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Research Article

Influence of Temperature-Dependent Internal Heating on Magnoteconvention in a Rotating Darcy Porous Layer

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Abstract

The commencement of conventions which are the stationary and oscillatory in the study of the influence of temperature-dependent internal heating on magnetoconvection in a rotating Darcy porous layer was systematically examined. The linear stability analysis was scrutinized with the boundary condition of the problem being free-free. A modified Boussinesq approximation is included in the momentum equation and the Coriolis force was taken into consideration. The given non-dimensional equations were linearized and the normal mode technique was used to obtain marginal stationary and the marginal oscillatory convection. The criteria for the onset of convection in the system are derived analytically. The effects of the parameters: heat source, γ, magnetic field, Ha, rotation, T_D and ratio of viscosities, Λ on the onset of convection are presented and analyzed graphically in details. The investigation showed that the result of raising magnetic field, rotation and ratio of viscosity slowed down the commencement of the convections, that is both the stationary and oscillatory convections, hence making the system steady. In the other hand, increasing heat source parameter, catalyzes the commencement of convection and destabilizes the mechanism. Prandtl number was found to slow the onset of oscillatory convection. Hence we can infer that magnetic field parameter, Ha, rotation parameter, T_D, and the Prandtl number, Pr, are balancing factors, while the heat source parameter, γ, speeds up the commencement of convection.

Keywords

Magnetoconvection, Rotating Darcy Porous Layer, Temperature – Dependent Heat Source, Free – free Boundaries

1. Introduction

Investigation of fluid convection in a rotating porous medium abounds due to its numerous practical applications in areas such as astrophysics, oceanic flows, chemical and material processing, metal casting such as in continuous casting or dendritic solidification in alloys, energy technology, and thermal management and engineering. The literature consistently demonstrates that whereas rotation and magnetic fields tend to stabilise the system by postponing the commencement of convective motion, internal heat generation generally destabilises the system, accelerating the onset of convection [12]. Extensive research works are available concerning the problem of thermal convection in a rotating porous medium. Falsaperla and Mulone [5] examined the traditional Bernard system, which is rotational and irrotational with specific boundary

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conditions and fixed heat fluxes for temperature field. Kang et al. [8] studied the problem of high Rayleigh number steady state thermal convection in a rotating porous half space in which rotation gave rise to downward flow as against the upward thermal convection. Particularly, Vadasz [13] consider the result of Coriolis force in the thermal convection when the Darcy model is prolonged by embracing the acceleration term in the momentum equation. Vadasz and Govender [14] investigated the impact of gravity and centrifugal forces on the commencement of convection in a rotating porous layer.

In practical situations such as nuclear heat scores, nuclear waste disposal, oil extractions and crystals growth in geophysics and engineering in the porous medium, the beginning of convection is influenced by external heating. Alex and Patil [1] studied the problem of thermal instability with combined effects of centrifugal acceleration and anisotropy for both Darcy and Brinkman limits.

The impact of external fields such as electric and magnetic fields becomes significant in many convective instability problems of practical applications involving electrically conducting fluids. Chandrasekhar [3] investigated extensively, the linear theory of Rayleigh-Bernard magnetoconvection in which the onset of instability was affected by the vertically imposed magnetic field. It was particularly noticed that the effects of magnetic field was more dominant when the fluid is highly electrically conducting.

Investigation of the effects of of magnetic field on Darcy – Brinkman flow through a rotating porous channel system was considered in [15]. A number of situations allow for concurrence circumstances of magnetic field and rotation in the same direction to the gravitational field, for example, [10] showed the independence of the critical Rayleigh number, Ra on the magnetic field, Q and rotation, Ta for free-free boundaries when the medium adjoining the fluid is electrically non-conducting. The problem of the onset of thermal convection boussinesq fluid with simultaneous effects of rotation and magnetic field for rigid-rigid surfaces and adiabatic boundaries was considered.

