Journal of Applied Fluid Mechanics, Vol. 9, No. 3, pp. 1081-1088, 2016.
Available online at www.jafmonline.net, ISSN 1735-3572, EISSN 1735-3645.
DOI: 10.18869/acadpub.jafm.68.228.24858

Electrothermo Convection in a Porous Medium Saturated by Nanofluid

R. Chand[1†], G. C. Rana[2] and D. Yadav[3]

[1]*Department of Mathematics, Government College Nurpur, Himachal Pradesh, 176202, INDIA*
[2]*Department of Mathematics, Government College Hamirpur, Himachal Pradesh, 177033, INDIA*
[3] *School of Mechanical Engineering, Yonsei University Seoul, South Korea*

†*Corresponding Author Email: rameshnahan@yahoo.com*

(Received April 2, 2015; accepted July 1, 2015)

ABSTRACT

Thermal instability in a horizontal layer of nanofluid with vertical AC electric field in a porous medium is investigated. The flux of volume fraction of nanoparticles is taken to be zero on the isothermal boundaries and the eigenvalue problem is solved using the Galerkin method. Darcy model is used for the momentum equation. The model used for nanofluid incorporates the effect of Brownian diffusion and thermophoresis. Linear stability theory based upon normal mode technique is employed to find the expressions for Rayleigh number for stationary and oscillatory convection. Graphs have been plotted to study the effects of Lewis number, modified diffusivity ratio, concentration Rayleigh number, AC electric Rayleigh number and porosity on stationary convection.

Keywords: Nanofluid; AC electric Rayleigh number; Brownian motion; Galerkin method; Porosity.

NOMENCLATURE

a	dimensionless resultant wave number
d	thickness of fluid layer
D	differential operator
D_B	Brownian diffusion coefficient
D_T	thermophoretic diffusion coefficient
g	acceleration due to gravity
k_m	thermal conductivity
Le	Lewis number
n	growth rate of disturbances
N_A	modified diffusivity ratio
N_B	modified particle -density increment
p	pressure
q	Darcy velocity vector
Ra	thermal Rayleigh number
Ra_c	critical Rayleigh number
Rn	concentration Rayleigh number
t	time
T	temperature
T_0	temperature at $z = 0$
T_1	temperature at $z = d$
(u, v, w)	Darcy velocity components
(x, y, z)	space co-ordinates
α	coefficient of the thermal expansion
μ	viscosity
ε	porosity
ρ	density of the nanofluid
ρ_0	density of nanofluid at $z = 0$
ρ_p	density of nanoparticles
ρ_f	density of base fluid
$(\rho c)_m$	heat capacity of fluid in porous medium
$(\rho c)_p$	heat capacity of nanoparticles
φ	volume fraction of the nanoparticles
φ_0	reference volume fraction of the nanoparticles at $z = 0$
κ	thermal diffusivity
ω	dimensionless frequency of oscillation
σ	thermal capacity ratio
∇_H^2	horizontal Laplacian operator
∇^2	Laplacian operator

Superscripts

'	non - dimensional variables
' '	perturbed quantities

Subscripts

c	critical
s	stationary convection
p	particle
b	basic state
f	fluid

1. INTRODUCTION

When a small amount of nano-sized particles are added to the base fluid, the thermal conductivity of the fluid enhances and such a fluid is called nanofluid which was first coined by Choi (1995). Nanofluids have unique properties that make them potentially useful in many applications of heat transfer and thus nanofluids considered to be the next-generation heat transfer fluids. Recent developments in the study of heat transfer using nanofluids can be reported by Wong and Leon (2010), Yu and Xie (2012), Taylor *et al*. (2013).
Thermal convection in nanofluids in a porous medium is an important phenomenon due to its wide ranges of applications in geophysics, food processing, oil reservoir modeling, petroleum industry, bio-mechanics, building of thermal insulations and nuclear reactors. The detailed study of thermal convection in a layer of nanofluid in porous medium based upon Buongiorno (2006) model has been given by Kuznetsov and Nield (210a, b, c), Nield and Kuznetsov (2009, 2010, 2011), Chand (2013), Chand and Rana (2012a, b, c), Rana *et al*. (2014a, b), Yadav and Kim (2015), Chand *et al*. (2015) and Yadav and Lee (2015). In all the above studies boundary condition on volume fraction of nanoparticle is physically not realistic as it is difficult to control the nanoparticle volume fraction on the boundaries and suggested the normal flux of volume fraction of nanoparticles is zero on the boundaries as an alternative boundary condition which is physically more realistic. Nield and Kuznetsov (2014), Chand and Rana (2014a, b), Chand *et al.* (2014) pointed out that this type of boundary condition on volume fraction of nanoparticles is physically not realistic as it is difficult to control the nanoparticle volume fraction on the boundaries and suggested the normal flux of volume fraction of nanoparticles is zero on the boundaries as an alternative boundary condition which is physically more realistic. Under the circumstances, it is desirable to investigate convective instability problems by utilizing these boundary conditions to get meaningful insight in to the problems.

