chandrasekhar number

The perturbation in the temperature on boundaries is zero, because the boundaries are kept at constant temperature. So the appropriate condition on boundary is

$$W = 0,\ Z = 0, \text{ at } z = 0 \ \&\ z = 1,\ DZ = D^2W = D^4W = 0 \text{ at } z = 0 \ \&\ z = 1 \qquad \dots(21)$$

From (21), it is clear that all even order derivative of W vanish on boundaries. Therefore proper solution of (20) characterizing the lowest mode is,

$$W = W_0 \sin \pi z ,\ W^0 \text{ is a constant} \qquad \dots(22)$$

By using (22)with (21), we get,

$$R_1 = \frac{1}{\lambda x}(1+x)(1+x+i\sigma_1 P_1)\left[\frac{i\sigma_1}{\varepsilon}+F_2(1+x)^2+\frac{(1+i\sigma_1 F_3)}{P}\right]+\frac{1}{\varepsilon^2\lambda x}\left[\frac{T_{A1}(1+x+i\sigma_1 P_1)(1+x+i\sigma_1 P_2)}{(1+x+i\sigma_1 P_2)\left[\frac{i\sigma_1}{\varepsilon}+F_2(1+x)^2+(1+x)+\frac{(1+i\sigma_1 F_3)}{P}\right]+\frac{Q_1}{\varepsilon}}\right]$$

$$+S_1\frac{(1+x+i\sigma_1 P_1)}{(1+x+i\sigma_1 P_2)}+\frac{1}{\lambda x}\frac{Q_1(1+x)(1+x+i\sigma_1 P_1)}{\varepsilon(1+x+i\sigma_1 P_2)}$$

…(23)

Where

$$x=\frac{a^2}{\pi^2}\;,i\sigma 1=\frac{\sigma}{\pi^2},F_2=\pi^2F,P=\pi^2Pt,S_1=\frac{S}{\pi^4}$$

$$F_3=\pi^2F_1\;,R_1=\frac{R_f}{\pi^4}\;,T_{A1}=\frac{T_A}{\pi^4},Q_1=\frac{Q}{\pi^2}$$

5. ANALYTICAL DISCUSSION

5.1 Stationary Convection: -at stationary convection, when stability sets, the marginal state will be characterized by Put in(23), we get,

$$R_1=\frac{(1+x)^2}{\lambda x}\left[\left\{F_2(1+x)^2+(1+x)+\frac{1}{P}\right\}+\frac{T_{A1}}{\varepsilon}\left\{\frac{1}{(1+x)\left\{F_2(1+x)^2+(1+x)+\frac{1}{P}\right\}+\frac{Q_1}{\varepsilon}}\right\}+\frac{Q_1}{e(1+x)}\right]+S_1$$

…(24)

Clearly (24) shows the modified Rayleigh number R_1 as a function of F_2, T_{A1}, P, Q1, S1 andx parameters. Clearly viscoelastic parameter F_3 disappears with σ_1. It shows that for stationary convection RivlinEricksen fluid behaves like an ordinary Newtonian Fluid.

To examine the effect of couple stress, permeability, rotation, solute gradient, magnetic field and magnetization we have to study the analytical behaviour of

$$\frac{dR_1}{dF_2},\frac{dR_1}{dP},\frac{dR_1}{dT_{A1}},\frac{dR_1}{dQ_1}\text{and}\frac{dR_1}{dM_0}.$$

$$\frac{dR_1}{dF_2}=\frac{(1+x)4}{\lambda x}\left[1-\frac{T_{A1}(1+x)}{\varepsilon^2\left[(1+x)\left\{F_2(1+x)^2+(1+x)+\frac{1}{P}\right\}+\frac{Q_1}{\varepsilon}\right]2}\right]$$

…(25)

(25) shows that couple stress has stabilizing effect on thermal instability of couple stress RivlinEricksen ferromagnetic fluid in presence of gravity field, rotation, solute gradient and magnetic field through porous medium under following condition,

$$\lambda>0,T_{A1}(1+x)<\varepsilon^2\left[(1+x)\left\{F_2(1+x)^2+(1+x)+\frac{1}{P}\right\}+\frac{Q_1}{\varepsilon}\right]^2$$

and

$$\lambda<0,T_{A1}(1+x)>\varepsilon^2\left[(1+x)\left\{F_2(1+x)^2+(1+x)+\frac{1}{P}\right\}+\frac{Q_1}{\varepsilon}\right]^2$$