[4] considered the onset of magnetoconvection in a rotating Darcy porous layer heated from below with temperature – dependent heat source filled with an electrically conducting Newtonian fluid. Their investigation was done using linear stability analysis to show the effects of various parameters on the onset of convection. This paper is to complement the rotating Darcy model of [4] with modified Boussinesq approximation involving temperature and solute concentration. This is to widen the applicability of problems of this nature. [2] Analyzes a horizontal layer of a dielectric fluid-saturated rotating porous medium, the study indicates that the presence of both electric and magnetic fields is more effective at suppressing convention (stabilizing the system) than an electric field alone.

2. Mathematical Formulation

Consider double-diffusive convection due to temperature dependent internal heating in an infinitely horizontal layer of a fluid with electrical conduction saturated by Darcy layer of thickness d . This fluid layer is held between $z^* = 0$ and$z^* = d$ stress-free boundaries. The lower and upper plates are maintained at temperature and solute concentration $T_h^*(= T_0 + \Delta T), c^*(= c_0 + \Delta c)$ and T_0, c_0, respectively such that $T_h^* > T_0, c_h^* > c_0$. The fluid system turns around the central axis consistently in the vertical direction with angular momentum, $\omega^* = \omega k$ and(x^*, y^*, z^*) taken with $z^* = 0$ as the starting point and the gravitational field acts vertically downwards. A uniform magnetic field of strength $\vec{B} = (0, 0, \ B_0)$ act vertically upwards. On account of small magnetic Reynolds number, induced magnetic field is neglected. The diagrammatic representation of the governing equation is given in Figure 1.

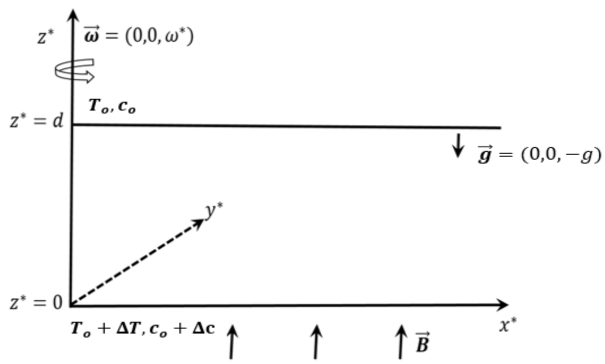

Figure 1. *Schematic diagram of the physical problem.*

2.1. Governing Equations

Employing Darcy model, Lorentz force and the Coriolis acceleration together with Boussinesq approximation, the governing equations are [6, 7, 9, 12].

$$\vec{\nabla}^*. \vec{V}^* = 0 \tag{1}$$

$$\frac{\rho_0}{\phi}\frac{\partial \vec{V}^*}{\partial t^*} = -\vec{\nabla}^* P^* - \rho_0[1 - \beta_t(T^* - T_0^*) + \beta_c(c^* - c^*)]g\vec{k} - \frac{\mu}{K}\vec{V}^* - \frac{2\rho_0}{\phi}\vec{\omega} \times \overrightarrow{V}^* + \mu_e \vec{\nabla}^{*2}\vec{V} + \ \sigma_c B_0^2(u^*, v^*, 0) \tag{2}$$

$$A\frac{\partial T^*}{\partial t^*} + (\overrightarrow{V}^*. \vec{\nabla}^*)T^* = \alpha_m \vec{\nabla}^{*2} T\ ^* + Q(T^* - T_0) \tag{3}$$

$$\phi \frac{\partial c^*}{\partial t^*} + (\overrightarrow{V}^*. \vec{\nabla}^*)c^* = D_c \vec{\nabla}^{*2} c^* \tag{4}$$

The variables entering the equations are defined in the nomenclature.

The boundary conditions are

$$\vec{V}^* = 0 \quad \text{on } z^* = 0, d \tag{5}$$

for the velocity, and

$$T^* = T_0 + \Delta T, c^* = c_0 + \Delta c \quad \text{on } z^* = 0 \tag{6}$$

$$T^* = T_0, c^* = c_0 \quad \text{on } z^* = d \tag{7}$$

The non-dimensional form of Eqs. (1) – (4) and the boundary conditions (5) and (6) can be written as

$$\vec{\nabla}.\overline{\vec{V}} = 0 \tag{8}$$

$$\left(\frac{1}{V_a}\frac{\partial}{\partial t} + 1\right)\vec{V} = -\vec{\nabla}P + RaT\vec{k} - Rs \quad c\vec{k} + \wedge D_a\overline{\nabla^2}\vec{V} - K_D\vec{V} - \sqrt{T_D\vec{k}} \quad \times \vec{V} - Ha^2(U, V, 0) \tag{9}$$