Natural convection under AC/DC electric field of electrically enhanced heat transfer in fluids and possible practical applications has been reviewed by Jones (1978) and Chen *et al*. (2003). Stiles *et al*. (1993) studied the problem of convective heat transfer through polarized dielectric liquids. They observed that the convection pattern established by the electric field is quite similar to the familiar Bénard cells in normal convection. Recently Shivakumara *et al*. (2012) studied the effect of velocity and temperature boundaries conditions on electro-thermal convection in a rotating dielectric fluid and found that AC electric field is to enhance the heat transfer and to hasten the onset of convection. Several studies have been carried out to assess the effect of AC and DC electric fields on natural convection due to the fact that many problems of practical importance involve dielectric fluids.

The nano dielectric fluid may be used in an electrical apparatus and other electrical equipment such as distribution transformers, regulating transformers, shunt reactors, converter transformers, instrument transformers and power transformers. The nano dielectric fluid used herein exhibits an increased thermal conductivity as compared to the insulating liquids commonly used without the nanoparticles. A high thermal conductivity of the nanoparticles is often desirable for the nano dielectric fluids.

Although EHD instability has been extensively investigated in Newtonian and non-Newtonian fluid dielectric fluid layer, but no effort has been made to study the EHD instability in a layer of nanofluid. So keeping in view the importance of thermal convection of dielectric (when fluid layer is subjected to a uniform vertical AC/DC electric field) nanofluids, an attempt has been made to study the electro thermo convection in a horizontal layer of nanofluid in a porous medium.

2. MATHEMATICAL FORMULATIONS OF THE PROBLEM

Consider an infinite horizontal layer of nanofluid of thickness'd' bounded by planes z = 0 and z = d. Fluid layer is heated from below in a porous medium whose medium permeability is k_1 and porosity is ε. Nanoparticles are being suspended in the nanofluid using either surfactant or surface charge technology, preventing the agglomeration and deposition of these on the porous matrix. Layer of fluid is subjected to a uniform vertical AC electric field applied across the layer; lower surface is grounded and upper surface is kept at an alternating potential whose root mean square is $\square_1$. A Cartesian coordinate system (x, y, z) is chosen with the origin at the bottom of the fluid layer and the z- axis normal to the fluid layer in the gravitational field g (0,0,-g). The normal component of the nanoparticles flux has to vanish at an impermeable boundary and the temperature T is taken to be T_0 at z = 0 and T_1 at z = d, ($T_0 > T_1$) as shown in Fig. 1. The reference scale for temperature and nanoparticles fraction is taken to be T_1 and φ_0 respectively.

According to the works of Chandrasekhar (1981), Nield and Kuznetsov (2014) and Shivakumara *et al*. (2012), the relevant equations under the Oberbeck- Boussinesq approximation in a porous medium are

$$\nabla \cdot \mathbf{q} = 0, \tag{1}$$

$$0 = -\nabla p + \left(\varphi\rho_p + (1-\varphi)\{\rho_{f0}(1-\alpha(T-T_0))\}\right)\mathbf{g} - \frac{\mu}{k_1}\mathbf{q} - \frac{1}{2}(\mathbf{E}\cdot\mathbf{E})\nabla\in, \tag{2}$$

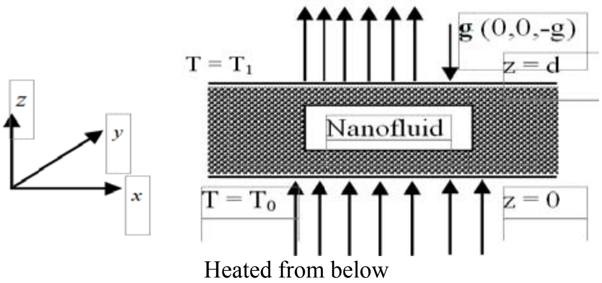

Fig. 1. Physical Configuration of the problem.