In reverse condition couple stress has destabilizing effect.

$$\frac{dR_1}{dQ_1}=\frac{(1+x)}{\varepsilon\lambda x}\left[1-\frac{(1+x)T_{A1}}{\varepsilon^2\left[(1+x)\left\{F_2(1+x)^2+(1+x)+\frac{1}{P}\right\}+\frac{Q_1}{\varepsilon}\right]^2}\right]$$

...(26)

(26) shows that permeability has stabilizing effect onthermal instability of couple stress RivlinEricksen ferromagnetic fluid in presence of gravity field, rotation, solute gradient and magnetic field through porous medium under following condition,

$$\lambda > 0, T_{A1}(1+x) > \varepsilon^2\left[(1+x)\left\{F_2(1+x)^2+(1+x)+\frac{1}{P}\right\}+\frac{Q_1}{\varepsilon}\right]2$$

and

$$\lambda < 0, T_{A1}(1+x) < \varepsilon^2\left[(1+x)\left\{F_2(1+x)^2+(1+x)+\frac{1}{P}\right\}+\frac{Q_1}{\varepsilon}\right]2$$

$$\frac{dR_1}{dT_{A1}} = \frac{(1+x)^2}{\varepsilon^2\lambda x\left[(1+x)\left\{F_2(1+x)^2+(1+x)+\frac{1}{P}\right\}+\frac{Q_1}{\varepsilon}\right]}$$

…(27)

Clearly (27) shows that rotation has stabilizing effect on thermal instability of couple stress Rivlin-Ericksen ferromagnetic fluid in presence of gravity field, rotation, solute gradient and magnetic field through porous medium if $\lambda > 0$, (when gravity increases upwards from its value at $z = 0$) and destabilizing effect if $\lambda < 0$ (when gravity decreases upwards from its value at $z = 0$) or rotation has dual character.

$$\frac{dR_1}{dS_1} = 1 \qquad \ldots(28)$$

(28) shows that solute gradient has stabilizing effect on thermal instability of couple stress Rivlin-Ericksen ferromagnetic fluid in presence of gravity field, rotation solute gradient and magnetic field through porous medium.

$$\frac{dR_1}{dQ_1} = \frac{(1+x)}{\varepsilon\lambda x}\left[1-\frac{(1+x)TA1}{\varepsilon^2\left[(1+x)\left\{F_2(1+x)^2+(1+x)+\frac{1}{P}\right\}+\frac{Q_1}{\varepsilon}\right]2}\right] \qquad \ldots(29)$$

(29) shows that magnetic field has stabilizing effect on thermal instability of couple stress Rivlin-Ericksen ferromagnetic fluid in presence of gravity field, rotation, solute gradient and magnetic field through porous medium under following condition,

$$\lambda > 0, T_{A1}(1+x) < \varepsilon^2\left[(1+x)\left\{F_2(1+x)^2+(1+x)+\frac{1}{P}\right\}+\frac{Q_1}{\varepsilon}\right]2$$

and

$$\lambda\left\langle 0, TA1(1+x)\right\rangle\varepsilon^2\left[(1+x)\left\{F_2(1+x)^2+(1+x)+\frac{1}{P}\right\}+\frac{Q_1}{\varepsilon}\right]2$$

Replace R1 by R_f / π^4 and R_f by $R\left[1-\dfrac{\gamma M_0 \nabla H}{\rho_0\alpha\lambda g_0}\right]$

From (30)

$$R=\frac{\frac{\pi^4(1+x)2}{\lambda x}\left[\left\{F_2(1+x)^2+(1+x)+\frac{1}{P}\right\}+\frac{T_{A1}}{\varepsilon^2\left[(1+x)\left\{F_2(1+x)^2+(1+x)+\frac{1}{P}\right\}+\frac{Q_1}{\varepsilon}\right]}+\frac{Q_1}{\varepsilon(1+x)}\right]+S1\pi^4}{\left[1-\frac{\gamma M_0\nabla H}{\rho_0\alpha\lambda g_0}\right]}$$