$$\frac{\partial T}{\partial t} + (\vec{\nabla}.\vec{\nabla})T = \left(\overline{\nabla^2} + \gamma\right)T \tag{10}$$

$$\varepsilon \quad \frac{\partial c}{\partial t} + (\vec{\nabla}.\vec{\nabla})c = \frac{1}{Le}\nabla^2 c \tag{11}$$

with boundary conditions

$$W = 0, T = 1, c = 1 \quad \text{on} \quad z = 0 \tag{12}$$

$$W = 0, T = 0, c = 0 \quad \text{on} \quad z = 1 \tag{13}$$

The dimensionless parameters are listed in the nomenclature.

2.2. Motionless State

The motionless system is

$v_b = 0, T = T_b(z), c = c_b(z), P = P_b(z),$ here, the subscript b denotes basic state. Then from Eqs. (8) - (11) and the boundary conditions (12) and (13), the governing equations of the basic state are

$$\frac{\partial P_b}{\partial z} = R_a T_b(z) - R_s c_b; \quad \frac{d^2 T_b}{dz^2} + \gamma T_b = 0; \quad \frac{d^2 c_b}{dz^2} = 0 \tag{14}$$

$$T_b = c_b = 1 \quad \text{on} \quad z = 0 \tag{15}$$

$$T_b = c_b = 0 \quad \text{on} \quad z = 1 \tag{16}$$

On solving Eqs. (14) subject to boundary conditions (15) and (16), we obtain the basic state pressure, temperature and solute concentration profiles, respectively, as

$$P_b(z) = Ra \quad \frac{Cos \ [\sqrt{\gamma} \ \ (1-z)]}{\sqrt{\gamma}Sin \ \ [\sqrt{\gamma}]} + Rs\left(\frac{z^2}{2} - z\right);$$

$$T_b(z) = \quad \frac{Sin \ \ [\sqrt{\gamma} \ \ (1-z)]}{Sin \ \ [\sqrt{\gamma}]}; \quad c_b(z) = 1 - z \tag{17}$$

2.3. Linearized Equations

Let

$$\vec{V} = \overline{v}, T = T_b(z) + \theta, P = p_b(z) + p, c = c_b(z) + s \tag{18}$$

in which the perturbed quantities $\overline{v}, p, \theta$ and s are assumed small compared to the equilibrium quantities. With Eq. (18), the governing Eqs. (8) - (11) and the boundary conditions (12) and (13) become

$$\vec{\nabla}.\vec{v} = 0 \tag{19}$$

$$\left(\frac{1}{V_a}\frac{\partial}{\partial t} + 1\right)\vec{v} + Ha^2(u, v, 0) + \vec{\nabla}P - R_a\theta\vec{k} + R_s s\vec{k} - \sqrt{T_D\vec{k}} \quad \times \vec{v} \tag{20}$$

$$\frac{\partial \theta}{\partial t} + \vec{v}.\overline{\nabla}\theta + \quad f(z)w = (\vec{\nabla}^2 + \gamma)\theta \tag{21}$$

$$Le\varepsilon\frac{\partial s}{\partial t} + \vec{v}.\overline{\nabla}s - Le \quad w = \vec{\nabla}^2 s \tag{22}$$

Where

$$-\frac{dT_b}{dz} = f(z) = \frac{\sqrt{\gamma}}{Sin[\sqrt{\gamma}]}Cos \quad [\sqrt{\gamma} \quad (1-z)]$$

is the basic state temperature distribution gradient, and boundary conditions becomes;

$$w = \quad \theta = s = 0 \quad \text{on} \quad z = 0,1 \tag{23}$$

2.4. Normal Mode Analysis

To facilitate our analysis, we take the *curl* and *curl curl* of equation (17) and keeping the z-component only we obtain

$$\left(\frac{1}{V_a}\frac{\partial}{\partial t} + 1 + Ha^2\right)\varsigma - \sqrt{T_D}Dw = 0 \tag{24}$$

$$\left(\frac{1}{V_a}\frac{\partial}{\partial t}+1\right)\nabla^2 W + Ha^2 D^2 w + \sqrt{T_D} D\varsigma - Ra\nabla^2{}_h\theta + R_s\nabla^2{}_h S = 0 \tag{25}$$

