Effect of coriolis force on soret driven ferrothermohaline convection in a medium of sparse particle suspension

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In ferrofluids three components namely core, surfactant and carrier fluids coexist. Thermal convection in a multicomponent fluid has wide applications in industrial, ionospheric and geothermal systems. In this paper, the effect of magnetic fields along the vertical axis on a soret driven thermohaline convective instability in a ferrofluid saturating rotating porous medium has been examined using linear stability analysis. The infinitely spread fluid layer is assumed to be contained in between two free flat conducting boundaries. The exact solutions for stationary and oscillatory instabilities are obtained. It is found that the stationary instability is possible for Taylor numbers up to 100. When the values of Taylor number are greater than 100, the system is found to stabilize through oscillatory mode. The calculations made on this study are shown graphically.

Keywords: Ferrofluids, Linear stability, Soret effect, Taylor number, Porous medium

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1 Introduction

Ferrodynamics is an interdisciplinary area having inherent interest of a physical and mathematical nature with many applications in tribology, sink float separation, printing, medicine etc\textsuperscript{1}. It deals with the mechanics of fluid motion, influenced by strong forces of magnetic polarization. Several types of magnetic colloidal fluids could be synthesized for ferrodynamic applications. A colloid is a suspension of finely divided particles in a continuous medium, including suspensions that settle down very slowly. This determines the lifetime or the stability of colloids.

Applications of ferrofluids span a very wide range. Some of them are zero leakage rotary shaft seals used in computer disk drives\textsuperscript{2}; pressure seals for compressors and blowers\textsuperscript{3}. The mere presence of a drop of a ferrofluid makes liquid cooled loudspeakers to have good hi-fi characteristics and conducts heat away from the speaker coils\textsuperscript{5}. Ferrofluid can pilot the path of a drug to the target site in the body, known as drug targeting\textsuperscript{5}.

Since the magnetization depends on the magnetic field, temperature and density, any variation of the above causes a change in body force of the fluid and ultimately gives rise to ferro convection which is similar to Benard convection\textsuperscript{6}.

Double diffusive convection\textsuperscript{7} is of great importance in various fields such as high quality crystal production, oceanography, production of pure medicine, solidification of molten alloys, geothermally heated lakes and magmas. In many systems, out of the two components, one acts as a solute and the other as solvent. Solute and solvent need not be solid – liquid. They can be in any phase. Both can be liquids of miscible system. The double diffusive convection occurs when the above system is heated up.

Finlayson\textsuperscript{8} studied the convective stability of a ferromagnetic fluid heated from below in the presence of a vertical uniform magnetic field. Vaidyanathan \textit{et al}\textsuperscript{9,10} analysed both ferrothermohaline convective instability and soret driven ferrothermohaline convective instability. They have also studied ferroconvective instability of fluids saturating a porous medium of very large permeability\textsuperscript{11}.

Sekar \textit{et al}\textsuperscript{12} examined the ferroconvection in fluids saturating a rotating densely packed porous medium. Vaidyanathan \textit{et al}\textsuperscript{13} studied the effect of magnetic field dependent viscosity on setting up ferroconvective instability in a single component fluid saturating a porous medium. They have also studied the effect of rotation\textsuperscript{14} and field dependent viscosity on the onset of ferroconvection. The soret driven ferrothermohaline convection in a porous medium has
been studied\(^{15}\). Thermoconvection in ferrofluids, saturating a rotating porous medium could throw some information regarding convection in ferromagnetic fluids entrapped in earth crust. Rosensweig \textit{et al.}\(^{16}\) studied experimentally the penetration of ferrofluids in the heleshaw cell. Rudraiah \textit{et al.}\(^{17}\) have analyzed Marangoni convection in the presence of non-uniform basic temperature gradient with the object of understanding the control of Marangoni ferroconvection. Several researchers studied the effect of various phenomenon in ferro convection 18–21. In this paper, linear stability analysis is resorted into the soret driven thermohaline convection in fluids with sparse particle suspension. The fluid is assumed to be Boussinesq fluid\(^{6}\).

Investigations are made for both stationary and oscillatory modes for various values of permeability, Taylor number, soret parameter, magnetization and the salinity Rayleigh number.

