DOI:10.26565/2312-4334-2022-4-09 ISSN 2312-4334

EFFECT OF ELECTRIC FIELD MODULATION ON THE ONSET OF ELECTROCONVECTION IN A COUPLE STRESS FLUID†

Chandrappa Rudresha*, Chandrashekar Balaji, Venkatesh Vidya Shree, Sokalingam Maruthamanikandan

Department of Mathematics, School of Engineering, Presidency University, Bengaluru, India

**Corresponding Author: rudresha.c@presidencyuniversity.in, E-mail: maruthamanikandan@presidencyuniversity.in*

Received August 20, 2022; revised September 23, 2022; accepted September 30, 2022

The problem of convective instability in a horizontal dielectric couple stress fluid layer with electric field modulation is investigated. The horizontal dielectric upper boundary layer is cooled, and the lower boundary layer is subjected to an isothermal boundary condition. The regular perturbation method is used to calculate the critical Rayleigh number and the corresponding wavenumber based on the small magnitude of the modulation. The strength of the system is characterised by a correction Rayleigh number, which is calculated as a function of the thermal, electrical, and couple voltage parameters and the frequency of the electric field modulation. Some of the well-known findings are taken up as special cases in this study. It is shown that the onset of convection can be accelerated or delayed by proper adjustment of various control parameters. The results of this study have potential implications for controlling electroconvection with a time-dependent electric field.

Keywords: Convection, Couple Stresses, Dielectric fluid, Electric field, Modulation.

PACS: 47.55.P-, 46.25.Hf, 77.84.Nh, 77.22.-d, 41.20.-q, 47.65.-d

1. Introduction

Electrohydrodynamic deals with the justice of the motion of fluids under the influence of electric energy. In microchannels, the interaction of electric fields with fluid flow has led to a variety of complex and interesting unstable events. In addition, the use of electrical energy to control fluids has been shown to be a very effective way to achieve many goals and functions in microfluidic devices.

When we add additives to oils or liquids, the energy contained in the liquid conflicts with the strength of the additives. This conflict leads to less fluid, which in turn leads to more stress for the couple. Couple stress fluid is the name for this type of fluid. The particular effects of couple stress fluid pressure on fluid is considered [1-3], and the basic statistical calculations for forcing couple stress are presented. Couple stress slows the onset of convection, while central infiltration accelerates the onset of convection [4-6], which allows to conclude that the system of stability exchange was heated in the couple stress fluid below the perforated area. As we have seen [7], the instability thresholds are changed when the fluid filling the porous medium exhibits pair-voltage behavior. They also assume that porous behavior is subject to small amplitude perpendicular oscillations. The convection variability of a chemically reactive fluid with coupling stresses in a porous medium heated from below is studied using a modified Darcy model by Taj et al. [8]. Coupling stresses improve system stability, and the stabilizing effect of coupling stresses is not diminished by the counteracting influence of chemical reactions and vice versa. In Maxwell-Cattaneo law [9], George & Thomas studied the consequences of gravity modulation and formation in the early phase of modulation within couple voltages. It is shown that by controlling the various regulating factors, the execution of convection transfer can be enhanced or postponed. The horizontal connection emphasizes the effect of the horizontal wavenumber and coupling stress fluid factors on the fluid layer, while the perforated parameters have a strong influence on the predominant fluid layer [10].

Analysis of convective instability in a horizontal viscoelastic dielectric fluid layer under the synchronous action of a direct alternating electric field with a precise temperature gradient was dealt with by Takashima & Ghosh [11]. It has been demonstrated that oscillatory processes of uncertainty occur only when the density of the fluid layer is less than 0.5 mm, and that the power of the current source in such a thin layer is more important than renewable energy. Sharma & Thakur [12] studied a porous material using a bottom heated conductive coupling voltage fluid in the absence of a homogeneous magnetic field. The coupling fluid and magnetic field retard the onset of thermal convection in a downward heated coupling stress in a porous medium in hydromagnetism, while the permeability of the medium accelerates it. Rayleigh-Bénard and Marangoni convection in dielectric fluids was studied by Maruthamanikandan [13]. This statement refers to the effects of the same internal heat dissipation and radiation. Thermorheological and electrical effects are considered in the management of the actual viscosity, such as the temperature function and the magnitude of the electric field. Rudraiah et al. [14] used a power method to study the stability of an electrohydrodynamic linear conductor flowing a pair of viscous fluid streams across a perforated medium in the presence of a uniform flexible electric field. It has been shown that the interaction of the electric current with the pair voltage is more efficient in stabilizing the pair voltages than for the conventional viscous Newtonian fluid. Shivakumara et al. [15] discuss the conjugation effects of electric body force, buoyancy force, Coriolis force and couple stress of the fluid in the formation of EHD instability. It is shown that