Where

$$\varsigma = \frac{\partial V}{\partial x} - \frac{\partial u}{\partial y},\ \nabla^2{}_h = \frac{\partial}{\partial x^2} - \frac{\partial}{\partial y^2},\ D \equiv \frac{\partial}{\partial z}.$$

For linear stability analysis, we convert Eqs. (19), (20), (21) and (22) to an eigenvalue problem by writing $W, \varsigma, \theta\ and\ s$ in the form

$$\begin{pmatrix} W \\ \varsigma \\ \theta \\ s \end{pmatrix} = \begin{pmatrix} W(z) \\ Z(z) \\ \Theta(z) \\ S(z) \end{pmatrix} f(x,y)e^{\omega t} \tag{26}$$

where the function $f(x,y)$ is the planform which tiles the plane and $\nabla^2{}_h = -a^2 f(x,y)$.

The substitution of Eq. (26) into Eqs. (19), (20), (21) and (22) yield the following system

$$(D^2 - a^2 + \gamma - \omega)\Theta + F(z)W = 0 \tag{27}$$

$$(D^2 - a^2 - Le\varepsilon\omega)S + LeW = 0 \tag{28}$$

$$\left(\frac{\omega}{V_a} + 1 + Ha^2\right)Z - \sqrt{T_D}DW = 0 \tag{29}$$

$$\left(\frac{\omega}{V_a}+1\right)(D^2 - a^2)W + Ha^2 D^2 W + \sqrt{T_D} DZ + a^2 Ra\Theta - a^2 R_c S = 0 \tag{30}$$

Now, the boundary conditions are

$$W = 0 = D^2 W = DZ = \Theta = S \text{ on } z = 0{,}1 \tag{31}$$

The elimination of Z between Eqs. (29) and (30) yields

$$\left(\frac{\omega}{Va}+M\right)\left(\frac{\omega}{Va}+1\right)(D^2-a^2)W + \left(\frac{\omega}{Va}+M\right) Ha^2 D^2 W + \sqrt{T_D} D^2 W + a^2\left(\frac{\omega}{Va}+M\right) Ra\ \Theta - a^2\left(\frac{\omega}{Va}+M\right) Rs\ S = 0 \tag{32}$$

Where $M = 1 + Ha^2$.

The boundary conditions reduce to

$$W = \Theta = \mathrm{S} = 0 \text{on z} = 0{,}1 \tag{33}$$

The boundary conditions suggest that we seek solutions of Eqs. (27), (28) and (32) in the form

$$W = W_0 Sin\pi \mathrm{z}, \Theta = \Theta_0 Sin\pi \mathrm{z}, S = S_0 Sin\pi \mathrm{z} \tag{34}$$

The substitution of Eq. (34) into Eqs. (27), (28) and (32) yield the following eigenvalue problem in matrix

$$H\overline{X} = 0 \tag{35}$$

where

$$H = \begin{pmatrix} -2F(z) & \delta^2 - \gamma + \omega & 0 \\ -Le & 0 & \delta^2 + Le\varepsilon\omega \\ \left(\frac{\omega}{Va}+M\right)\left[\left(\frac{\omega}{Va}+1\right)(\delta^2) + T_D\pi^2\right] & -a^2 Ra\left(\frac{\omega}{Va}+M\right) & a^2 Rs\left(\frac{\omega}{Va}+M\right) \end{pmatrix}$$

$\overline{X}^T = (W_0, \ \Theta_0, \ S_0), \delta^2 = \pi^2 + a^2$ and

$$F = \frac{2\pi^2}{4\pi^2 - \gamma}.$$

The solvability of system given in Eqs. (35) requires that $|H| = 0$, from which

$$Ra = (\delta^2 - \gamma + \omega)\frac{[(\delta^2 + Le\omega)(Ha^2\pi^2 V_a + \delta^2 Va + \delta^2\omega)]}{2a^2 F\ \ Va(\delta^2 + Le\omega)} + \frac{Le\ \ Rs}{2F(\delta^2 + Le\omega)} + \frac{\pi^2 T_D\ \ Va}{2a^2 F(M\ \ Va + \omega)} \tag{36}$$

It would be remarked that the growth rates s, given by $s = \omega_r + i\omega_i$, where ω_r, ω_i are real. Whenever $\omega_r < 0$ the system is stable, unstable when $\omega_r > 0$ and neutrally or marginally stability when $\omega_r = 0$.

