

Soret and Magnetic Field Effects on Thermosolutal Convection in a Porous Medium with Concentration Based Internal Heat Source

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Abstract This paper investigates the effects of Soret and magnetic field on thermosolutal convection in a porous medium with concentration based internal heat source. In formulating the leading equations we assume that the Boussinesq approximation is valid and the Darcy law is governing the flow. Linear stability analysis was employed to determine the onset of instability. The influence of Soret, Hartmann number and internal heat are shown in figures and tables. Increase in Hartmann number delays the onset of instability while increase in Soret hastens the onset of instability for both stationary and oscillatory convection. The study established that the stability of the system occurred for values of internal heat, $\gamma_c < 0.7$, while instability sets in for $\gamma_c \geq 0.7$ for all values of Hartmann number, Ha and Soret, Sr .

Keywords Magnetic field, Soret, Concentration Based Internal Heat, Linear Stability Analysis

1. Introduction

The phenomena of combined heat and mass transfer has been an active area of research for many years. In a system where two species with different diffusivities are present, variety of interesting convective phenomena can occur. Understanding of the phenomena has attracted the attention of researchers because of its application in geothermal reservoirs, metallurgy, migration of solutes in water-saturated soils, migration of moisture through air contained fibrous insulations and many others. A comprehensive review of studies in double diffusive convection can be found in [1-4].

There are situations in which convection can be driven by internal heat sources in porous media and such applications can be found to occur in nuclear reactions and high quality crystal production. Multiconstituent liquids subjected to long-lasting temperature gradients are liable to experience thermal diffusion flows and modification of the specie concentration. The effect can be useful in elaboration of high-technology materials (solidification of semiconductors), optimization of petroleum extraction, Montel [5]. In view of utilization of molten semi-conducting materials in the control of molten iron flow in steel industry, knowledge of Soret and Magnetic field is needed in above application.

Tveitereid [6] studied thermal convection with internal heat and obtained steady solutions in the form of hexagons and two-dimensional rolls. The result show that down-hexagons are stable for Rayleigh numbers up to 8 times the critical value, while up-hexagons are unstable for all values of the Rayleigh number. Gaikwad and Dhanraj [7] investigated the effect of internal heat source on the onset of double-diffusive reaction-convection where the linear stability analysis is based on the usual normal mode method. Hill [8], in his study of double diffusive convection in a porous medium, showed that internal heat source advances the onset of convection.

Studies of the magnetic effect on convection is relevant in technological processes and has been considered. Rudraiah [9] studied the effect of an externally imposed vertical magnetic field on double diffusive convection principally in a Boussinesq fluid. Shlomis [10] considered the linearized relation for magnetized perturbed quantities at the limit of instabilities. Amos and Israel-Cookey [11] showed that stabilization of convective flow can be achieved on the application of magnetic field. Rakoto- Ramambason and Vasseur [12] considered analytical and numerical investigation on the effect of magnetic field on natural convection in a horizontal shallow porous cavity. The result shows that magnetic field decreases the flow velocity. Cheng [13] studied the effect of magnetic field on natural convection using an integral approach. The results show that the application of transverse magnetic field normal to the flow direction decreases the Nusselt number and Sherwood

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number. In the study also, the thickness ratio of the thermal boundary layer to the concentration boundary layer is found to be independent of the intensity of the magnetic field. Takhar [14] studied free convection heat transfer due to simultaneous action of buoyancy radiation and transverse magnetic field in a semi-infinite plate and showed that the magnetic field exerts a strong influence on the velocity of the flow. Bhadauria and Sherani [15] considered onset of double diffusive convection in a sparsely packed porous medium under modulated temperature at the boundaries using linear stability analysis. Gupta and Singh [16] also used linear stability analysis to study double diffusive reaction-convection in a fluid layer with viscous fluid heated and salted below subject to chemical equilibrium on the boundaries. Benacer et al [17] studied Soret effect on convection in a horizontal porous medium submitted to a concentration based internal energy. Platen and Costesque [18] studied experimentally the Soret coefficient in a pure fluid and in a porous medium and concluded that the coefficient is the same for both media.

It is, therefore, the subject of this study to consider the simultaneous effects of Soret and magnetic field field on thermosolutal convection in a porous medium with concentration based internal heat source.