2 Mathematical Formulation

An infinitely spread horizontal layer of Boussinesq ferromagnetic fluid of thickness \(d\) saturating a sparsely rotating porous medium in the presence of applied magnetic field heated from below and salted from above is considered. The temperature and salinity at the bottom surface \(z = -d/2\) are \(T_o+\Delta T/2\) and \(S_o-\Delta S/2\) and at the upper surface \(z = +d/2\) are \(T_o-\Delta T/2\) and \(S_o+\Delta S/2\) , respectively. Both boundaries are taken to be free and perfect conductors of heat and solute. Considering the Soret effect on the temperature gradient, the mathematical equations governing the system are given as:

The continuity equation for an incompressible Boussinesq fluid is:

\[ \nabla \cdot \mathbf{q} = 0 \]  

... (1)

The corresponding momentum equation is:

\[ \frac{\rho_o}{\varepsilon} \frac{D \mathbf{q}}{Dt} = -\nabla p + \rho g + \nabla \cdot (\mathbf{HB}) + \frac{\eta}{k} \nabla^2 \mathbf{q} + \frac{\rho_o}{\varepsilon} \left( \mathbf{q} \times \Omega \right) \]

\[ + \frac{\rho_o}{2} \nabla \left( \mathbf{r} \cdot \mathbf{x} \right) - \frac{\eta}{k} \mathbf{q} \]

... (2)

\[ \frac{D \mathbf{q}}{Dt} = -\nabla p + \rho g + \nabla \cdot (\mathbf{HB}) + \eta \nabla^2 \mathbf{q} + 2 \rho_o \left( \mathbf{q} \times \Omega \right) \]

\[ + \frac{\rho_o}{2} \nabla \left( \mathbf{r} \cdot \mathbf{x} \right) - \frac{\eta}{k} \mathbf{q} \]

... (2a)

The temperature equation for an incompressible ferrofluid is

\[ \frac{\rho_o}{C_v \cdot H} - \mu_o H \left( \frac{\partial M}{\partial T} \right)_{H \cdot H} \frac{dt}{dt} + \mu_o T \left( \frac{\partial M}{\partial T} \right)_{H \cdot H} \]

\[ \times \frac{dH}{dt} = K_1 \nabla^2 T + \Phi \]

... (3)

The mass flux equation is given by:

\[ \frac{D S}{Dt} = K_s \nabla^2 S + S_T \nabla^2 T \]

... (4)

where \(\rho_o, g, q, q' = \frac{q}{\varepsilon}, k, t, \eta, \eta' = \eta e, H, B, C_v, H\).

\(T, M, K_i, K_S, S, K, \Omega, S_T\) and \(\Omega\) are the density, acceleration due to gravity, velocity, perculatory velocity, porosity, consequent permeability of porous matrix due to sparse suspension, time, pressure, coefficient of viscosity, effective viscosity, magnetic field, magnetic induction , heat capacity at constant volume and magnetic field, temperature, magnetization, relative thermal diffusivity of fluids with reference to thermal conductivity of solid motion, concentration diffusivity, salinity, mass diffusivity, viscous dissipation factor containing second order terms in velocity, soret coefficient and angular velocity, respectively.

It is assumed that the magnetization is aligned with the magnetic field and it depends on the magnitude of magnetic field, temperature and salinity. Using Maxwell’s equation for non-conducting fluids, the magnetization is written as:

\[ M = \frac{H}{H} M \left( H, T, S \right) \]

... (5)

The linearised magnetic equation of state is written as:

\[ M = M_0 + \chi \left( H - H_0 \right) - K \left( T - T_0 \right) + K_2 \left( S - S_0 \right) \]

... (6)

where \(\chi = \left( \frac{\partial M}{\partial H} \right)_{H_0, T_0}\) is the susceptibility

\[ K = - \left( \frac{\partial M}{\partial T} \right)_{H_0, T_0} \]

is the pyromagnetic coefficient and

\[ K_2 = \left( \frac{\partial M}{\partial S} \right)_{H_0, S_0} \]

is the salinity magnetic coefficient
The density equation of state for a two-component Boussinesq fluid is
\[ \rho = \rho_0 \left[ 1 - \alpha_1 (T - T_0) + \alpha_s (S - S_0) \right] \] ... (7)
where \( \alpha_1 \) is the thermal expansion coefficient and \( \alpha_s \) is the solute analog of \( \alpha_1 \). Basic state is assumed to be quiescent state and the basic state quantities are obtained by substituting the velocity of quiescent state in the governing Eqs (1)-(4).