…(30)

$$\frac{\frac{\pi^4(1+x)2}{\lambda x}\left[\begin{array}{c}\left\{F_2(1+x)^2+(1+x)+\frac{1}{P}\right\}\\ +\frac{TA1}{\varepsilon^2\left[(1+x)\left\{F_2(1+x)^2+(1+x)+\frac{1}{P}\right\}+\frac{Q1}{\varepsilon}\right]}+\frac{Q_1}{\varepsilon(1+x)}\end{array}\right]\left(\frac{\gamma\nabla H}{\rho_0\alpha\lambda g_0}\right)+s1\pi4\left(\frac{\gamma\nabla H}{\rho_0\alpha\lambda g_0}\right)}{\left[1-\frac{\gamma M_0\nabla H}{\rho_0\alpha\lambda g_0}\right]2}$$

..... (31)

Clearly (31) shows that magnetization has stabilizing effect on thermal instability of couple stress Rivlin-Ericksen ferromagnetic fluid in presence of gravity field, rotation, solute gradient and magnetic field through porous medium for each value of λ either λ > 0, or λ< 0 (either gravity increases upwards from its value at z = 0 or gravity decreases upwards from its value at z = 0).

STABILITY OF THE SYSTEM & OSCILLATORY MODES:-

On applying mathematical operation we obtain,

$$\left[\frac{\sigma}{\varepsilon}+\frac{(1+\sigma F_1)}{P_t}\right]I_1+I_2+FI_3+d^2\left[\begin{array}{c}\left\{\frac{\sigma^*}{\varepsilon}+\frac{(1+\sigma^* F_1)}{P_t}\right\}I_4+I_5+\\ FI_6+\frac{\mu_e\eta\grave{o}}{4\pi\rho_0\nu}(I_7+P_2\sigma I_8)\end{array}\right]$$

$$-\frac{\alpha a^2\lambda\kappa_T}{\beta\nu}\left(g_0-\frac{\gamma M_0\nabla H}{\rho_0\alpha\lambda}\right)\left[I_9+\sigma^*P_1I_{10}\right]+\frac{\alpha' a^2\lambda g_0\kappa_S}{\beta'\nu}\left(I_{11}+P_3\sigma^*I_{12}\right)++\frac{\mu_e\eta\grave{o}}{4\pi\rho_0\nu}\left(I_{13}+P_2\sigma^*I_{14}\right)=0$$

…(32)

Where

$$I_1=\int\left(|DW|^2+a^2|W|^2\right)dz$$

$$I_2=\int\left(|D^2W|^2+a^4|W|^2+2a^2|DW|^2\right)dz$$

$$I_3=\int\left(|D^3W|^2+3a^2|D^2W|^2+3a^4|DW|^2+a^6|W|^2\right)dz$$

$$I_4=\int\left(|Z|^2\right)dz$$

$$I_5 = \int\left(\left|DZ\right|^2 + a^2\left|Z\right|^2\right)dz$$

$$I_6 = \int\left(\left|D^2Z\right|^2 + a^4\left|Z\right|^2 + 2a^2\left|DZ\right|^2\right)dz$$

$$I_7 = \int\left(\left|DX\right|^2 + a^2\left|X\right|^2\right)dz$$

$$I_8 = \int\left(\left|X\right|^2\right)dz$$

$$I_9 = \int\left(\left|D\Theta\right|^2 + a^2\left|\Theta\right|^2\right)dz$$

$$I_{10} = \int\left(\left|\Theta\right|^2\right)dz$$

$$I_{11} = \int\left(\left|DL\right|^2 + a^2\left|L\right|^2\right)dz$$

$$I_{12} = \int\left(\left|L\right|^2\right)dz$$

$$I_{13} = \int\left(\left|D^2V\right|2 + a^4\left|V\right|^2 + 2a^2\left|DV\right|^2\right)dz$$

$$I_{14} = \int\left(\left|DV\right|^2 + a^2\left|V\right|^2\right)dz$$

All above specified integrals I1- I14 are +ve definite.

Put $\sigma = \sigma_{r+}\, i\, \sigma_i$ in (32) where σ_r and σ_i real. Equating real and imaginary part, we obtain,

$$\sigma_r\begin{bmatrix} \left(\frac{1}{\varepsilon}+\frac{F_1}{P_t}\right)I_1+\left(\frac{d^2}{\varepsilon}+\frac{d^2F_1}{P_t}\right)I_4+\frac{\mu e\eta\varepsilon d2}{4\pi\rho_0\nu}P_2I_8 \\ -\frac{\alpha a^2\lambda\kappa_T}{\beta\nu}\left(g_0-\frac{\gamma M_0\nabla H}{\rho_0\alpha\lambda}\right)P_1I_{10}+\frac{\alpha' a^2\lambda\kappa_S g_0}{\beta'\nu}P_3I_{12}++\frac{\mu_e\eta\epsilon}{4\pi\rho_0\nu}P_2I_{14}\end{bmatrix} = $$