2. Mathematical Formulation

We consider an electrically conducting fluid-saturated porous layer of height h , bounded by two horizontal parallel planes $z' = -\frac{h}{2}$ and $z' = +\frac{h}{2}$. The porous layer is heated and salted from below in such a way that the greater salt concentration is towards the bottom of the layer. The temperature T' at the lower and upper planes are maintained at T'_1 and T'_2 respectively such that $T'_1 > T'_2$, while the salt concentration $C'_1 > C'_2$. A magnetic field of strength \vec{B}_0 is applied on the z' direction. We assume that the Boussinesq approximation is valid and that the Darcy law is governing the flow. We also assume that the magnetic Reynold's number is small so that the induced magnetic field is neglected. Under the flow configurations and assumptions, the governing equations are,

$$\vec{\nabla}' \cdot \vec{V}' = 0 \quad (1)$$

$$\vec{\nabla}' P' = -\frac{\mu}{K} \vec{V}' \cdot \vec{J} \times \vec{B} - \rho(T', C') \vec{g} \hat{k} \quad (2)$$

$$(\rho C_p)_m \frac{\partial T'}{\partial t'} + (\rho C_p)_f \vec{\nabla}' \cdot \vec{V}' T' = k_m \vec{\nabla}'^2 T' + \beta(C' - C_0) \quad (3)$$

$$\phi \frac{\partial C'}{\partial t'} + \vec{\nabla}' \cdot \vec{V}' C' = D_m \vec{\nabla}'^2 C' + D_{CT} \vec{\nabla}'^2 T' \quad (4)$$

$$\rho(T', C') = \rho_0 \beta_T (T' - C_0) + \beta_c (C' - C_0) \quad (5)$$

$$\vec{J} = \sigma_c (\vec{E} + \vec{V}' \times \vec{B}), \quad \vec{\nabla}' \cdot \vec{J} = 0 \quad (6)$$

where $T_0 = \frac{T_1 + T_2}{2}$, $C_0 = \frac{C_1 + C_2}{2}$, are reference temperature and concentration respectively, β_T is the thermal

expansion coefficient, β_c is the solutal expansion, σ_c is electrical conductivity, $(\rho C_p)_m$ and $(\rho C_p)_f$ are heat capacity of the porous medium and the fluid respectively, k_m is the thermal conductivity of the porous medium, D_m and D_{CT} are mass diffusivity and thermal diffusion coefficient respectively, K is permeability of the porous medium, g is acceleration due to gravity, μ is dynamic viscosity, ρ is density, \vec{B} is the magnetic field, \vec{J} is electric density, \vec{E} is the electric field, ρ_0 is a reference density, \hat{k} is a unit vector in the z -direction, ϕ is a porosity parameter, P is the pressure.

The boundary conditions are

$$\vec{V}' = 0, \quad T' = T_1, \quad C' = C_1 \quad \text{on } z' = +\frac{h}{2} \quad (7a)$$

$$\vec{V}' = 0, \quad T' = T_2, \quad C' = C_2 \quad \text{on } z' = -\frac{h}{2} \quad (7b)$$

In the absence of electric field, the current density reduces to $\vec{J} = \sigma_c (\vec{V}' \times \vec{B})$ and the electromagnetic force $\vec{J} \times \vec{B} = -\sigma_c B_0^2 V(u, v, o)$.

Hence the governing equations take the form

$$\vec{\nabla}' \cdot \vec{V}' = 0 \quad (8)$$

$$\vec{\nabla}' P' + \frac{\mu}{K} \vec{V}' = \rho \vec{g} \beta_T (T' - T_0) \hat{k} - \rho \vec{g} \beta_c (C' - C_0) \hat{k} - \sigma_c B_0^2 V(u, v, o). \quad (9)$$

$$A \frac{\partial T'}{\partial t'} + \vec{\nabla}' \cdot \vec{V}' T' = \alpha_m \vec{\nabla}'^2 T' + \frac{\beta}{(\rho C_p)_f} (C' - C_0) \quad (10)$$

$$\phi \frac{\partial C'}{\partial t'} + \vec{\nabla}' \cdot \vec{V}' C' = D_m \vec{\nabla}'^2 C' + D_{CT} \vec{\nabla}'^2 T' \quad (11)$$

where $A = \frac{(\rho C_p)_m}{(\rho C_p)_f}$ and $\alpha_m = \frac{k_m}{(\rho C_p)_f}$.