2.5. Marginal Stationary Convection

In this case $\omega = 0$, so that $\omega_r = \omega_i = 0$ at the margin of stability. Now, setting $\omega = 0$ and $Ra = Ra^{st}$ in Eq. (36), gives

$$Ra^{st} = \frac{(\delta^2-\gamma)}{2F}\left[\left(\frac{\pi^2 Ha^2+\delta^2}{a^2}\right) + \frac{LeRs}{\delta^2} + \frac{\pi^2 T_D}{a^2 H}\right] \quad (37)$$

By setting the wavenumber $a = a_c$ in Eq. (37) and minimizing according to $\frac{\partial Ra^{st}}{\partial a_c^2} = 0$, we obtain the following 8th order polynomial

$$a_8 a_c^8 + a_6 a_c^6 + a_4 a_c^4 - a_2 a_c^2 - a_0 = 0 \quad (38)$$

where

$$a_8 = (1 + Ha^2) = M,$$

$$a_6 = 2M\pi^2,$$

$$a_4 = \mathrm{M}[(\pi^2 + LeR_s)\gamma + \pi^2 Ha^2(\gamma - \pi^2)] - \pi^2(\pi^2 - \gamma)T_D,$$

$$a_2 = 2\pi^4(\pi^2 - \gamma)[M + T_D], a_0 = \pi^6(\gamma - \pi^2)[M^2 + T_D]$$

2.6. Marginal Oscillatory Convection

For oscillatory convection, we set $\omega = i\omega_i \neq 0, Ra = Ra^{os}$ in Eq. (36) and obtain

$$Ra^{os} = \Delta_1 + i\omega_i \Delta_2 \quad (39)$$

Where

$$\Delta_1 = \frac{d_1 d_2 - \delta^2}{2a^2 F\ Va} + \frac{Le\ \ Rs(d_1\delta^2 + Le\ \ \varepsilon\omega_i^2)}{2F(\delta^4 + Le^2\varepsilon^2\omega_i^2)} + \frac{\pi^2 T_D Va(MVad_1 + \omega_i^2)}{2a^2 F(M^2 Va^2 + \omega_i^2)}$$

$$\Delta_2 = \frac{d_1\delta^2 + d_2}{2a^2 F\ \ Va} + \frac{Le\ \ Rs(\delta^2 - L_e\varepsilon d_1)}{2F(\delta^4 + Le^2\varepsilon^2\omega_i^2)} + \frac{\pi^2 T_D Va(MVa - d_1)}{2a^2 F(M^2 Va^2 + \omega_i^2)}$$

$$d_1 = \delta^2 - \gamma, d_2 = V_a(Ha^2\pi^2 + \delta^2), \delta^2 = \pi^2 + a^2.$$

Since $Ra^{os} > 0$ and setting $\Delta_2 = 0, \omega_i \neq 0$ in Eq. (39) yields the frequency of oscillation as

$$\omega_i^2 = \frac{1}{2Le^2\varepsilon^2(d_1\delta^2 + d_2)}\Big[-d_1\delta^4 - \delta^2(Le\ \ Va(a^2 Rs + LeM^2 Va\ \ \varepsilon^2 d_1) + d_2) + Le^2 Va\ \ \varepsilon(a^2 Rs\ \ d_1 - M^2 Va\ \ \varepsilon d_2 + \pi^2 Va\ \ \varepsilon(d_1 - MVa)T_D) + \big(-4Le^2 Va^2\varepsilon^2(d_1\delta^2 + d_2)\big(M^2(\delta^4 - a^2 Le^2 Rs\ \ Va\ \ \varepsilon)d_1 + \delta^2(a^2 Le\ \ Rs\ \ Va + d_2)\big) + \delta^2\pi^2(MVa - d_1)T_D\big) + (a^2\delta^2 Le\ \ Rs\ \ Va + d_1\delta^2 - a^2 Le^2 Rs\ \ Va\ \ \varepsilon d_1 + \delta^2 Le^2 M^2 Va^2\varepsilon^2 d_1 + \delta^2 d_2 + Le^2 M^2 Va^2\varepsilon^2 d_2 + Le^2\pi^2 Va^2\varepsilon^2(MV_a - d_1)T_D)^2)^{\frac{1}{2}}\Big] \quad (40)$$