$$-\begin{bmatrix} \frac{1}{P_t}I_1+I_2+FI_3+d^2\left(\frac{1}{P_t}I_4+I_5+FI_6+\frac{\mu_e\eta\epsilon}{4\pi\rho_0\nu}I_7\right) \\ -\frac{\alpha a^2\lambda\kappa_T}{\beta\nu}\left(g_0-\frac{\gamma M_0\nabla H}{\rho_0\alpha\lambda}\right)I_9+\frac{\alpha' a^2\lambda g_0\kappa_S}{\beta'\nu}I_{11}+\frac{\mu_e\eta\epsilon}{4\pi\rho_0\nu}I_{13}\end{bmatrix} \quad \ldots(33)$$

$$\sigma_i\begin{bmatrix} \left(\frac{1}{\varepsilon}+\frac{F_1}{P_t}\right)I_1-d^2\left(\frac{1}{\varepsilon}+\frac{F_1}{P_t}\right)I_4+\frac{\mu e\eta\varepsilon d^2}{4\pi\rho_0\nu}P_2I_8 \\ +\frac{\alpha a^2\lambda\kappa_T}{\beta\nu}\left(g_0-\frac{\gamma M_0\nabla H}{\rho_0\alpha\lambda}\right)P_1I_{10}-\frac{\alpha' a^2\lambda g_0\kappa_S}{\beta'\nu}P_3I_{12}-\frac{\mu_e\eta\epsilon}{4\pi\rho_0\nu}P_2I_{14}\end{bmatrix} = 0 \quad \ldots(34)$$

In absence of rotation, solute gradient and magnetic field(34) becomes,

$$\sigma_i\left[\left(\frac{1}{\varepsilon}+\frac{F1}{Pt}\right)I1+\frac{\mu_e\eta\varepsilon d^2}{4\pi\rho 0\nu}P_2I_8+\frac{\alpha a^2\lambda\kappa T}{\beta\nu}\left(g_0-\frac{\gamma M_0\nabla H}{\rho_0\alpha\lambda}\right)P_1I_{10}\right]=0 \quad (35)$$

From (35) the quantity is in bracket will be positive definite if $g_0 > \frac{\gamma M_0\nabla H}{\rho_0\alpha\lambda}$

It meansσ_i 0, modes are non oscillatory or oscillatory modes are not allowed and principle of exchange of stability is satisfied if $g_0 > \frac{\gamma M_0\nabla H}{\rho_0\alpha\lambda}$. From (33) when $\sigma_i \neq 0$,

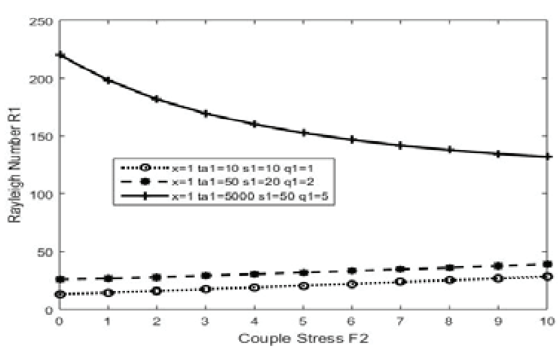
$$2\sigma_r\left[\left(\frac{1}{\varepsilon}+\frac{F_1}{P_t}\right)I_1+\frac{\mu_e\eta\varepsilon d^2}{4\pi\rho_0\nu}P_2I_8\right]=-\left[\begin{array}{c}\frac{1}{P_t}I_1+I_2+FI_3+d^2\left(\frac{1}{P_t}I_4+I_5+FI_6+\frac{\mu_e\eta\epsilon}{4\pi\rho_0\nu}I_7\right)\\ -\frac{\alpha a^2\lambda\kappa_T}{\beta\nu}\left(g_0-\frac{\gamma M_0\nabla H}{\rho_0\alpha\lambda}\right)I_9+\frac{\alpha' a^2\lambda g_0\kappa_S}{\beta'\nu}P_3I_{12}+\frac{\mu_e\eta\epsilon}{4\pi\rho_0\nu}I_{14}\end{array}\right]$$

…(36)