We introduce the following non dimensional variables:

$$(x, y, z) = \frac{1}{h} (x', y', z'), \quad t = \frac{\alpha_m}{Ah^2} t', \quad V = \frac{h}{\alpha_m} V', \quad P = \frac{k}{\mu \alpha_m} (P' + \rho_0 g z), \quad T = \frac{T' - T_0}{T_1 - T_2}, \quad C = \frac{C' - C_0}{C_1 - C_2}, \quad (12)$$

On substitution of equation (12) into equations (7 - 11), we have

$$\nabla \cdot \vec{V} = 0 \quad (13)$$

$$\vec{V} = -\nabla P + R_a T \hat{k} - R_s C \hat{k} - H_a V(u, v, 0) \quad (14)$$

$$\frac{\partial T}{\partial t} + V \cdot \nabla T = \nabla^2 T + \gamma C \quad (15)$$

$$\varepsilon \frac{\partial C}{\partial t} + V \cdot \nabla C = \frac{1}{Le} \nabla^2 C + S_r \nabla^2 T \quad (16)$$

Subject to

$$V = 0, \quad T = \pm \frac{1}{2}, \quad C = \pm \frac{1}{2} \quad \text{on } z = \mp \frac{1}{2} \quad (17)$$

where $R_a = \frac{\rho_0 g \beta_T k h (T_1 - T_2)}{\mu \alpha_m}$, is the thermal Rayleigh number, $R_s = \frac{\rho_0 g \beta_c k h (C_1 - C_2)}{\mu \alpha_m}$ is the solutal Raleigh number, $Le = \frac{\alpha_m}{D_m}$ is the Lewis number, $\varepsilon = \frac{\phi}{A}$ is a constant parameter,

$$H_a = B_0 \sqrt{\frac{\sigma_c k}{\mu}}, \quad \gamma = \frac{\beta (C_1 - C_2)}{(T_1 - T_2) (\rho C_p)_f}, \quad S_r = \frac{D_{CT} (T_1 - T_2)}{(C_1 - C_2) \alpha_m}.$$

3. Method of Solution

3.1. Steady State Solution

We admit a steady state solution in the infinite layer. The basic or motionless state of the system is given by $\vec{V} = 0$, $\frac{\partial}{\partial t} = 0$, so that equations (13-17) becomes

$$\frac{dP_s}{dz} = R_a T_s - R_s C_s \quad (18)$$

$$\frac{d^2 T_s}{dz^2} + \gamma C_s = 0 \quad (19)$$

$$\frac{d^2 C_s}{dz^2} + Le S_r \frac{d^2 T_s}{dz^2} = 0$$

$$\frac{d^2 C_s}{dz^2} - \Gamma C_s = 0 \quad (20)$$

where $\Gamma = Le S_r \gamma$, and the subscript s denote steady state, subject to the conditions

$$T_s = \pm \frac{1}{2} = C_s \text{ on } z = \mp \frac{1}{2} \quad (21)$$

The solutions to equations (18)-(20) subject to conditions (21) yield the steady state as

$$T_s(z) = -\{2(1 - \Gamma) + \text{cosech}\left[\sqrt{\frac{\Gamma}{z^2}}\right] \sinh[\sqrt{\Gamma}z]\} \quad (22)$$

$$C_s(z) = \frac{-\{\cosh\left[\sqrt{\frac{\Gamma}{2}}(1-2z)\right] + \sinh\left[\sqrt{\frac{\Gamma}{2}}(1-2z)\right]\} \{\cosh[2\sqrt{\Gamma}z] + \sinh[2z\sqrt{\Gamma}] - 1\}}{2(\cosh\sqrt{\Gamma} + \sinh\sqrt{\Gamma} - 1)} \quad (23)$$

$$P_s(z) = \int (R_a T_s - R_s C_s) dz \quad (24)$$

3.2. Linear Stability Analysis

To access the stability of the steady state solutions, we define perturbations of the form

$$V = V_s, \quad T = T_s + \theta, \quad C = C_s + \varphi, \quad P = P_s + p \quad (25)$$

($\theta \ll T_s, \varphi \ll C_s, p \ll p_s$)

Introducing equation (25) into equations (13-17) and using the steady state solutions (22)-(24), we obtain

$$\nabla \cdot \vec{V} = 0 \quad (26)$$

$$\vec{V} = -\nabla p + R_a \theta \hat{k} - R_s \varphi \hat{k} - H_a^2(u, v, 0) \quad (27)$$

$$\frac{\partial \theta}{\partial t} + \frac{\partial T_s}{\partial z} W = \nabla^2 \theta + \gamma \varphi \quad (28)$$

$$\varepsilon \frac{\partial \varphi}{\partial t} + \frac{\partial C_s}{\partial z} W = \frac{1}{Le} \nabla^2 \varphi + S_r \nabla^2 \theta \quad (29)$$