The techniques of linearization and normal mode are used in finding the solutions of the Eqs (1)-(4). This can be written as:
\[ f(x,y,z,t) = f(z,t) \exp \{ k_x x + k_y y \} \] ... (8)
where \( f(z,t) \) represents perturbed variables \( w(z,t), \theta(z,t), \phi(z,t) \) and \( S(z,t) \).

The wave number \( k_o \), is given by:
\[ k_o^2 = k_x^2 + k_y^2 \] ... (9)

The normal mode equations in dimensionless form can be written as:
\[
\frac{\partial^2}{\partial t^*} \left[ D^2 w^* \right] =
-(Ta)^{1/2} D \xi^* + a R^{1/2} \left[ M_1 D \phi^* - (1 + M_1 (1 - S_1)) T^* \right]
+ M_1 M_5 a R^{1/2} D \phi^* M_1 M_5 a R^{1/2} (1 - S_1) T^*
+ (D^2 - a^2)^2 w^* + a R^{1/2} \left( 1 + M_4 + \frac{M_5}{M_3} \right) S^* \] ... (10)

\[
\frac{\partial^2}{\partial t^*} \left[ D^2 \phi^* \right] =
\frac{\partial}{\partial t^*} \left[ D \phi^* \right] =
\left( D^2 - a^2 \right) T^* + (1 - M_2 - M_3 M_5) a R^{1/2} w^*
\] ... (11)

\[
\frac{\partial}{\partial t^*} \frac{\partial S^*}{\partial t^*} = \tau \left( D^2 - a^2 \right) S^* - a R^{1/2} M_6 w^*
+ S_f \left( \frac{M_5}{M_6} \right) R^{1/2} \left( D^2 - a^2 \right) T^*
\] ... (12)

where the dimensionless parameters used are:
\[ t^* = \frac{vt}{d^2}, \quad w^* = \frac{wd}{v}, \quad T^* = \left( \frac{K_a R^{1/2}}{\rho_0 c \beta vd} \right) \theta, \]
\[ \phi^* = \left( \frac{(1 + \chi) K_a R^{1/2}}{K \rho_0 c \beta \nu d^2} \right) \phi, \]
\[ z^* = \frac{z}{d}, \quad a = k_0 d, \]
\[ D = \frac{\partial}{\partial z^*}, \quad S^* = \left( \frac{K_a R^{1/2}}{\rho_0 c \beta \nu d} \right) S, \quad \nu = \frac{\eta}{\rho_0}, \quad k^* = \frac{k}{d^2}, \]
\[ \xi^* = \frac{\xi d^2}{v^2}. \quad M_1 = \frac{\mu_0 K^2 \beta_s}{(1 + \chi) \rho_0 g \alpha_s}, \quad M_2 = \frac{\mu_0 K^2 T_0}{(1 + \chi) \rho_0 c}, \]
\[ M_3 = \frac{1 + \frac{M_0}{H_0}}{(1 + \chi)}, \quad M_4 = \frac{\mu_0 K^2 \beta_s}{(1 + \chi) \rho_0 g \alpha_s}, \]
\[ M_5 = \frac{K_s \beta_s}{K_1}, \quad M_6 = \frac{K_s}{K_1}, \quad \eta = \frac{\nu c}{K_1}, \]
\[ R = \frac{\rho_0 c \beta_s g d^4}{v K_1}, \quad R_s = \frac{\rho_0 c \beta_s \alpha_s g d^4}{v K_s}, \]
\[ \tau = \rho_0 c \left( \frac{K_s}{K_1} \right). \] ... (15)

where \( R \) is the thermal Rayleigh number, \( R_s \) the salinity Rayleigh number and \( P_r \) is the Prandtl number. The other parameters \( M_1 \) to \( M_5 \) are the respective magnetization parameters. \( M_6 \) is the ratio of concentration diffusivity to thermal diffusivity.