3. Results and Discussions

The problem of rotating Darcy model with modified Boussinesq approximation involving temperature and solute concentration together with stress-free boundaries have been studied analytically for the determination of the conditions leading to the occurrence of stationary and oscillatory convections with vertical magnetic field and temperature -dependent internal heating. We are going to examine graphically and numerically the consequence of the parameters in the mathematical model and the stability curves $Ra - a$ for the criteria leading to marginal stationary convection for the parameters $Ha, Ta, Rs, Le,$ and γ.

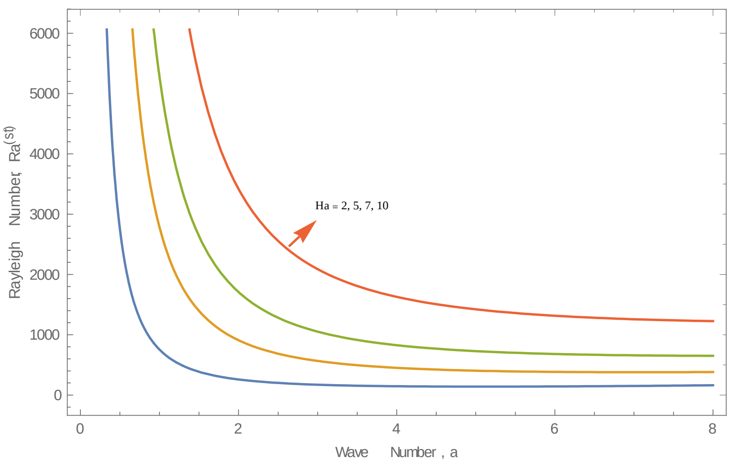

Figure 2. *Marginal stability curves for electrically insulated walls for fixed $Ta = 10, \gamma = 0.2, Rs = 10, Le = 1$ and various values of Hartman Number, Ha.*

Figure 2 illustrates variation of $Ra^{(st)}$with a of marginal stability curves for electrically insulated walls. It is found that for fixed values of $Ta = 10, \gamma = 0.2, Rs = 10, Le = 1$ the stationary Rayleigh number increase with increased with increasing values of Ha. Hence, magnetic field act in such a manner that the system is stabilized. This result is consistent with earlier results of [4].

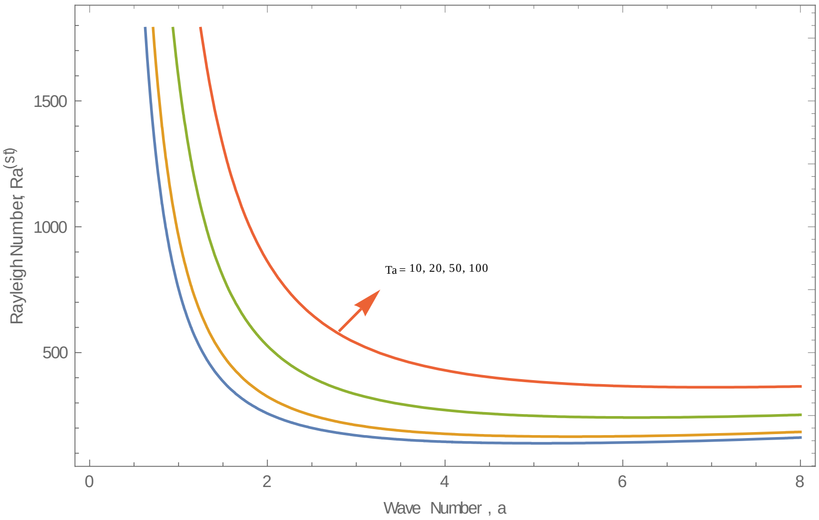

Figure 3. *Marginal stability curves for electrically insulated walls for fixed* $Ha = 2, \gamma = 0.2, Rs = 10, Le = 1$ *and various values of rotation parameter,* Ta.