Subject to

$$W = 0, \quad \theta = 0 = \varphi, \text{ on } z = \mp \frac{1}{2} \quad (30)$$

By taking the double curl of equation (27) and using the continuity equation (26), the pressure perturbation is eliminated and we obtain

$$\nabla^2 W = R_a \nabla_h^2 \theta - R_s \nabla_h^2 \varphi - H_a^2 \frac{\partial^2 W}{\partial z^2} \quad (31)$$

where $\nabla_h^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$ is the Laplacian in the horizontal plane,

We now consider the reaction of the system to all possible disturbances by taking normal modes of the form

$$[w, \theta, \varphi] = [W(z), \Theta(z), \Phi(z)] f(x, y) e^{\Omega t} \quad (32)$$

where $\Omega = \sigma_r + i\omega$ is the growth rate and is in general complex. σ_r, ω are real and $f(x, y)$ varies periodically and satisfies $\nabla_h^2 + a^2 f = 0$, (Drazin and Reid [19]), so that

$$(D^2 - a^2)W + H_a^2 D^2 W + a^2 R_a \Theta - a^2 R_s \Phi = 0 \quad (33)$$

$$FW + (D^2 - a^2 - \Omega)\Theta + \gamma \Phi = 0 \quad (34)$$

$$GW + Le S_r (D^2 - a^2)\Theta + (D^2 - a^2 - \varepsilon Le \Omega)\Phi = 0 \quad (35)$$

$$W = 0 = \Theta = \Phi, \text{ at } z = \pm \frac{1}{2},$$

$$D^2 W = 0 \text{ on a free surface} \quad (36)$$

where $D = \frac{d}{dz}$.

Now, assuming the solutions to be periodic of the form

$$\begin{pmatrix} \Theta \\ \Phi \\ W \end{pmatrix} = \begin{pmatrix} \Theta_0 \\ \Phi_0 \\ W_0 \end{pmatrix} \sin \pi z \quad (37)$$

in Equations (33)-(35) and letting $J = \pi^2 + a^2$, we obtain the following eigenvalue problem

$$A \bar{X} = 0 \quad (38)$$

$$\text{where } A = \begin{pmatrix} J + Ha^2 \pi^2 & -a^2 R_a & a^2 R_s \\ F & -(J + \Omega) & \gamma \\ G & -J Le S_r & -(J + \varepsilon Le \Omega) \end{pmatrix},$$

$$\bar{X} = \begin{pmatrix} \Theta_0 \\ \Phi_0 \\ W_0 \end{pmatrix}$$

Equation (38) is solvable if the determinant of A is equal to zero, that is $|A| = 0$. Letting $\Omega = i\omega$, and separating the real and imaginary parts yields

$$J^3 + Le S_r \gamma J^2 + Ha^2 \pi^2 J^2 - Ha^2 \pi^2 \varepsilon Le \omega^2 + \varepsilon Le J \omega^2 + Ha^2 \pi^2 Le S_r \gamma - a^2 R_a (FJ + G\gamma) + a^2 R_s (GJ - Le S_r FJ) = 0 \quad (39)$$

and

$$J^2 + \varepsilon Le J^2 + Ha^2 \pi^2 \varepsilon Le J - a^2 R_a \varepsilon Le F + Ha^2 \pi^2 J + a^2 G R_s = 0 \quad (40)$$

Equations (39) and (40) accounts for the principle of exchange of stabilities (steady state) and the marginally oscillatory case.

3.2.1. Stationary Convection

For stationary convection, we set $\omega = 0$ in equation (39) and obtain the Rayleigh number, $R_a^{(s)}$, for stationary convection as

$$R_a^{(s)} = \frac{J^3 + (Le S_r \gamma + Ha^2 \pi^2) J^2 + Ha^2 \pi^2 Le S_r \gamma J}{a^2 (FJ + G\gamma)} + \frac{(G - Le S_r F) R_s J}{FJ + G\gamma} \quad (41)$$