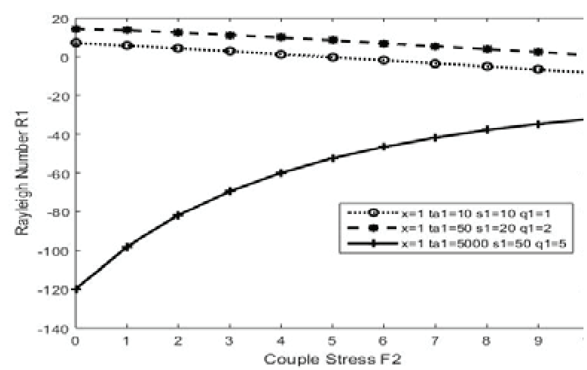
From (36) clearlyis negative if λ < 0.Therefore the system is stable in the presence of solute gradients, viscoelastic parameter F1,rotation and magnetic field. The presence of solute gradient, viscoelastic parameter F1, rotation and magnetic field introduces oscillatory modes, stability in the system and principle of exchange of stability is not satisfied if λ < 0.From (36) clearly may be positive or negative if λ > 0. So system may be stable or unstable if λ > 0.

NUMERICAL COMPUTATIONS:

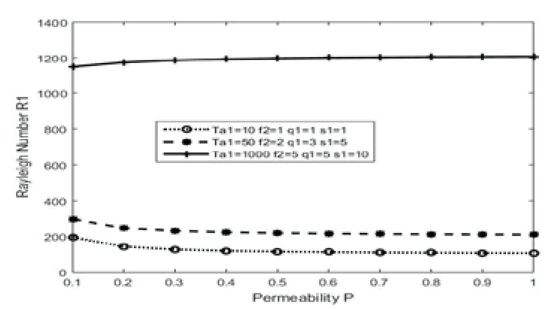
Dispersion equation (44) is analysed also. The critical Rayleigh number R_l& Rayleigh number for ferromagnetic fluid is calculated for different values of couple stress F_2, rotation T_{A1}, permeability P, magnetic field Q1 and Magnetization M_0.



λ=10, x=1, P=0.5, ε=0.5, T_{A1}= [10, 50,5000], Q1= [1, 2, 5] S1=[10 20 50] Figure 2

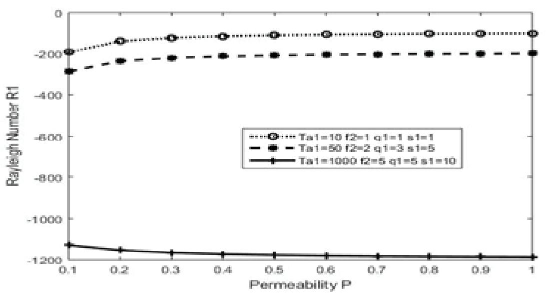


λ=-10, x=1, P=0.5, ε=0.5, T_{A1}= [10, 50,5000], Q1= [1, 2, 5] S1=[10 20 50] Figure 3



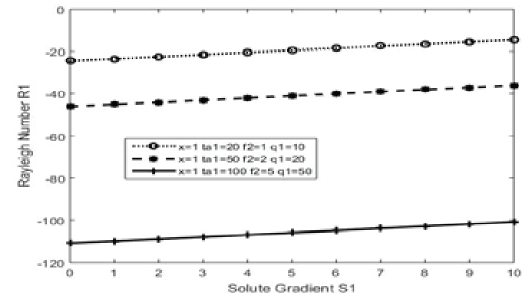
λ=1, x=1,P=0.5,ε=0.5, F_2=[1,2,5] ,T_{A1}=[10,50,1000],Q1=[1,3,5], S1=[1,5,10]

Figure 4



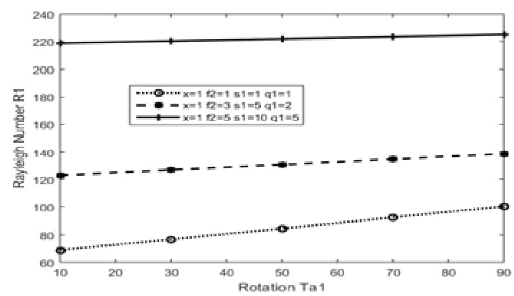
λ=-1, x=1,P=0.5,ε=0.5, F_2=[1,2,5] ,T_{A1}=[10,50,1000],Q1=[1,3,5], S1=[1,5,10]