3 Exact Solution for Free Boundaries

The boundary conditions on velocity, temperature, salinity are:
\[ w^* = D^2 w^* = T^* = D \phi^* = S^* = 0 \quad \text{at} \quad z^* = \pm \frac{1}{2} \] ... (16)

The exact solutions satisfying Eq. (16) are:
\[ w^* = A e^{\sigma \pi z^*}, \quad T^* = B e^{\sigma \pi z^*}, \]
\[ S^* = C e^{\sigma \pi z^*}, \quad D \phi^* = F e^{\sigma \pi \sin \pi z^*} \]
\[ \phi^* = \frac{F}{\pi} e^{\sigma \pi \sin \pi z^*} \] ... (17)
where $A$, $B$, $C$ and $F$ are constants. In the solution given in Eq. (17), the lowest mode of $\cos(n\pi z)$, for $n=1$ is assumed as solution. The solution can be odd or even modes compatible with boundary conditions. The choice of reference layer at the centre enables to choose lowest non zero even mode, namely $\cos(\pi z)$ for all dynamical variables. Substitution of Eq. (17) in Eqs (10) - (14) leads to:

\[
\left(\pi^2 + a^2\right)^2 + \left(\sigma + \frac{1}{k}\right)\left(\pi^2 + a^2\right) + \frac{T a \pi^2}{\sigma + \frac{1}{k} + \pi^2 + a^2}
\]

\[
A - \left[1 + M_1 \left(1 - S_T\right) + M_4 \left(1 - S_r\right)\right]
\]

\[
a R^{\frac{1}{2}} B \left(1 + M_4 + M_4 M_5^{-1}\right) a R^{\frac{1}{2}} C
\]

\[
+ a R^{\frac{1}{2}} M_1 \left(1 + M_5\right) F = 0
\]

\[
a R^{\frac{1}{2}} M_4 A + S_T \left[\frac{R^{\frac{1}{2}}}{R^{\frac{1}{2}} + \left(M_5\right)}\right] \left(\pi^2 + a^2\right) B
\]

\[
+ \left[T \left(\pi^2 + a^2\right) + \sigma Pr\right] C = 0
\]

\[
-(\pi^2 - 1 - S_T) R^{\frac{1}{2}} B + M_5 M_6^{-1} \pi^2 R^{\frac{1}{2}} C
\]

\[
+ \left(\pi^2 + a^2\right) M_3 \right) R^{\frac{1}{2}} F = 0
\]

For the existence of non-trivial eigen functions, the determinant of the coefficients of $A$, $B$, $C$ and $F$ in Eqs (18)-(21) must vanish and equating coefficient of time independent part to zero, the stationary critical thermal Rayleigh number $R_c$ is

\[
R_c = \frac{Nr}{Dr},
\]

where,

\[
Nr = \left(\pi^2 + a^2\right) \left[\frac{Ta\pi^2}{\frac{1}{k} + \left(\pi^2 + a^2\right)} + \frac{1}{k} \left(\pi^2 + a^2\right) + \left(\pi^2 + a^2\right)^{\frac{3}{2}}\right]
\]

\[
- a^2 R s \left[\left(1 + M_4 + M_4 M_5\right) \tau^{-1} M_6 + S_T \left(M_5 M_6\right)\right]
\]

\[
M_1 \pi^2 \left(1 + M_5\right) \left(S_T \left(M_5 M_6\right) \tau^{-1} + \left(1 - S_T\right) + M_5 \tau^{-1}\right)
\]

\[
\left(\pi^2 + a^2 M_3\right)
\]

\[
\frac{NR}{Dr} = a^2 \left[1 + \left(1 - S_T\right) M_1 \left(1 + M_5\right)\right]
\]

when the salinity Rayleigh number is taken as zero, this tends to the critical Rayleigh number obtained by Finlayson for single component ferrofluid. When $M_1 = 1000$, the classical Rayleigh problem for buoyancy-induced convection is obtained. It is worthwhile to point out that in the absence of rotation when $Ta=0$, Eq. (22) is identical with that of the thermal Rayleigh number obtained in and in the absence of porous medium when $\frac{1}{k} = 0$, Eq. (22) is exactly the same as that of the thermal Rayleigh number obtained. When there is no rotation and porosity, Eq. (22) is identical with that of the Rayleigh number obtained. When all the magnetic parameters $M_1$ to $M_6$ vanish, this reduces to double diffusive convection. For $M_1$ very large, one gets the results for the magnetic mechanism and the critical thermo magnetic Rayleigh number for stationary mode is obtained using:

\[
N_c = RM_1 = \frac{Nr}{Dr},
\]

where,

\[
NR = \left(\pi^2 + a^2\right) \left[\frac{Ta\pi^2}{\frac{1}{k} + \left(\pi^2 + a^2\right)} + \frac{1}{k} \left(\pi^2 + a^2\right) + \left(\pi^2 + a^2\right)^{\frac{3}{2}}\right]
\]

\[
- a^2 R s \left[\left(1 + M_4 + M_4 M_5\right) \tau^{-1} M_6 + S_T \left(M_5 M_6\right)\right]
\]

and
\[ \text{Dr} = a^2 \left( 1 + M_s \right) \]
\[
\times \left[ \pi^2 \left( \frac{M_5}{M_6} \right)^2 \tau^{-1} + \left( 1 - S_T \right) + M_5 \tau^{-1} \right] \]
\[
\left( \pi^2 + a^2 M_3 \right) \]