† *Cite as:* C. Rudresha, C. Balaji, V.V. Shree, and S. Maruthamanikandan, East Eur. J. Phys. **4**, 104 (2022), https://doi.org/10.26565/2312-4334-2022-4-09

the influence of the couple stress parameter as well as Taylor number of the system of stability properties is considered in the situation of isothermal boundary. Using the method of small perturbation [16], the influence of variations of thermal conductivity on the onset of Rayleigh-Bénard instability in a horizontal layer of a Cattaneo-dielectric fluid under the simultaneous action of an alternating electric field and a temperature gradient was studied. The Rayleigh-Bénard solution of the Cattaneo-dielectric fluid layer is more stable than the Fourier dielectric fluid problem. Nagouda & Maruthamanikandan [17] studied the effect of radiation on Darcy electroconvection in the presence of an alternating electric field. It has been shown that the system is more stable in the presence of radiative heat transfer.

The Navier-Stokes equations in the Boussinesq approximation and the heat conduction equation in the presence of rigid boundary conditions are explored by Andreeva & Tkachenko [18] and Patochkina [19] as a linear steady-state system of equations. At the onset of Rayleigh-Bénard convection, gravity migrates in a weakly conducting couple stress fluid with a saturated porous layer, as shown by Sameena & Pranesh [20]. Shankar et al [21] found that the buoyancy of a vertical dielectric fluid layer between vertical surfaces maintained at constant but different temperatures drive the combined influence of a couple stress and a horizontal AC field on the accompanying shear flow stability in the horizontal direction. The effect of radiant heat on a dielectric fluid filled with an anisotropic porous medium is evaluated according to the Milne-Eddington standard and treated by Myson and Nagouda [22]. They showed that the conduction and radiation parameters stabilize the system. In addition, the critical Darcy-Rayleigh number shows the effects of stabilization when there are no coupling stresses and dielectric boundaries. The suitability of the stability exchange policy is evaluated and it is found that the marginal strength is a preferred mode over the oscillatory mode. The effect of intermittent temperature fluctuations in the open unstable surface of the semiconductor layer of the fluid leading to the instability of the first quasi-equilibrium fluid is studied by Smorodin & Gershuni [23]. They found that if the Marangoni and Rayleigh numbers do not vanish, the results depend on the accuracy of the set temperature.

Smorodin & Velarde [24] and Smorodin [25] found that destabilization and stabilization of the basic state is possible depending on the frequency of the electric field and the number of Rayleigh numbers. In the horizontal layer, only the positive response to the outgoing electric field is considered, since the dielectrophoretic force does not depend on the direction of the electric field and consequently does not change its direction during the fluctuation period. The stability of a viscous incompressible conductive cylindrically structured fluid in the external magnetic field of a vacuum arc current flowing through it may be utilized to investigate many features of such processes [26] and [27]. Rudresha et al. [28] investigated the effect of electric modulation on the onset of electrothermal convective instability of the horizontal dielectric porous layer using a stability analysis based on the assumption that the amplitude of the peripheral power is very small.

In many practical scenarios, it is possible to postpone or accelerate the onset of convection by modifying one of the determining factors. Several studies of the effects of modulation have shown that by applying the proper transitions to a control parameter, the conduction state can be stabilized or destabilized. As a result, the concept of applying transitions to a control parameter is critical because it provides an effective tool for addressing the problem of Raleigh-Bénard convection in a pair of stress fluids, which is particularly relevant to engineering applications. Many heat transfer applications involving these couple stresses as a function now recognize that this can improve or reduce heat transfer in parallel with the final Newtonian convection. In this paper, we have investigated the effects of modulating an electric field on the boundary at the onset of convection in the dielectric fluid layer with couple stresses.