Figure 5



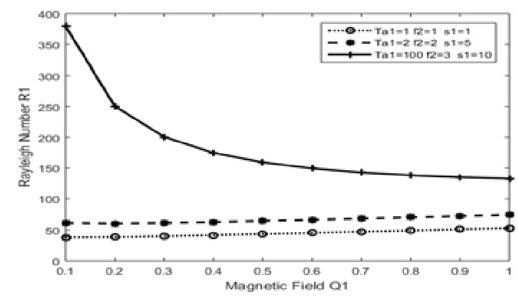
λ=-10, x=1, P=0.5, ε=0.5, F_2=[1, 2, 5] T_{A1}= [20, 50, 100] Q1=[10 20 50]

Figure 9



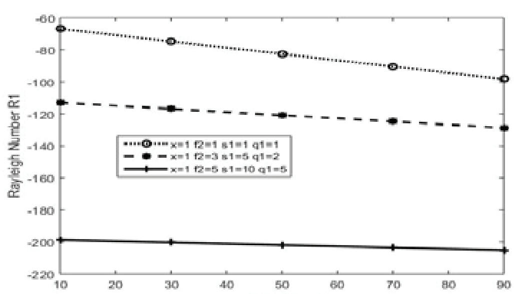
λ=1, x=1, P=0.5, ε=0.5, F_2=[1, 2, 5] Q_1= [1, 3, 5] S1=[1 5 10]

Figure 6



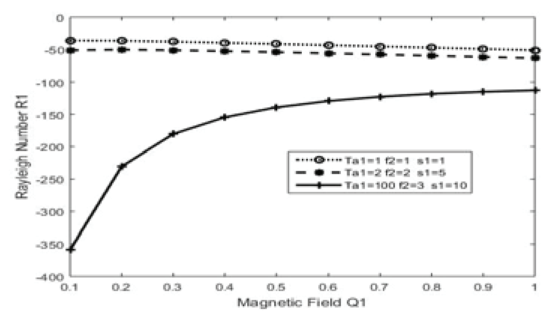
λ=1, x=1, P=0.5, ε=0.5, F_2=[1, 2, 3] T_{A1}= [1 2 100], S1=[1 5 10]

Figure 10



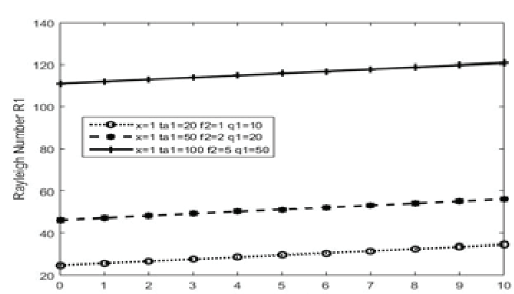
λ=1, x=1, P=0.5, ε=0.5, F_2=[1, 2, 5] Q_1= [1, 3, 5] S1=[1 5 10]

Figure 7



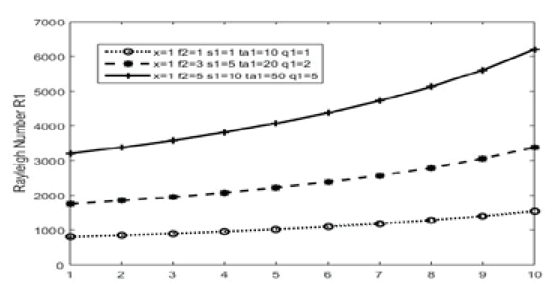
λ=-1, x=1, P=0.5, ε=0.5, F_2=[1, 2, 3] T_{A1}= [1 2 100] S1=[1 5 10]

Figure 11



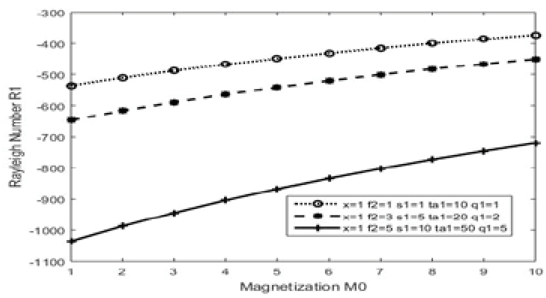
λ=10, x=1, P=0.5, ε=0.5, F_2=[1, 2, 5] T_{A1}= [20, 50, 100] Q1=[10 20 50]

Figure 8



λ=10, x=1,P=0.5,ε=0.5, γ=1, ρ0=1, g=9.8, α=1, T_{A1}=[10,20,50],Q1=[1,2,5], F_2=[1,3,5] S1=[1 5 10]