Taking \( \sigma = i \sigma_1 \) and \( \sigma_1 > 0 \), following the analysis and techniques \(^8_{-11}\), the critical Rayleigh number for oscillatory mode is calculated as follows:

\[
R = \frac{C_i A_2 + B_i D_i}{A_2^2 + B_2^2} \quad \ldots \quad (24)
\]

where

\[ A_2 = \left( -W_2 \sigma_1^2 + Y_2 \right) \]
\[ B_2 = X_2 \sigma_1 \]
\[ C_2 = \left( -U \sigma_1^4 + W \sigma_1^2 - Y \right) \]
\[ D_2 = \left( V \sigma_1^3 - X_1 \sigma_1 \right) \]
\[ U = h_1 h_2 \text{Pr}^2 \]
\[ V = h_1 h_2 \text{Pr} \left( h_2 \left( 1 + \tau \right) + 2 c_i P_r \right) \]
\[ h_1 = \left( \pi^2 + a^2 M_3 \right) \]
\[ h_2 = \left( \pi^2 + a^2 \right) \]
\[ h_3 = M_1 \left( 1 + M_3 \right) \]
\[ h_4 = \left( 1 + M_4 + M_4 M_5^{-1} \right) \]
\[ c_i = \frac{1}{k} + h_2 \]
\[ W_1 = h_1 \left( P_r^2 \left( T a \pi^2 + c_i^2 h_2 \right) + \tau h_2^3 + 2 c_i h_2^2 \text{Pr} \left( 1 + \tau \right) \right) \]
\[ -a^2 R h_i h_i M_6 \text{Pr} \]
\[ W_2 = -a^2 R h_i \text{Pr} \left( 1 + h_3 \left( 1 - S_T \right) \right) \]
\[ + a^2 R \pi^2 \text{Pr} h_3 \left( \left( 1 - S_T \right) + M_5 \right) \]
\[ X_1 = h_1 \left( h_2 \text{Pr} \left( 1 + \tau \right) \left( T a \pi^2 + c_i^2 h_2 \right) + 2 c_i \tau h_2^3 \right) \]
\[ -a^2 R h_i h_i M_6 \left( h_2 + \text{Pr} c_i \right) \]
\[ X_2 = h_1 a^2 R \pi^2 \left( 1 - S_T \right) \left( \tau h_2 + \text{Pr} c_i \right) + M_5 \left( h_2 + \text{Pr} c_i \right) \]
\[ + h_2 S_T \left( M_5 \right)^2 - a^2 R h_i \left( \tau h_2 + \text{Pr} c_i \right) \left( 1 + h_3 \left( 1 - S_T \right) \right) \]
\[ Y_1 = h_1 \left( h_2 \left( T a \pi^2 + c_i^2 h_2 \right) \right) \]
\[ - \left( a^2 R h_i h_i c_i \left( S_T \left( M_5 \right) + M_6 \right) \right) \]
\[ Y_2 = - \left( a^2 R \tau h_i h_i c_i \left( 1 + h_3 \left( 1 - S_T \right) \right) \right) \]
\[ + h_2 h_1 a^2 R \pi^2 c_i \left( S_T \left( M_5 \right)^2 + \tau \left( 1 - S_T \right) + M_3 \right) \]
\[
\sigma_1^2 = \frac{-B_i \pm \sqrt{B_i^2 - 4 A_i C_i}}{2 A_i} \quad \ldots \quad (25)
\]

where

\[ A_i = X_i U - VW_2 \]
\[ B_i = V Y_2 + X_i W_2 - X_i W_1 \]
\[ C_i = X_2 Y_i - X_1 Y_2 \]

If \( R_{oc} > R_{sc} \), the system stabilizes through stationary mode. If \( R_{oc} < R_{sc} \), the system stabilizes through oscillatory mode where \( R_{oc} \) and \( R_{sc} \) are critical Rayleigh numbers for oscillatory and stationary convection system.