2. MATHEMATICAL FORMULATION

The problem at hand considers boundless horizontal dielectric fluid layer of couple stress fluid of thickness d. The lower surface and the upper surfaces are $z = 0$ and $z = d$ and they are sustained at constant temperatures T_1 and T_0 respectively and modulation electric potential $\phi = \pm U(\eta_1 + \eta_2 \cos \omega t)$ is retained on boundaries (see **Figure. 1**), where U is the magnitude of the modulation of the potential, ω is the frequency of modulation and η_1 and η_2 are the relative amplitudes of the components of constant and reciprocating potential difference.

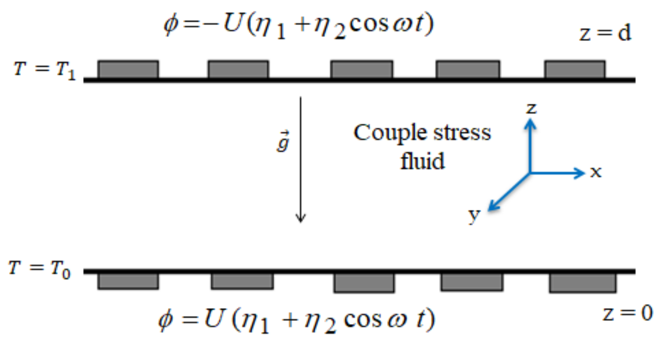

Figure 1. Schematic Diagram

The relationship between the shear tension and the flow field within a large fluid class is different from that of Newtonian fluids. These fluids are non-Newtonian in nature. The problem of Raleigh-Bènard couple stress fluid convection is particularly relevant in terms of technical applications. In heat transfer applications concerning this fluid as a functioning medium, it is now recognized that this might have improved or decreased heat transmission associated with the conventional Newtonian fluids. The relevant fundamental equations in the Boussinesq approximation [8], [11], and the dielectric constant are assumed to be linear functions of temperature.

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

$$\rho_0\left[\frac{\partial\vec{q}}{\partial t}+\left(\vec{q}\cdot\nabla\right)\vec{q}\right]=-\nabla p+\rho\,\vec{g}+\left(\mu_f\nabla^2\vec{q}-\mu_c\nabla^4\vec{q}\right)-\frac{1}{2}\left(\vec{E}\cdot\vec{E}\right)\nabla\varepsilon\,, \tag{2}$$

$$\rho_c\frac{\partial T}{\partial t}+\rho_c\left(\vec{q}\cdot\nabla\right)T=k\nabla^2 T\,, \tag{3}$$

where $\vec{q}\ =\ (\mathrm{x},\mathrm{y},\mathrm{z})$ is the velocity vector, T and $\vec{E}$ are temperature and root mean square value of the electric field, p is the improved pressure, ε and ρ are respectively dielectric constant and the fluid density, μ_f and μ_c are viscosity of the fluid and constant of the material which determines the couple stress attribute called couple stress viscosity, k is thermal conductivity, $\vec{g}$ is the gravity acceleration, ρ_0 is the density.

For most dielectric fluids, the dielectrophoretic force dominates the coulomb force. Hence the coulomb force has been omitted in Eq. (2). Consequently, the applicable Maxwell equations are

$$\nabla\cdot\ \left\lfloor\varepsilon\vec{E}\right\rfloor=0\,, \tag{4}$$

$$\nabla\times\vec{E}=\ 0\Rightarrow\vec{E}=-\nabla\phi\,, \tag{5}$$

$$\rho=\rho_0\left[1-\alpha\left(T-T_0\right)\right], \tag{6}$$

$$\varepsilon=\varepsilon_0\left[1-e\left(T-T_0\right)\right], \tag{7}$$

where α is the thermal expansion coefficient, ϕ is average quadratic value of the electric potential modulation. $e\ (>0)$ is dielectric steady-state thermal expansion coefficient, which is tiny.