Figure 12



λ=-10, x=1,P=0.5,ε=0.5, γ=1, ρ0=1, g=9.8, α=1, T_{A1}=[10,20,50],Q1=[1,2,5], F_2=[1,3,5] S1=[1 5 10]

Figure 13

In figure 2, a graph has been plotted between critical Rayleigh number R_1 and couple stress parameter F_2 for λ=10, x=1, P=0.5, ε=0.5, T_{A1}= [10, 50,5000], Q_1= [1, 2, 5] , S_1=[10 20 50]and λ = 10> 0, which shows R_1increases with increases in F_2 for T_{A1}= 10 and 50So couple stress has stabilizing effect on the system for T_{A1}=10 and 50, but reverse effect for T_{A1}=5000 because stabilize condition fails.

In figure 3, a graph has been plotted between critical Rayleigh number R_1 and couple stress parameter F_2 for λ=10, x=1, P=0.5, ε=0.5, T_{A1}= [10, 50,5000], Q_1= [1, 2, 5] , S_1=[10 20 50] and λ = -10 < 0, which shows R_1 decreases with increases in F_2 for T_{A1} =10 and 50 so couple stress has destabilizing effect on the system for λ <0, but reverse effect for T_{A1} =5000 because destabilize condition fails for T_{A1} =5000.

So figure 2 and figure 3 shows couple stress has both stabilizing and destabilizing effect conditionally.

In figure 4,a graph has been plotted between critical Rayleigh number R_1 and permeability of the medium P for λ=1, x=1,P=0.5,ε=0.5, F_2=[1,2,5] , T_{A1}=[10,50,1000], Q_1=[1,3,5], S_1=[1,5,10] and λ =1 > 0, which shows R_1 decreases with increases P for T_{A1}=10 and 50 but reverse effect for T_{A1}=1000. So permeability has destabilizing effect on the system for T_{A1}=10 and 50 but stabilizing effect for T_{A1}=1000 for λ> 0.

In figure 5, a graph has been plotted between critical Rayleigh number R_1 and permeability of the medium P for λ=-1, x=1,P=0.5,ε=0.5, F_2=[1,2,5] , T_{A1}=[10,50,1000], Q_1=[1,3,5], S_1=[1,5,10] and λ =-1 > 0, which shows R_1 increases with increases P for T_{A1}=10 and 50 but reverse effect for T_{A1}=1000. So permeability has stabilizing effect on the system for T_{A1}=10 and 50 but destabilizing effect for T_{A1}=1000 for λ > 0.

In figure 6, a graph has been plotted between critical Rayleigh number R_1 and Rotation T_{A1} for λ=1, x=1, P=0.5, ε=0.5, F_2= [1, 2, 5] Q_1= [1, 3, 5] S_1=[1 5 10] and λ =1>0, which shows R_1 increases with increases inT_{A1}. So Rotation has stabilizing effect on the system for λ = 1 > 0.

In figure 7, a graph has been plotted between critical Rayleigh number R_1 and Rotation $T_{A1}$for λ=-1, x=1, P=0.5, ε=0.5, F_2= [1, 2, 5] Q_1= [1, 3, 5] S_1=[1 5 10] and λ =-1<0, which shows R_1 decreases with increases inT_{A1}. So Rotation has destabilizing effect on the system for λ = -1 < 0.

In figure 8, a graph has been plotted between critical Rayleigh number R_1 and Solute Gradient S1 for λ=10, x=1, P=0.5, ε=0.5, F_2= [1, 2, 5] T_{A1}= [20, 50, 100] Q_1=[10 20 50], which shows R_1 increases with increases in S_1. So solute gradient has stabilizing effect on the system for λ = 10>0.

In figure 9, a graph has been plotted between critical Rayleigh number R_1 and Solute Gradient S1 for λ=-10, x=1, P=0.5, ε=0.5, F_2= [1, 2, 5] T_{A1}= [20, 50, 100] Q_1=[10 20 50], which shows R_1 decreases with increases in S_1. So solute gradient has destabilizing effect on the system for λ = -10<0.

In figure 10, a graph has been plotted between critical Rayleigh number R_1 and Magnetic Field Q_1 for λ=1, x=1, P=0.5, ε=0.5, F_2= [1, 2, 3] T_{A1}= [1 2 100], S_1=[1 5 10] and λ =1>0, which shows R_1 increases with increases in Q_1. So Magnetic Field has stabilizing effect on the system for λ = 1>0.