Figure 3 depicts the contribution of rotation on conditions leading to instability with fixed other parameters. The result indicates that as the rotation increases, the stationary Rayleigh number, also increases. This implies that rotation raised the value of the control parameter *Ra* leading to more stability. This is agreement with the early result obtained by [13]. Equally, increase in solutal Rayleigh number.

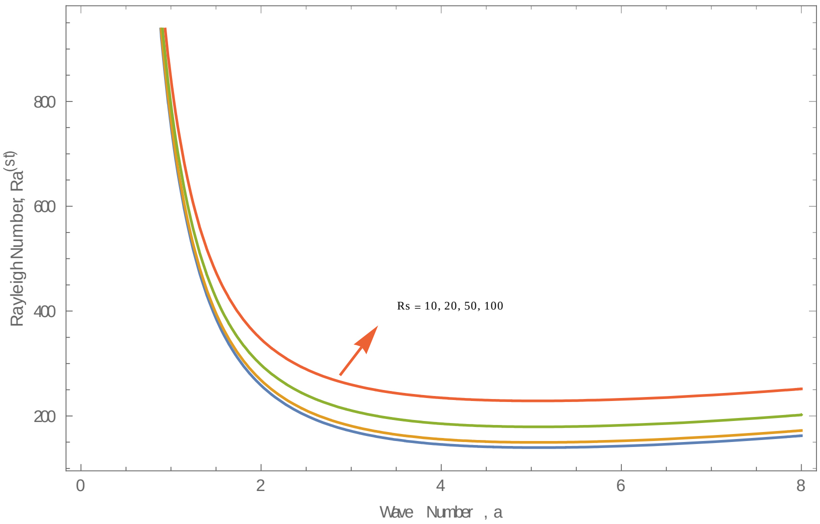

Figure 4. *Marginal stability curves for electrically insulated walls for fixed* $Ha = 2, \gamma = 0.2, Ta = 10, Le = 1$ *and various values of solutal Rayleigh number,* Rs.

Figure 4 lead to increased values of *Ra*. This delayed the onset of instability and enhanced stability.

Heating parameter, γ as depicted

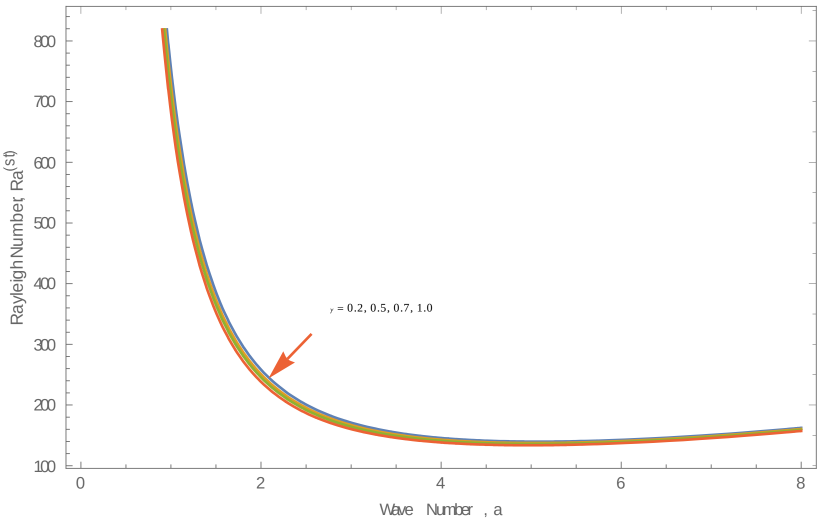

Figure 5. *Marginal stability curves for electrically insulated walls for fixed* $Ha = 2, Rs = 10, Ta = 10, Le = 1$ *and various values of heat source parameter,* γ.