Minimizing (41), we obtain the critical cell size for the onset of instability. That is

$$\left(\frac{\partial R_a^{(s)}}{\partial a^2} \right)_{a=a_c} = 0$$

Performing the operation, we obtain the critical wave number as $a_c = \pi$ and the corresponding critical Rayleigh

number as

$$R_{ac}^{(s)} = \frac{4\pi^4 + 4A + B}{\pi^2} + R_s G \quad (42)$$

where $A = LeS_r\gamma + Ha^2\pi^2$, $B = LeS_r\gamma Ha^2\pi^2$,

$$G = \frac{\frac{1}{2} \cosh(\frac{\sqrt{\Gamma}}{2})}{\sinh(\frac{\sqrt{\Gamma}}{2})}, F = \frac{[2(\Gamma - 1) + \frac{\sqrt{\Gamma}}{\sinh(\frac{\sqrt{\Gamma}}{2})}]}{2\Gamma}$$

Setting $Ha = 0, S_r = 0, \gamma = 0, F = 1$,
 $G = 1, Le = 1$ on equation (41) yields

$$R_{ac}^{(s)} = 4\pi^2 + R_s \quad (43)$$

which is consistent with results earlier obtained by Lambardo et al. [20], Israel-Cookey and Omubo-Pepple [21]. In the absence of solute parameter ($R_s = 0$), our result is consistent with Nield [22]. That is

$$R_{ac}^{(s)} = 4\pi^2 \quad (44)$$

which is consistent with the result obtained by Horton and Rogers [23] and Lapwood [24]

3.2.2. Oscillatory Convection

When the growth rate, $\omega \neq 0$, we obtain the thermal Rayleigh number for oscillatory convection from equation (40) in the form

$$R_a^{(o)} = \frac{J^2 + \epsilon Le J^2 + Ha^2 \pi^2 \epsilon Le J + Ha^2 \pi^2 J}{a^2 \epsilon Le F} + \frac{GR_s}{\epsilon Le F} \quad (45)$$

In the absence of magnetic field, ($Ha = 0$) and $F \rightarrow 1, G \rightarrow 1$ we obtain the critical Rayleigh number for oscillatory convection as

$$R_a^{(o)} = \frac{4\pi^2(1+\phi)}{\epsilon Le} + \frac{R_s}{\epsilon Le} \quad (46)$$

This result is consistent with previous results obtained by Lambardo et al [20] and Israel-Cookey and Omubo-Pepple [21].

4. Results and Discussion

In order to understand the physical situation, we have computed numerical values of the critical wave number for the onset of instability for various values of Soret, Hartmann number, porosity and radiation using the arithmetic built-in-function of the software Mathematica (Wolfram, [25]). Figure 1 shows results for stationary convection for $S_r = 0.5, Le = 10, R_s = 2, \epsilon = 0.2$. It is observed that increase in Hartmann number delays the onset of instability with higher values of the Hartmann number leading to a greater stabilization of the system.

For the values $\gamma = 0.2, Le = 10, R_s = 2, \epsilon = 0.2, Ha = 0.3$ for stationary convection, it is observed from Figure 2 that increase in Soret hastens the onset of instability and leads to destabilization of the system. Figure 3 shows that, for fixed values $S_r = 0.5, Le = 10, R_s = 2, \epsilon = 0.2, Ha = 0.3$, increase in the heat parameter decreases the thermal Rayleigh number, indicating that the internal heat

parameter hastens the onset of instability for stationary convection.

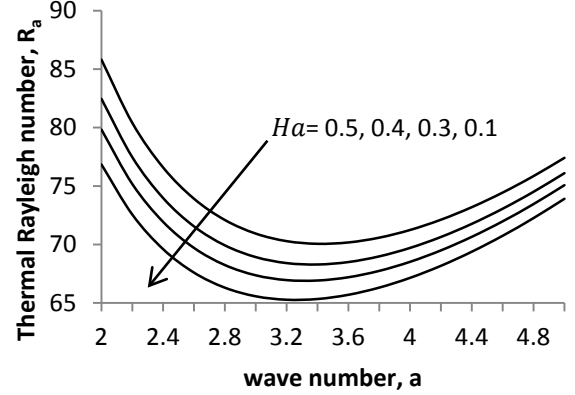


Figure 1. Variation of thermal Rayleigh number on stationary convection for different values of Hartmann number, Ha