In figure 11, a graph has been plotted between critical Rayleigh number R_1 and Magnetic Field Q_1 for λ=-1, x=1, P=0.5, ε=0.5, F2= [1, 2, 3] T_{A1}= [1 2 100], S_1=[1 5 10] and λ =-1<0, which shows R_1 increases with increases in Q_1. So Magnetic Field has destabilizing effect on the system for λ = -1<0.

In figure 12, a graph has been plotted between Rayleigh number R and magnetization of ferromagnetic fluid M_0 for λ=10, x=1,P=0.5,ε=0.5, γ=1, ρ0=1, g=9.8, α=1, T_{A1} = [10,20,50], Q_1=[1,2,5], F_2=[1,3,5] S_1=[1 5 10], which shows Rincreases with increases in M_0. So magnetization has stabilizing effect on the system for λ>0.

In figure 13, a graph has been plotted between Rayleigh number R and magnetization of ferromagnetic fluid M_0 for λ=-10, x=1,P=0.5,ε=0.5, γ=1, ρ0=1, g=9.8, α=1, T_{A1} = [10,20,50], Q_1=[1,2,5], F_2=[1,3,5] S_1=[1 5 10], which shows Rincreases with increases in M_0. So magnetization has stabilizing effect on the system for λ <0.

CONCLUSION

In the present paper, the effect of different parameters such as couple stress, viscoelastic, permeability, Solute Gradients, rotation, magnetic field and magnetization has been examined on thermal instability of couple stress rivlinericksen ferromagnetic fluid in presence of rotation, magnetic and gravity field in porous medium.

RESULTS OF INVESTIGATION ARE AS FOLLOWS:

1. Couple stress has stabilizing effect on thermal instability of couple stress RivlinEricksen ferromagnetic fluid in presence of gravity field, rotation, solute gradients and magnetic field through porous medium under following condition, couple stress has destabilizing effect on thermal instability of couple stress Rivlin-Ericksen ferromagnetic fluid in presence of gravity field, rotation, solute gradients and magnetic field through porous medium under reverse condition.

$$\lambda > 0, T_{A1}(1+x) < \varepsilon^2 \left[(1+x)\left\{ F_2 (1+x)^2 + (1+x) + \frac{1}{P} \right\} + \frac{Q_1}{\varepsilon} \right] 2$$

and

$$\lambda > 0, T_{A1}(1+x) > \varepsilon^2 \left[(1+x)\left\{ F_2 (1+x)^2 + (1+x) + \frac{1}{P} \right\} + \frac{Q_1}{\varepsilon} \right] 2$$

2. Rotation has stabilizing effect if λ> 0 and destabilizing effect if λ< 0.
3. Permeability has stabilizing effect on thermal instability of couple stress Rivlin-Ericksen ferromagnetic fluid in presence of gravity field, solute gradients, rotation and magnetic field through porous medium under following condition,

$$\lambda > 0, T_{A1}(1+x) > \varepsilon^2 \left[(1+x)\left\{ F_2 (1+x)^2 + (1+x) + \frac{1}{P} \right\} + \frac{Q_1}{\varepsilon} \right] 2$$

and

$$\lambda < 0, T_{A1}(1+x) < \varepsilon^2 \left[(1+x)\left\{ F_2 (1+x)^2 + (1+x) + \frac{1}{P} \right\} + \frac{Q_1}{\varepsilon} \right] 2$$

4. Magnetic field has stabilizing effect on thermal instability of couple stress Rivlin-Ericksen ferromagnetic fluid in presence of gravity field, rotation, solute gradient and magnetic field through porous medium under following condition,

$$\lambda > 0, TA1(1+x) < \varepsilon^2 \left[(1+x)\left\{ F_2 (1+x)^2 + (1+x) + \frac{1}{P} \right\} + \frac{Q_1}{\varepsilon} \right] 2$$

and

$$\lambda > \varepsilon^2 \left[(1+x)\left\{ F_2 (1+x)^2 + (1+x) + \frac{1}{P} \right\} + \frac{Q_1}{\varepsilon} \right] 2$$

5. Magnetization has always stabilizing effect on considered fluid layer.
6. The presence of solute gradient, viscoelastic parameter F1, rotation and magnetic field introduces oscillatory modes, stability in the system and principle of exchange of stability is not satisfied if λ < 0.

Declaration: *We also declare that all ethical guidelines have been followed during this work and there is no conflict of interest among authors.*

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