Figure 5 is to hasten the breakdown of stability. In other words, it allows instability to set early, and therefore act as a destabilizing agent in the system [4]. The illustration of the variation of *Ra* with *a* depicted

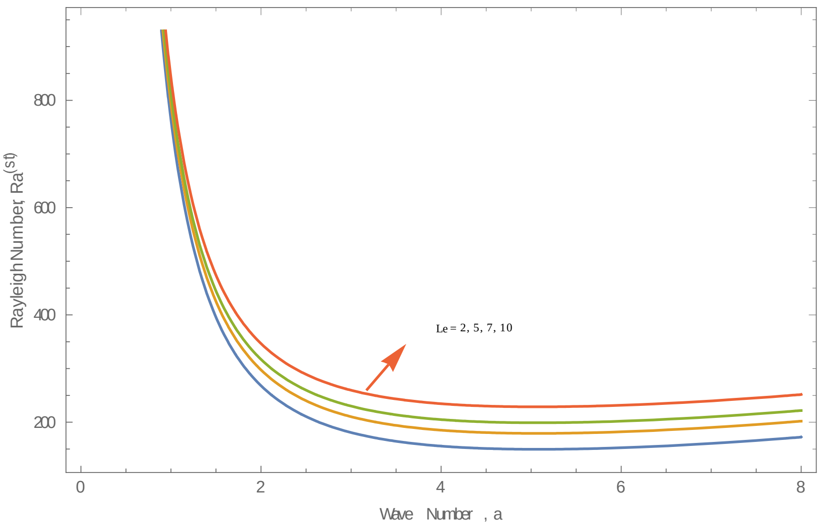

Figure 6. *Marginal stability curves for electrically insulated walls for fixed* $Ha = 2, \gamma = 0.2, Rs = 10, Ta = 10, Le = 1$ *and various values of Lewis number,* Le.

Figure 6 show that increase in Lewis number delay the onset of instability. Hence, the Lewis number act in a manner that make the system more stable [11].

4. Conclusions

The pinnacle for the onset temperature-dependent internal heating magnetoconvection in a rotating Darcy porous layer heated from below with the given boundary conditions was systemically examined. The method used was the linear stability analysis to established the requirement for the commencement of stationary and oscillatory convection in the structure. The outcome of physical parameters in the mathematical model as given are illustrated with the appropriate graphs. The analysis shows that maximizing the magnetic field and rotation parameters moderates the commencement of both stationary and oscillatory convection, whereas Prnndtl number delay the commencement of oscillatory convection. The conclusion of this is that magnetic field parameter, Ha, rotation parameter, T_D, and the Prandtl number, Pr, are balancing factors, while the heat source parameter, γ, speeds up the commencement of convection.

Abbreviations

EQS Equations

Acknowledgments

This goes to my Ph.D supervisor, C. Israel Cookey and my family.

Author Contributions

Edmond Obiem Odok: Conceptualization, Data curation, Methodology, Validation, Writing – original draft

Liberty Ebiwareme: Formal Analysis, Supervision, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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Biography

Edmond Obiem Odok is a Senior Lecturer in the Department of Mathematics, University of Cross River State. He completed his PhD in Mathematical Physics from River State University in 2019, and his Master in Applied Mathematics from University of Port Harcout in 2012. His research interest are Mathematical Physics, Fluid Mechanic, ODE, PDE, Numerical Method and Algebra. Recognized for his exceptional contributions, he’s the SIWES and Project coordinator, Mathematics Department, university of Cross River State. He has published several articles in reputable local and international journals, contributing to the advancement of applied mathematics research.

Liberty Ebiwareme is a Lecturer in Mathematics at Rivers State University, Nigeria, holding MSc and PhD degrees in Applied Mathematics with a focus on Magnetohydrodynamic fluid stability. His research covers fluid dynamics, heat and mass transfer in porous media, boundary layer theory, and MHD flow stability, among other areas. He has a strong publication record in both local and international journals and has contributed to book chapters and conference proceedings, advancing the field of Mathematical Sciences.

Research Field

Edmond Obiem Odok: Mathematical Physics, Numerical Methods, Partial Differential Equations and Numerical Analysis and Simulations.
Liberty Ebiwareme: Mathematical Physics, Boundary Layer Theorem, Computational Methods and Numerical Analysis