$$(\rho c)_m\left(\frac{\partial T}{\partial t}+\mathbf{q}\cdot\nabla T\right)=k_m\nabla^2 T+\varepsilon(\rho c)_p\left(D_B\nabla\varphi\cdot\nabla T+\frac{D_T}{T_0}\nabla T\cdot\nabla T\right) \tag{3}$$

$$\frac{\partial\varphi}{\partial t}+\frac{1}{\varepsilon}\mathbf{q}\cdot\nabla\varphi=D_B\nabla^2\varphi+\frac{D_T}{T_0}\nabla^2 T, \tag{4}$$

where q is the Darcy velocity of fluid, p is the pressure, ρ_0 is the density of nanofluid at lower layer, ρ_p is the density of nanoparticles, φ is the volume fraction of the nanoparticles, T is the temperature, α is coefficient of the thermal expansion, g is acceleration due to gravity, k_1 is medium permeability of fluid, ε is the porosity of porous medium and μ is the viscosity, $(\rho c)_m$ is the heat capacity of fluid in porous medium, $(\rho c)_p$ is the heat capacity of nanoparticles, k_m is the thermal conductivity of the fluid, D_B is the Brownian diffusion coefficient, D_T is the thermoporetic diffusion coefficient of the nanoparticles, E is the root mean square value of the electric field and $\in$ is the dielectric constant.

Since there is no free charge, the relevant Maxwell equations are

$$\nabla\times\mathbf{E}=0, \tag{5}$$

$$\nabla\cdot(\in\mathbf{E})=0. \tag{6}$$

In view of equation (5), **E** can be expressed as

$$\mathbf{E}=-\nabla\psi, \tag{7}$$

where ψ is the root mean square value of the electric potential.

The dielectric constant is assumed to be a linear function of temperature in the form

$$\in=\in_0\left(1-\gamma(T-T_0)\right)=0, \tag{8}$$

where $\gamma(>0)$ is the thermal expansion coefficient of dielectric constant and is assumed to be small.

We assume that the temperature is constant and nanoparticles flux is zero on the boundaries. Thus boundary conditions (Chandrasekhar 1981, Nield and Kuznetsov 2014) are

$$w=0,\quad T=T_0, D_B\frac{\partial\varphi}{\partial z}+\frac{D_T}{T_1}\frac{\partial T}{\partial z}=0 \text{ at } z=0 \quad \text{and}$$

$$w=0,\quad T=T_1,\ D_B\frac{\partial\varphi}{\partial z}+\frac{D_T}{T_1}\frac{\partial T}{\partial z}=0 \text{ at } z=d. \tag{9}$$

2.1 Steady State and its Solutions

The steady state is given as

$$\mathbf{q}=\mathbf{q}_s=0,\quad p=p(z),\quad T=T_s(z),\quad \in=\in_s(z),$$
$$E=E_s(z),\quad \psi=\psi_s(z). \tag{10}$$

The solution of steady state is

$$T_s=T_0-\frac{\Delta T}{d}z,\quad \varphi_s=\varphi_0+\left(\frac{D_T\Delta T}{D_B T_1 d}\right)z,$$

$$\in_s=\in_0\left(1+\frac{\gamma\Delta T}{d}z\right)\hat{k},\quad E_s=\frac{E_0}{1+\frac{\gamma\Delta T}{d}z}\hat{k},$$

where subscript s denote the steady state.

Also we have

$$\psi_s(z)=-\frac{E_0 d}{\gamma\Delta T}\log\left(1+\frac{\gamma\Delta T}{d}\right)\hat{k},$$

where $\mathbf{E}_0=-\frac{\psi_1\frac{\gamma\Delta T}{d}}{\log(1+\gamma\Delta T)}$ is the root mean square value of the electric field at z = 0.

2.2 Perturbation Equations

Let the initial steady state as described by equation be slightly perturbed so that the perturbed state is given by

$$q=q',T=T_s+T',p=p_s+p',\in=\in_s+\in',$$
$$\mathbf{E}=\mathbf{E}_s+\mathbf{E}',\psi=\psi_s+\psi', \tag{11}$$

where the prime denote the perturbed quantities. Substituting the Eq. (11) into the Eqs. (1) – (9), linearizing by neglecting the products of primed quantities, the obtained perturbations equations to be converted into to non-dimensional form by introducing the following dimensionless variables as follows

$$(x'',y'',z'')=\left(\frac{x',y',z'}{d}\right),\qquad (u'',v'',w'')=\left(\frac{u',v',w'}{\kappa}\right)d,$$

$$t'' = \frac{\kappa}{\sigma d^2} t', \; p'' = \frac{k_1}{\mu\kappa} p', \; T'' = \frac{T'}{\Delta T},$$

$\psi'' = \dfrac{\psi'}{\gamma E_0 \Delta T d}$, where $\kappa = \dfrac{k_m}{(\rho c)_f}$ the thermal diffusivity of the fluid is, $\sigma = \dfrac{(\rho c_p)_m}{(\rho c_p)_f}$ is the thermal capacity ratio.