The fundamental condition is quiet and is provided by $\vec{q}=\vec{q}_b(z)=0$; $\varepsilon=\varepsilon_b(z)$; $T=T_b(z)$; $\phi=\phi_b(z)$; $p=p_b(z)$; $\rho=\rho_b(z)$; and $\vec{E}=\vec{E}_b=[0,0,E_b(z)]$, index b is a basic state and using these constraints we obtain

$$\phi_b=\frac{-2U\left(\eta_1+\eta_2\cos\omega t\right)}{\log\left(1+e\beta d\right)}\log\left(1+e\beta z\right)+U\left(\eta_1+\eta_2\cos\omega t\right), \tag{8}$$

and

$$E_b=\frac{2U\left(\eta_1+\eta_2\cos\omega t\right)}{d}\left(1-e\beta z\right). \tag{9}$$

In order to investigate the stability of the basic state, we place over a negligible perturbation of the fundamental state of the form $\vec{q}=\vec{q}'=(u',v',w')$; $\varepsilon=\varepsilon_b+\varepsilon'$; $p=p_b+p'$; $T=T_b+T'$; $\vec{E}=\vec{E}_b+\vec{E}'$and $\phi=\phi_b+\phi'$, where $(u',v',w'),T',p',\varepsilon',\phi'$ and $\vec{E}'$ are the velocity, temperature, pressure, dielectric constant, potential and electric field disturbances, respectively. Substituting these quantities into eqn. (1) to (7), and keeping the vertical component, the pressure from the momentum equation is removed. The resultant equations are nondimensionalized by using scalings $(x,y,z)=\left(dx^*_, dy^*_, dz^*_\right)$; $\phi=2U(\eta_1+\eta_2\cos\omega\,t)e\Delta T\phi^*$; $T=\Delta TT^*$; $t=d^2t^*/\kappa$; and $w=\kappa\,w^*/d$. By eliminating (u',v',w'), T',p',ε',ϕ' and $\vec{E}'$ from the perturbation equations and to facilitate tilde suppression, we get the following nondimentionalized equations:

$$\left(\frac{1}{\Pr}\frac{\partial}{\partial t}-\nabla^2+C_s\nabla^4\right)\nabla^2 w=R\nabla_1^2 T+R_e\left(1+\eta_3\cos\omega t\right)^2\nabla_1^2 T+R_e\left(1+\eta_3\cos\omega t\right)^2\frac{\partial}{\partial t}\left(\nabla_1^2\phi\right), \tag{10}$$

$$\left(\nabla+\frac{\partial}{\partial z}\right)\phi=-\frac{\partial T}{\partial z}\,, \tag{11}$$

$$\left(\frac{\partial}{\partial t}-\nabla^2\right)T=w\,, \tag{12}$$

where $R = \alpha\rho_0 g d^3 \Delta T/\mu_f \kappa$ is the thermal Rayleigh number, $Pr = \nu/\kappa$ is the Prandtl number, $C_s = \mu_c/\mu_f d^2$ is the couple stress parameter, $R_e = 4e^2U^2\beta\varepsilon_0\Delta T d\eta_1^2/\mu_f\kappa$ is the electrical Rayleigh number, $\eta_3 = \eta_2/\eta_1$ is the ratio of the amplitudes.

The assumed boundaries are stress-free and isothermal; therefore, the boundary conditions are given as follows.

$$w = \frac{\partial^2 w}{\partial z^2} = T = \phi = 0 \quad \text{at} \quad z = 0 \quad \text{and} \quad z = 1. \tag{13}$$

After eliminating the coupling between the Eqns. (10) to (12) we obtain the single equation for vertical component of velocity in the form

$$\left(\frac{1}{\Pr}\frac{\partial}{\partial t} - 1 + C_s\nabla^2\right)\left(\frac{\partial}{\partial t} - \nabla^2\right)\nabla^6 w = \left[R\nabla^2 + R_e\nabla_1^2(1+\eta_3 f)^2\right]\nabla_1^2 w, \tag{14}$$

where $f = \cos\omega t$.