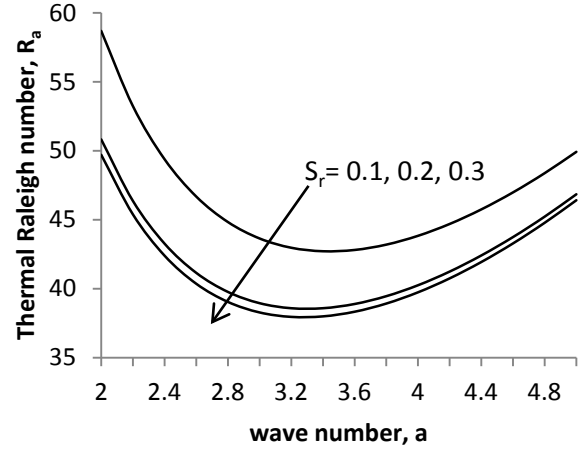


Figure 2. Variation of the thermal Rayleigh number on stationary convection for different values of Soret, S_r

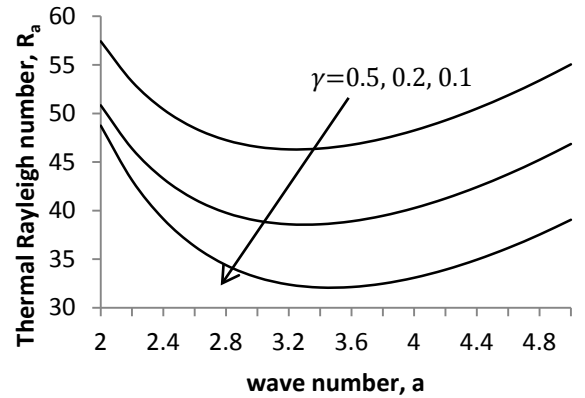


Figure 3. Variation of the thermal Rayleigh number on stationary convection for different values of the internal heat, γ

Table 1 shows the critical thermal Rayleigh values for stationary convection for various values of the internal heat parameter, γ , and Hartmann number, Ha . The thermal

Rayleigh number, R_a , increases as the Hartmann number increases for the values of the internal heat parameter considered. Furthermore for $0.1 \leq \gamma \leq 0.6$, increase in γ results in decrease in R_a . This implies that increase in γ leads to instability in the system. For all values of the Hartmann number, instability sets in at the critical internal heat parameter, $\gamma_c \geq 0.7$. We considered the thermal Rayleigh values for the oscillatory case in Table 2. It is observed that increase in the magnetic field parameter increases the thermal Rayleigh number value while increase in the internal heat parameter decreases the thermal Rayleigh number value. This implies that γ is a destabilizing parameter while H_a is a stabilizing parameter for fixed Soret parameter, S_r .

Table 1. The variation of internal heat, γ , and Hartmann number, H_a , for stationary convection for $S_r = 0.5, Le = 10, R_s = 2, \epsilon = 0.02$

	$H_a = 0.3$		$H_a = 0.5$		$H_a = 1.0$	
γ	a_c	$R_{a_c}^{(s)}$	a_c	$R_{a_c}^{(s)}$	a_c	$R_{a_c}^{(s)}$
0.1	2.93983	76.815	3.04566	79.9364	3.44112	93.5505
0.2	3.04448	58.8738	3.14635	61.9052	3.5212	75.1772
0.3	3.10694	53.2822	3.2062	56.2785	3.58114	69.4275
0.4	3.16043	50.8228	3.25778	53.7927	3.62724	66.8689
0.5	3.21225	49.6455	3.30822	52.6013	3.67405	65.6696
0.6	3.26483	49.1622	3.35987	52.1366	3.72361	65.216
0.7	3.319	49.1675	3.4135	52.1376	3.77654	65.2748
0.8	3.37477	49.5201	3.46905	52.4976	3.83234	65.7246
1.0	3.49056	50.9935	3.57509	54.0284	3.95152	67.4622

Table 2. The variation of internal heat, γ , and Hartmann number, H_a , for oscillatory convection for $S_r = 0.5, Le = 10, R_s = 2, \epsilon = 0.02$

	$H_a = 0.3$		$H_a = 0.5$		$H_a = 1.0$	
γ	a_c	$R_{a_c}^{(o)}$	a_c	$R_{a_c}^{(o)}$	a_c	$R_{a_c}^{(o)}$
0.2	3.04448	191.638	3.14635	210.818	3.5212	292.864
0.3	3.10694	187.433	3.2062	206.478	3.58114	288.169
0.4	3.16043	185.066	3.25778	203.989	3.62724	285.336
0.5	3.21225	183.446	3.30822	202.248	3.67405	283.231
0.6	3.26483	182.233	3.35987	200.911	3.72361	281.512
0.7	3.319	181.299	3.4135	199.853	3.77654	280.056
0.8	3.37477	181.261	3.46905	199.021	3.83234	278.824
1.0	3.49056	179.754	3.57509	197.952	3.95152	276.981