The linearized perturbation equations in non-dimensional form

$$\nabla \cdot \mathbf{q} = 0, \tag{12}$$

$$0 = -\nabla p - \mathbf{q} + Ra T \hat{e}_z - Rn \varphi \hat{e}_z, \tag{13}$$

$$\frac{\partial T}{\partial t} - w = \nabla^2 T + \frac{N_B}{Le}\left(\frac{\partial T}{\partial z} - \frac{\partial \varphi}{\partial z}\right) - \frac{2 N_A N_B}{Le}\frac{\partial T}{\partial z}, \tag{14}$$

$$\frac{1}{\sigma}\frac{\partial \varphi}{\partial t} + \frac{1}{\varepsilon} w = \frac{1}{Le}\nabla^2 \varphi + \frac{N_A}{Le}\nabla^2 T \tag{15}$$

$$\nabla^2 \psi = \frac{\partial T}{\partial z}. \tag{16}$$

[Dashes (") are dropped for simplicity]

Where

$Le = \dfrac{\kappa}{D_B}$ is the Lewis number, $Ra = \dfrac{\rho_0 g \alpha \Delta T k_1 d}{\mu\kappa}$ is the thermal Rayleigh number, $Rn = \dfrac{(\rho_p - \rho)(\varphi_1 - \varphi_0) g k_1 d}{\mu\kappa}$ is the nanoparticle Rayleigh number, $Re = \dfrac{\gamma^2 \in E_0^2 (\Delta T)^2 d^2}{\mu\kappa}$ is the AC electric Rayleigh number, $N_A = \dfrac{D_T \Delta T}{D_B T_1 \varphi_0}$ is the modified diffusivity ratio, $N_B = \dfrac{(\rho c)_p \varphi_0}{(\rho c)_f}$ is the modified particle-density increment.

Non- dimensional boundary conditions are given as

$$w = \frac{\partial^2 w}{\partial z^2} = \frac{\partial \psi}{\partial z} = T = 0, \frac{\partial \phi}{\partial z} + N_A \frac{\partial T}{\partial z} = 0$$

at z = 0 and z = 1. (17)

Now eliminating the pressure from Eq. (13) by using the identity curl curl = grad div– ∇^2 together with Eq. (12), we obtain z-component of the momentum equation as

$$\nabla^2 w = Ra \nabla_H^2 T - Rn \nabla_H^2 \varphi + Re \nabla_H^2 \left(T - \frac{\partial \psi}{\partial z}\right). \tag{18}$$

3. NORMAL MODES ANALYSIS

Analyzing the disturbances into the normal modes and assuming that the perturbed quantities are of the form

$$[w, T, \varphi, \psi] = [W(z), \Theta(z), \Phi(z), \Psi(z)] \exp(i k_x x + i k_y y + nt), \tag{19}$$

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

Using Eq. (19), Eqs. (18), (14) - (16) become

$$(D^2 - a^2) W + a^2 Ra \Theta - a^2 Rn \Phi + a^2 Re(\Theta - D\Psi) = 0, \tag{20}$$

$$W + \left(D^2 + \frac{N_A}{Le} D - \frac{2 N_A N_B}{Le} D - a^2 - n\right)\Theta + \frac{N_B}{Le} D\Phi = 0, \tag{21}$$

$$\frac{W N_A}{\varepsilon} - \frac{N_A}{Le}(D^2 - a^2)\Theta - \left(\frac{1}{Le}(D^2 - a^2) - \frac{n}{\sigma}\right)\Phi = 0, \tag{22}$$

$$(D^2 - a^2)\Psi = D\Theta, \tag{23}$$

where $D = \dfrac{d}{dz}$ and $a = \sqrt{k_x^2 + k_y^2}$ is the dimensionless the resultant wave number.

The boundary conditions of the problem in view of normal mode analysis are

$$W = 0, D^2 W = 0, \Theta = 0, D\Psi = 0, D\Phi + N_A D\Theta = 0 \text{ at } z = 0,1 \tag{24}$$

4. LINEAR STABILITY ANALYSIS

For the present formulation, we have considered the case of free -free boundaries for which system of Eqs. (20) - (23) together with the boundary conditions (24) constitute a linear eigenvalue problem with variable coefficient for the growth rate of disturbance of the system. The resulting eigenvalue problem is solved numerically by the Galerkin method of first order (N = 1), which gives the expression for Rayleigh number Ra as

$$Ra = \frac{1}{a^2}(\pi^2 + a^2)(\pi^2 + a^2 + n) - \frac{a^2}{(\pi^2 + a^2)} Re - \frac{N_A(\pi^2 + a^2) + \frac{Le}{\varepsilon}(\pi^2 + a^2 + n)}{(\pi^2 + a^2) + \frac{nLe}{\sigma}} Rn. \tag{25}$$