Also, the boundary conditions of the fluid layer are supposed to be isothermally free at temperature disturbances with decreasing couple stress and the following are the boundary conditions [28]:

$$w = \frac{\partial^2 w}{\partial z^2} = \frac{\partial^4 w}{\partial z^4} = \frac{\partial^8 w}{\partial z^8} = \frac{\partial^{10} w}{\partial z^{10}} = 0 \text{ at } z = 0,\ 1. \tag{15}$$

3. METHOD OF SOLUTION

We wish to determine the value of w and R of Eq. (14) by utilizing the control quantity η_3. Thus, the values proper to the current problem differ from those of the ordinary orders of Bènard convection of magnitude η_3. We wish to come up with the solution Eq. (14) by way of

$$\left.\begin{aligned} w &= w_0 + \eta_3 w_1 + \eta_3^2 w_2 + \ldots\ldots\ldots\ldots\ldots\ldots \\ R &= R_0 + \eta_3 R_1 + \eta_3^2 R_2 + \ldots\ldots\ldots\ldots\ldots\ldots \end{aligned}\right\}, \tag{16}$$

where R_0 is the unmodulated Rayleigh number ($\eta_3 = 0$), and R_i ($i \geq 2$) are the modulation adjustments to the critical Rayleigh number.

The odd powers of η_3 appearing in the second equation of (16) are not addressed because altering the sign of η_3 just alters the temporal origin, which has no effect on the stability problem. Therefore, R is independent of η_3, and any odd powers of η_3 should be equal to zero (see [28]). To get the following system of equations, the extension (16) is changed into Eq. (14) and the coefficients of the different powers of η_3 are assimilated into one or another of the equations.

$$L w_0 = 0, \tag{17}$$

$$L w_1 = R_1\nabla^2\nabla_1^2 w_0 + 2R_e f\nabla_1^2 w_0, \tag{18}$$

$$L w_2 = R_1\nabla^2\nabla_1^2 w_1 + R_2\nabla^2\nabla_1^2 w_0 + 2R_e f\nabla_1^4 w_1, \tag{19}$$

where

$$L = \left(\frac{1}{\Pr}\frac{\partial}{\partial t} - 1 + C_s\nabla^2\right)\left(\frac{\partial}{\partial t} - \nabla^2\right)\nabla^6 - R_0\nabla_1^2\nabla^2 - R_e\nabla_1^4. \tag{20}$$

Each of w_n is necessary to meet the boundary criteria (15). The marginal stable solution to the problem is overall solution of Eq. (17), i.e.

$$w_0 = \sin\pi z. \tag{21}$$

In the deficiency of electric field modulation, the zeroth order solution is like the Rayleigh-Bénard problem of the dielectric fluid with couple stress fluid. Shivakumara & Akkanagamma [15] carefully examined Rayleigh Bénard analysis of linear and nonlinear electroconvection in couple stress fluid without modulation. The system of stability is explored in the absence of electric field modulation by introducing a vertical temperature perturbation with w_0 corresponding to the lowest mode of convection and the related eigenvalue. The associated eigenvalues are provided by

$$R_0^n = \frac{\left(\alpha^2 + n^2\pi^2\right)^3 + C_s\left(\alpha^2 + n^2\pi^2\right)^4}{\alpha^2} - \frac{R_e\,\alpha^2}{\left(\alpha^2 + n^2\pi^2\right)}. \tag{22}$$

The least eigenvalue occurs at $n = 1$ for a fixed value of the wave number and is given by

$$R_0 = \frac{\left(\alpha^2 + \pi^2\right)^3 + C_s\left(\alpha^2 + \pi^2\right)^4}{\alpha^2} - \frac{R_e\,\alpha^2}{\left(\alpha^2 + \pi^2\right)}. \tag{23}$$

The solution to Eq. (18) is inhomogeneous due to the inclusion of reverberation factors. To satisfy the solvency condition, the time-independent element of the right part of Eq. (18) must be orthogonal to w_0. $R_1 L_1 \nabla^2 \nabla_1^2 w_0$ is the time free term on the right side, hence $R_1 = 0$, as a result, all the odd coefficients, in other words, $R_1, R_3, R_5, \dots \dots$ in Eq. (16) should disappear. If we expand the right-hand side of Eq. (18), we obtain

$$L w_1 = 2R_e\,\alpha^4\,R_{eal}\left[\sum_{n=1}^{\infty} e^{-i\omega t}\sin n\pi z\right]. \tag{24}$$