Table 3 shows oscillatory convection values for various values of the Soret, S_r , and Hartmann number, H_a , for fixed $\gamma (= 0.2)$. It is observed that increase in Soret decreases the critical thermal Rayleigh value but simultaneous increase in Soret and magnetic field intensity increases the thermal Rayleigh number. Therefore, increase in S_r destabilizes but sustained increase in S_r and H_a stabilizes the system. The variation of Soret and internal heat parameter for stationary convection is depicted in Table 4. Increase in the internal heat parameter, γ , decreases the critical thermal Rayleigh number value, $R_{a_c}^{(s)}$, for different values of Soret, S_r , considered. This, therefore, hastens the onset of instabilities.

Table 3. The variation of Soret, S_r , and Hartmann number, H_a , for oscillatory convection for $\gamma = 0.2, Le = 10, R_s = 2, \epsilon = 0.02$

	$H_a = 0.3$		$H_a = 0.5$		$H_a = 1.0$	
S_r	a_c	$R_{a_c}^{(o)}$	a_c	$R_{a_c}^{(o)}$	a_c	$R_{a_c}^{(o)}$
-1	3.35448	175.706	3.43535	194.294	3.7538	275.175
-0.75	3.38698	174.252	3.47311	192.761	3.80972	273.183
-0.5	3.43989	171.152	3.53261	189.56	3.89166	269.451
-0.25	3.4853	161.043	3.5939	179.444	4.00863	258.972
0.25	2.74838	206.478	2.84076	226.690	3.19226	312.300
0.5	3.04448	191.638	3.14635	210.740	3.5292	299.204
0.75	3.1546	187.245	3.26184	206.141	3.66182	287.156
1.0	3.21689	184.962	3.32884	203.719	3.74352	284.191

Table 4. The variation of Soret, S_r , and internal heat, γ , for stationary convection for $H_a = 0.5, Le = 10, R_s = 2, \epsilon = 0.02$

	$\gamma = 0.5$		$\gamma = 0.3$		$\gamma = 0.1$	
S_r	a_c	$R_{a_c}^{(s)}$	a_c	$R_{a_c}^{(s)}$	a_c	$R_{a_c}^{(s)}$
-1	3.42842	58.6453	3.44916	72.0859	3.51596	75.4945
-0.75	3.45032	47.3427	3.48421	66.3497	3.53235	70.4557
-0.5	3.46046	28.7449	3.55206	59.1622	3.58187	65.3801
-0.25	3.22839	24.2349	3.70023	44.3825	3.76554	57.902
0.25	2.6347	111.412	2.93646	66.3487	3.04898	58.7527
0.5	3.04547	79.9829	3.20619	56.2862	3.30818	52.6132
0.75	3.18506	65.2895	3.228	49.0818	3.44926	46.748
1.0	3.25477	55.1292	3.39842	42.5248	3.54736	40.8644

5. Conclusions

Soret and magnetic effects on thermosolutal convection in a porous medium with concentration based internal heat source is investigated using linear stability analysis. The roles of Soret, magnetic field and internal heat in the onset of convection has been deduced. The findings reveals that increase in magnetic field intensity delays the onset of instabilities in stationary convection. The internal heat hastens the onset of instabilities. For all values of the Hartmann number, instability sets in at the critical internal heat value, $\gamma_c = 0.7$. In the oscillatory case, internal heat source produces the same effect as for the oscillatory case. The analysis also show that Soret hastens the onset of instabilities for both stationary and oscillatory convection. In the limiting case when Soret, magnetic field and internal heat were set at zero, our results is in agreement with earlier studies on related areas of double diffusive convection.