For neutral stability, the real part of n is zero. Hence on putting n = iω, (where ω is real and is dimensionless frequency) in Eq. (25), we have

$$Ra = \Delta_1 + i\omega\Delta_2, \tag{26}$$

where

$$\Delta_1 = \frac{(\pi^2 + a^2)^2}{a^2} - \frac{a^2}{(\pi^2 + a^2)} \mathrm{Re} - \frac{(\pi^2 + a^2)^2 \left(N_A + \frac{Le}{\varepsilon}\right) + \frac{\omega^2}{\sigma\varepsilon}}{(\pi^2 + a^2)^2 + \left(\frac{\omega Le}{\sigma}\right)^2} \mathrm{Rn}. \quad (27)$$

and

$$\Delta_2 = \frac{(\pi^2 + a^2)}{a^2} - \frac{(\pi^2 + a^2)\left(\frac{Le}{\varepsilon} - \frac{Le}{\sigma}\left(N_A + \frac{Le}{\varepsilon}\right)\right)}{(\pi^2 + a^2)^2 + \left(\frac{\omega Le}{\sigma}\right)^2} \mathrm{Rn}. \quad (28)$$

Since Ra is a physical quantity, so it must be real. Hence, it follow from the Eq. (26) that either $\omega = 0$ (exchange of stability, steady state) or $\Delta_2 = 0$ ($\omega \neq 0$ over stability or oscillatory onset).

4.1 Stationary Convection

For the case of stationary convection [n = ω = 0], Eq. (25) reduces to

$$(\mathrm{Ra})_s = \frac{(\pi^2 + a^2)^2}{a^2} - \frac{a^2}{(\pi^2 + a^2)} \mathrm{Re} - \left(N_A + \frac{Le}{\varepsilon}\right) \mathrm{Rn}. \quad (29)$$

It is observed that stationary Rayleigh number $(\mathrm{Ra})_s$ is function of the Lewis number Le, the modified diffusivity ratio N_A, the nanoparticles Rayleigh Rn, porosity ε and AC electric Rayleigh number Re but independent of modified particle-density increment N_B. Thus the instability is purely a phenomenon due to buoyancy coupled with the conservation of nanoparticles.

To find the critical value of $(\mathrm{Ra})_s$, Eq. (29) is differentiated with respect to 'a^2' and then equated to zero. A polynomial in a^2 whose coefficients are function of parameter AC Rayleigh number Re influencing the stability is given as

$$(a_c^2)^4 + 2\pi^2 (a_c^2)^3 - \pi^2 \mathrm{Re} (a_c^2)^2 - 2\pi^6 (a_c^2) - \pi^8 = 0. \quad (30)$$

The above equation is solved for various value of AC Rayleigh number Re and critical value a_c is obtained and then corresponding critical Rayleigh number is obtained.

In the absence of electrical field (Re = 0), Eq. (29) reduces to

$$(\mathrm{Ra})_s = \frac{(\pi^2 + a^2)^2}{a^2} - \left(N_A + \frac{Le}{\varepsilon}\right) \mathrm{Rn}. \quad (31)$$

This result agrees with the result obtained by Nield and Kuznetsov (2012).

The minimum of first term of right- hand side of Eq. (31) is attained at $a_c = \pi$ and minimum value found to $4\pi^2$, so the corresponding critical Rayleigh number given by $(\mathrm{Ra})_s = 4\pi^2 - \left(N_A + \frac{Le}{\varepsilon}\right)\mathrm{Rn}.$

(32)

This is same result which was derived by Nield and Kuznetsov (2010).

One recognizes that in the absence of nanoparticles ($Rn = Le = N_A = 0$) and AC vertical electric field (Re = 0), one recovers the well- known results that the critical Rayleigh-Darcy number is equal to $4\pi^2$.

Thus presence of the nanoparticles lowers the value of the critical Rayleigh number by usually by substantial amount. Also parameter N_B does not appear in the Eq. (29), thus instability is purely phenomena due to buoyancy coupled with conservation of nanoparticles. Thus average contribution of nanoparticles flux in the thermal energy equation is zero with one-term Galerkin approximation.

4.2 Oscillatory Convection

For oscillatory convection $\omega \neq 0$, we must have $\Delta_2 = 0$, thus Eq. (28) gives an expression for frequency of oscillations as

$$\omega^2 = \sigma^2 \left\{ \frac{a^2}{Le}\left(\frac{1}{\varepsilon} - \frac{1}{\sigma}\left(N_A + \frac{Le}{\varepsilon}\right)\right)\mathrm{Rn} \right\} - \left(\frac{\pi^2 + a^2}{Le}\right)^2. \quad (33)$$

Since $\omega^2 > 0$ for the occurrence oscillatory convection, but the values of the parameters considered in the range $10^2 \le Ra \le 10^5$ (thermal Rayleigh number), $1 \le N_A \le 10$ (modified diffusivity ratio), $10^2 \le Le \le 10^4$ (Lewis number), $10^{-1} \le Rn \le 10$ (nanoparticles Rayleigh number), $0.1 \le \sigma \le 5$ (capacity ratio), $0.1 \le \varepsilon \le 1$ (porosity parameter) (Chand and Rana 2012a) and $10 \le \mathrm{Re} \le 10^4$ (AC electric Rayleigh number) (Shivakumara *et al*. 2012), the value of ω^2 in Eq. (33) is found to be negative, which imply that oscillatory convection is not possible for the problem.