### 4 Results and Discussion

The soret–driven thermo convective instability in ferrofluids in a rotating system of sparse particle suspension using Brinkman model has been analysed. Linear stability analysis is carried out as the perturbations are small. The Taylor number is assumed to vary from 10 to \( 10^8 \). The soret parameter \( S_T \) is varied from -0.002 to +0.002. The salinity Rayleigh number is taken to vary from –500 to +500 and \( \tau \), the ratio of mass transport to heat transport is considered from 0.05 to 0.13. The magnetization parameter \( M_1 \) is assumed to be 1000. For magnetic
fluids $M_2$ is negligible and hence, taken to be zero$^6$. $M_3$ is varied from 5 to 25. It has been found that the system stabilizes through stationary mode for Taylor number $Ta=10$ and $10^2$. When $Ta > 10^2$ the system has been found to stabilize only through oscillatory mode.

Fig.1(a) gives the variation of the critical thermal Rayleigh number $R_c$ versus the magnetization parameter $M_3$ for $Ta=10$. When the permeability $k$ is varied from 0.1 to 0.9, it is seen that, when $M_3$ increases from 5 to 25, $R_c$ decreases indicating onset of instability. This is because the high magnetization tends to release large energy to the system causing instability to set in earlier. Also as the permeability of the porous medium $k$ increases from 0.1 to 0.9, there is a fall in the values of $R_c$. Thus, the large permeability is found to induce instability through the stationary mode. This is because, as the pore size increases the fluid flows easily.

Fig.1(b) indicates the variation of $R_c$ versus $M_3$ for $Ta =10^5$ for different $k$. The same trend is seen in Fig.1 (a). The magnetization of the fluid is found to destabilize the system through oscillatory mode.

Fig.2(a) shows the variation of $R_c$ versus the salinity Rayleigh number $R_s$ for different values of $\tau$ and the ratio of mass transport to heat transport when $Ta =10^5$. When $R_s$ increases from $-500$ to $500$, there is a decrease in $R_c$ promoting instability. This is due to the fact that the fluid is salted from above and heated from below making the system top heavy. Again, when it is salted from below and heated from above the trend is reversed.

In Fig.2(b), the variation of $R_c$ versus $R_s$ for various values of $M_3$ for $Ta=10^5$ is analysed. It is clear that there is a destabilization when both $R_c$ and $M_3$ are increased. This is shown by a fall in $R_c$ values. Fig.3 (a) gives the variation of $R_c$ versus $k$ for the Taylor numbers 10 and $10^2$.

Fig.3 (a and b) gives the variation of $R_c$ versus $k$ for different Taylor numbers. An increase in Taylor number leads to an increase in critical thermal Rayleigh number. Fig.4(a) and 4(b) give the variation of $R_c$ versus $S_T$ for values of Taylor number 10 and $10^2$ and variation of $R_c$ versus $k$ for $Ta=10$ and for different $S_T$. 

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![Fig. 1(a)—Variation of $R_c$ versus $M_3$ of stationary instability for different $k$, when $R_s=-500$ and $\tau=0.05$ when $Ta=10$ and $S_T=-0.002$.](image1)

![Fig. 1(b)—Variation of $R_c$ versus $M_3$ of oscillatory instability for different $k$ when $R_s=-500$ and $S_T=-0.002$ and $Ta=10^5$.](image2)

![Fig. 2(a)—Variation of $R_c$ versus $R_s$ of oscillatory instability for different $\tau$ when $Ta=10^5$.](image3)

![Fig. 2(b)—Variation of $R_c$ versus $R_s$ of oscillatory instability for different $M_3$ and $k=0.1$and $Ta=10^5$and $S_T=-0.002$. M3 indicates $M_3$ in the text](image4)
From Figs 3 (a) and 4(a and b), it is seen that as $S_T$ increases from –0.002 to 0.002, there is an increase in the values of the critical thermal Rayleigh number $R_c$ indicating stabilization. This is due to the effect of soret parameter, which provides additional temperature gradient by cross diffusion of salinity on temperature. From Fig.3 (a) and Fig.4 (b), it is clear that as the permeability $k$ increases from 0.1 to 0.9, the $R_c$ values tend to decrease leading to destabilization. This is due to the fact that increase in pore size makes the flow of the fluid easier causing instability to set in earlier. Rotation tends to stabilize the system.

References
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