REFERENCES

- [1] D.A. Nield and A. Bejan, Convection in porous media, 3rd Ed. Springer, Berlin, 2006.
- [2] S. N. Gaikwad and S. S. kamble, Analysis of linear stability on double diffusive convection in a fluid saturated anisotropic porous layer with Soret effect, Advances in Applied Science

- Research, 3(3), pp. 1611-1617, 2012.
- [3] M. S. Malshetty and B. S. Birador, The onset of double diffusive convection in a binary Maxwell fluid saturated porous layer with cross-diffusion effects. *Physics of Fluids*, 23, 064109: 1-13, 2011.
- [4] C. Israel-Cookey and E. Amos, Soret and Radiation absorption effects on the onset of magneto-thermosolutal convection in a porous medium, *Journal of Applied Mathematics and Bioinformatics*, 4(1), pp. 71-87, 2014.
- [5] F. Montel, Importance de la thermodiffusion en exploitation et production pétrolières, *Entropie*, Vol. 184/185, pp. 86-93, 1994.
- [6] M. Tveitereid, Thermal convection in a horizontal porous layer with internal heat source, *International Journal of Heat Mass Transfer*, Vol. 20, pp. 1045-1050, 1977.
- [7] S. N. Gaikwad and M. Dhanraj, Onset of double diffusive reaction-convection in an anisotropic porous layer with internal heat source, *Proceedings of 5th International Conference on Porous Media and their Applications in Science, Engineering and Industry*, 2014.
- [8] A. A. Hill, Double diffusive convection in a porous medium with a concentration based internal heat source, *Proceedings Royal Society A461*, pp. 561-574, 2005.
- [9] N. Rudraiah, Double diffusive magnetoconvection, *Journal of Physics*, Vol. 21, pp. 233-266, 1986..
- [10] M. I. Shliomis, Magnetic fluid. *Soviet Physics (English translation)*, Vol. 17, pp. 153-169, 1974.
- [11] E. Amos and C. Israel-Cookey, Soret and magnetic effects on the onset of convection in a shallow horizontal porous layer with thermal radiation, *International Journal of Engineering and Applied Sciences*, Vol.8, pp. 10-18, 2016.
- [12] D. S. Rakoto-Ramambason, and P. Vasseur, Influence of magnetic field on natural convection in a shallow porous enclosure saturated with a binary fluid. *ACTA Mechanica*, 191, 21-35, 2007.
- [13] C. Y. Cheng, Effect of magnetic field on heat and mass transfer by natural convection from vertical surfaces in a porous media – an integral approach, *International Communications of Heat and Mass Transfer*, Vol. 26, pp. 935-943, 1999.
- [14] H. S. Takhar, R. S. R. Gorla, and V. M. Soundalgekar, Radiation effects on magnetohydrodynamics free convection flow past a semi-infinite vertical plate. *International. Journal of Numerical Methods and Heat Fluid Flow*, Vol. 6, pp. 77-83, 1996.
- [15] B. S. Bhadauria, and A. Sherani, Onset of double diffusive convection in a thermally modulated fluid-saturated porous media. *Z.Naturforsch* 63a, 291-300, 2008.
- [16] V. K. Gupta, and A. K. Singh, Double diffusive reaction-convection in viscous fluid layer. *International Journal Industrial Mathematics*, 6(4), 285-296, 2014.
- [17] R. Benacer, A. Mahidjiba, P. Vasseur, H. Beji, and R. Duval, The Soret effect on convection in a horizontal porous domain under cross temperature and concentration gradients. *International Journal of Numerical Methods heat Fluid flow*, Vol. 13, pp. 199-215, 2003.
- [18] J. K. Platen, and P. Costesque, The Soret coefficient in porous media, *Journal of Porous media*, 7(4), pp. 317-329, 2004.
- [19] P. G. Drazin and W. H. Reid, *Hydrodynamic stability*, 2nd Ed. Cambridge University Press, Cambridge, 2004.
- [20] S. Lambardo, G. Mulone and B. Sraughan, Nonlinear stability in the Bernard problem for a double diffusive mixture in a porous medium. *Journal of Methods of Applied Science*, 24, pp. 1229-1246, 2003.
- [21] C. Israel-Cookey and V. B. Omubo-Pepple, Onset of convection of a reacting fluid layer in a porous medium with temperature dependent heat source, *American Journal of Scientific and Industrial Research*, 2(6), pp. 860-864, 2011.
- [22] D. A. Nield, *Convection in porous media*. 3rd Ed. Springer, Berlin. 1991.
- [23] C. W. Horton and F. T. Rogers, Convection currents in a porous medium, *Journal of Applied Physics*, Vol. 16, pp. 367-370, 1945.
- [24] E. R. Lapwood, Convection of a fluid in a porous medium, *Proceedings of the Cambridge philosophical Society*, Vol. 44, pp. 508-521, 1948.
- [25] S. Wolfram, *The Mathematica Handbook*, 5th ed., Wolfram Media, Cambridge University Press, New York., 2003.