5. RESULT AND DISCUSSION

An expression for the stationary Rayleigh number, which characterize the stability of the system are obtained for free-free boundary conditions. The computations are carried out for different values of parameters considered in the range $10^2 \le \mathrm{Ra} \le 10^5$ (thermal Rayleigh number), $1 \le N_A \le 10$ (modified diffusivity ratio), $10^2 \le Le \le 10^4$ (Lewis number), $10^{-1} \le Rn \le 10$ (nanoparticles Rayleigh number), $0.1 \le \sigma \le 5$ (capacity ratio), $0.1 \le \varepsilon \le 1$ (porosity parameter) [Chand and Rana (2012a)] and $10 \le \mathrm{Re} \le 10^4$ (AC electric Rayleigh number) [Shivakumara *et al*. (2012)] to find the effects of various parameters on the stationary convection.

Stability curves for Lewis number Le, modified diffusivity ratio N_A, AC electric Rayleigh number Re, nanoparticles Rayleigh number Rn and porosity parameter are shown in figures 2-6.

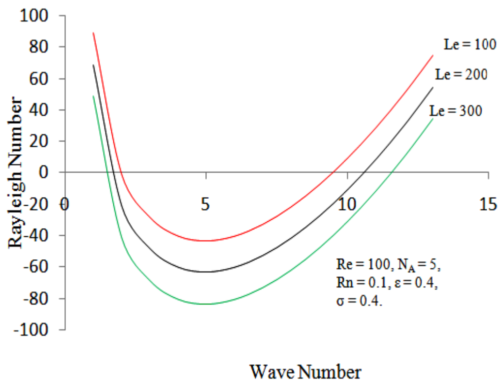

Fig. 2. Variation of the thermal Rayleigh number (Ra)s with wave number for different value of Lewis number.

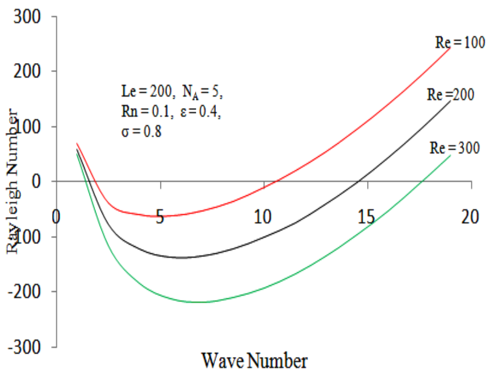

Fig. 3. Variation of the thermal Rayleigh number (Ra)s with wave number for different value of AC electric Rayleigh number.

The variation of the stationary Rayleigh numbers $(Ra)_s$ with wave number have been plotted graphically.

Fig. 2 shows the variation of stationary Rayleigh numbers $(Ra)_s$ with wave number for different value of Lewis number Le and fixed value of other parameters and it is found that stationary Rayliegh number decreases as the values of Lewis number increases, indicating that Lewis number destabilize the stationary convection. This is good agreement of the result obtained by Chand and Rana (2014).

Fig. 3 shows the variation of stationary Rayleigh numbers $(Ra)_s$ with wave number for different value of AC electric Rayleigh number Re and fixed value of other parameters and it is found that stationary Rayliegh number decreases with an increase in the value of AC electric Rayleigh number Re, indicating that the AC electric Rayleigh number Re destabilze the stationary convection. This is good agreement of the result obtained by Shivakumara *et al*. (2012).

Fig. 4 shows the variation of stationary Rayleigh numbers $(Ra)_s$ with wave number for different value of modified diffusivity ratio and fixed value of other parameters and it is found that stationary Rayliegh number decreases with an increase in the value modified diffusivity ratio, indicating that the modified diffusivity ratio destabilze the stationary convection. This is good agrement of the result obtained by Chand and Rana (2014).

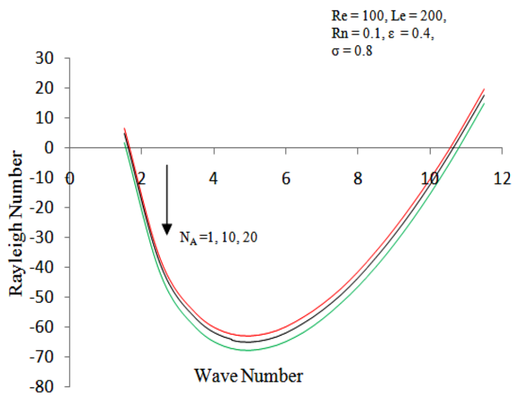

Fig. 4. Variation of the thermal Rayleigh number (Ra)s with wave number for different value of modified diffusivity ratio.

Fig. 5 shows the variation of stationary Rayleigh numbers $(Ra)_s$ with wave number for different values of nanoparticle Rayleigh number and it is found that stationary Rayliegh number decreases with an incease in the value of nanoparticles Rayleigh number. This is good agrement of the result obtained by Chand and Rana (2014).

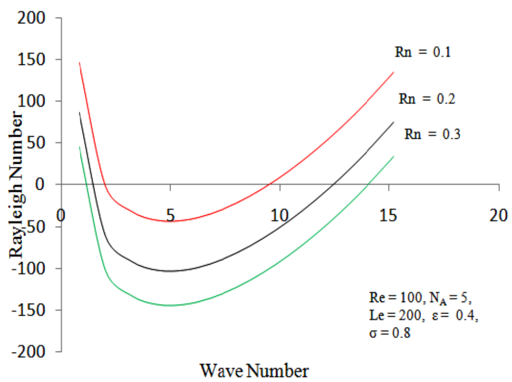

Fig. 5. Variation of the Rayleigh number (Ra)s with wave number for different value of nanoparticle Rayleigh number.

Fig. 6 represent the variation of stationary Rayleigh numbers $(Ra)_s$ with wave number for different value of porosity parameter and it is found that stationary Rayliegh number increases with an increase in the value of porosity parameter, thus porosity stabilize the stationary convection. This is good agrement of the result obtained by Chand and Rana (2014).

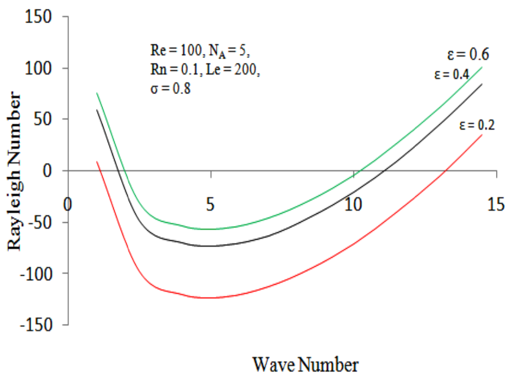

Fig. 6. Variation of the Rayleigh number (Ra)s with wave number for different value of porosity parameter.

7. CONCLUSIONS

Thermal instability in a horizontal layer of nanofluid with vertical AC electric field in a porous medium is studied using linear instability theory by employing a model for nanofluid that incorporates the effects of Brownian motion and thermophoresis. The flux of volume fraction of nanoparticles is taken to be zero on the isothermal boundaries and the eigenvalue problem is solved using the Galerkin residual method. The main conclusions of present analysis are as follows

(i) The instability purely phenomenon due to buoyancy coupled with the conservation of nanoparticle and is independent of the contribution of Brownian motion and thermophoresis.

(ii) Oscillatory convection is not possible for the problem.

(iii) Porosity parameter stabilizes the

stationary convection while Lewis number, AC electric field, modified diffusivity ratio and concentration Rayleigh number destabilize the stationary convection.

ACKNOWLEDGMENT

The authors are grateful to the reviewers for their valuable comments and suggestions for improvement of the paper.

REFERENCES

Buongiorno, J. (2006). Convective transport in nanofluids. *ASME Journal of Heat Transfer* 128, 240-250.

Chand, R. (2013). Thermal instability of rotating nanofluid. *Int. J. Appl. Math and Mech.* 9(3), 70-90.

Chand, R. and G. C. Rana (2012a). Oscillating convection of nanofluid in porous medium. *Transp Porous Med* 95, 269-284.

Chand, R. and G. C. Rana (2012). On the onset of thermal convection in rotating nanofluid layer saturating a Darcy-Brinkman porous medium. *Int. Journal of Heat and Mass Transfer* 55, 5417-5424.

Chand, R. and G. C. Rana (2012). Thermal instability of Rivlin-Ericksen elastico-viscous nanofluid saturated by a porous medium. *J. Fluids Eng.* 134(12), 121203.

Chand, R. and G. C. Rana (2014). Thermal instability in a Brinkman porous medium saturated by nanofluid with no nanoparticle flux on boundaries. *Special Topics & Reviews in Porous Media: An International Journal* 5(4), 277-286.

Chand, R. and G. C. Rana (2014). Magneto convection in a layer of nanofluid in porous medium-A more realistic approach. *Journal of Nanofluids* 4, 196-202.

Chand, R. and G. C. Rana and A. K. Hussein (2015). On the onset of thermal instability in a low Prandtl number nanofluid layer in a porous medium. *Journal of Applied Fluid Mechanics* 8(2), 265-272.

Chand, R., S. K. Kango and G. C. Rana (2014). Thermal instability in anisotropic porous medium saturated by a nanofluid-a realistic approach. *NSNTAIJ* 8(12), 445-453.

Chandrasekhar, S. (1981). *Hydrodynamic and Hydro magnetic Stability*, Dover Publications, New York.

Chen, X., J. Cheng and X. Yin (2003). Advances and applications of electro hydrodynamics. *Chinese Science Bulletin* 48, 1055-1063.

Choi, S. (1995). Enhancing thermal conductivity of fluids with nanoparticles. In: Siginer D.A., Wang, H.P. (eds.) *Developments and Applications of Non-Newtonian Flows, ASME FED* 66, 99-105.

Jones, T. B. (19787). *Electrohydrodynamically enhanced heat transfer in liquids - a review, in*: T. F. Irvine Jr., J.P. Hartnett (Eds.), Advances in Heat Transfer, Academic Press.

Kuznetsov, A. V. and D. A. Nield (2010). Effect of local thermal non-equilibrium on the onset of convection in a porous medium layer saturated by a nanofluid. *Transport in Porous Media* 83, 425-436.

Kuznetsov, A. V. and D. A. Nield (2010). Thermal instability in a porous medium layer saturated by a nanofluid: Brinkman Model. *Transp. Porous Medium* 81, 409-422.

Kuznetsov, A. V.and D. A. Nield (2010). The Onset of Double-Diffusive Nanofluid Convection in a Layer of a Saturated Porous Medium. *Transport in Porous Media* 85,3, 941-951.

Nield, D. A. and A. V. Kuznetsov (2009). Thermal instability in a porous medium layer saturated by a nanofluid. *Int. J. Heat Mass Transf* 52, 5796–5801.

Nield, D. A. and A. V. Kuznetsov (2010). The onset of convection in a layer of cellular porous material: Effect of temperature-dependent conductivity arising from radiative transfer. *J. Heat Transfer* 132(7), 074503-4.

Nield, D. A. and A. V. Kuznetsov (2011). The onset of double-diffusive convection in a nanofluid layer. *International Journal of Heat and Fluid Flow* 32, 771-776.

Nield, D. A. and A. V. Kuznetsov (2014). Thermal instability in a porous medium layer saturated by a nanofluid: a revised model. *Int. J. Heat Mass Transf*. 68(4), 211-214.

Rana, G. C., R. C Thakur and S. K. Kango (2014). On the onset of Thermosolutal instability in a layer of an elastico-viscous nanofluid in porous medium. *FME Transactions* 42, 1-9.

Rana, G. C., R. C. Thakur and S. K. Kango, (2014). On the onset of double-diffusive convection in a layer of nanofluid under rotation saturating a porous medium. *Journal of Porous Media* 17(8), 657-667.

Shivakumara, I. S., J. Lee, K. Vajravelu and M. Akkanagamma (2012). Electrothermal convection in a rotating dielectric fluid layer: Effect of velocity and temperature boundary conditions. *Int. Journal of Heat and Mass Transfer* 55, 2984-2981.

Stiles, P. J., F. Lin, and P. J. Blennerhassett (1993). Convective heat transfer through polarized dielectric liquids. *Phys. Fluids* 5, 3273-3279.

Taylor, R., S. Coulombe, T. Otanicar, P. Phelan, A. Gunawan, W. Lv, G. Rosengarten, Prashar and H. Tyagi (2013). Small particles, R. big impacts: A review of the diverse applications of nanofluids. *J. Appl. Phys.* 113, 011301.

Wong, K., V. Leon and O. de. (2010). Applications of nanofluids: current and future. *Advances in Mechanical Engineering* 1-11.

Yadav, D. and J. Lee (2015). The effect of local thermal non equilibrium on the onset of Brinkman convection in a nanofluid saturated rotating porous layer. *Journal of Nanofluids* 4, 335-342.

Yadav, D. and M. C. Kim (2015). The onset of transient Soret-driven buoyancy convection in a nanoparticles suspension with particle concentration-dependent viscosity in a porous medium. *Journal of Porous Media* 18, 369-378.

Yu, W. and H. Xie (2012). A Review on Nanofluids Preparation, Stability Mechanisms and Applications. *Journal of Nanomaterials* 1-17.