We get w_1 by flipping the operator L term by term, as in

$$w_1 = 2R_e\,\alpha^4\,R_{eal}\left[\sum_{n=1}^{\infty}\frac{e^{-i\omega t}}{L(\omega,n)}\sin n\pi z\right], \tag{25}$$

where

$$L(\omega,n) = -\left[\begin{array}{l}\frac{\omega^2}{\Pr}\left(n^2\pi^2+\alpha^2\right)^2 - \left(n^2\pi^2+\alpha^2\right)^4 - C_s\left(n^2\pi^2+\alpha^2\right)^5 \\ +R_0\,\alpha^2\left(n^2\pi^2+\alpha^2\right) + R_e\,\alpha^4\end{array}\right] - i\omega\left\{\left(n^2\pi^2+\alpha^2\right)^3\left[1+\frac{1}{\Pr}\right] + C_s\left(n^2\pi^2+\alpha^2\right)^4\right\}.$$

A term proportionate to $sin(\pi z)$ is intervened in the solution of the homogenous equation corresponding to Eq. (24). Including this term for the overall solution of Eq. (24), on the other hand, it is equal to the reconfiguration of w_n as all the equals of $sin(\pi z)$ may be combined to describe the new w_0 with the same meanings of w_1, w_2, ... As a result, we may conclude that w_0 is orthogonal to all other w_n's. We find from Eq. (19)

$$L w_2 = R_2 \nabla^2 \nabla_1^2 w_0 + 2R_e f\,\nabla_1^4 w_1. \tag{26}$$

We don't need to solve this equation; we just need to know R_2, the first nonzero adjustment to R. The stable component of right-hand side should be orthogonal to $sin(\pi z)$ for the solvability requirement to be met. Thus,

$$R_{2c} = \frac{2R_e^2\,\alpha^6}{\left(\alpha^2+\pi^2\right)}\left[\sum_{n=1}^{\infty}\frac{C_n}{D_n}\right], \tag{27}$$

where

$$C_n = \frac{\omega^2}{\Pr}\left(n^2\pi^2+\alpha^2\right)^2 - \left(n^2\pi^2+\alpha^2\right)^4 - C_s\left(n^2\pi^2+\alpha^2\right)^5 + R_0\,\alpha^2\left(n^2\pi^2+\alpha^2\right) + R_e\,\alpha^4,$$

$$D_n = \left[\begin{array}{c}\frac{\omega^2}{\Pr}\left(n^2\pi^2+\alpha^2\right)^2 - \left(n^2\pi^2+\alpha^2\right)^4 \\ -C_s\left(n^2\pi^2+\alpha^2\right)^5 + R_0\,\alpha^2\left(n^2\pi^2+\alpha^2\right) + R_e\,\alpha^4\end{array}\right] + \omega^2\left\{\begin{array}{l}\left(n^2\pi^2+\alpha^2\right)^3\left(1+\frac{1}{\Pr}\right) \\ +C_s\left(n^2\pi^2+\alpha^2\right)^4\end{array}\right\}^2.$$

4. RESULTS AND DISCUSSION

The perturbation procedure method is used to study the stability condition of a modulated dielectric fluid layer with a couple stress and an electric field. This approach is used to determine the Rayleigh number, wave number, and correction Rayleigh number. The present analysis assumes that the amplitude of the electric field modulation is very small in comparison to the central electric field, that convective currents are weak, allowing indirect effects to be ignored, and that the dielectric constant is considered to be a linear function of temperature. When the modulating frequency ω is low, violating these assumptions has a major impact on the outcomes. This is because the perturbation technique requires that amplitude of $\eta_3 w_1$ not exceeding that of w_0, resulting in the condition $\omega > \eta_3$. As a result, the validity of the results is dependent on the modulating frequency value. When $\omega << 1$, the modulation time is large and impacts the full volume of the fluid. The impact of the modulation decreases at high frequencies because the electric force takes an average value, resulting in an unmodulated equilibrium state. Consequently, modulation has a significant effect only in small and moderate quantities of ω.

Before delving into the results displayed in **Fig. 2-4**, it is worth noting that the oscillatory mode will not be present in couple stresses (see [8]), and these figures demonstrate the fluctuation of R_{2c} versus ω for various parameters. As we can observe that, R_{2c} is always positive for entire array of ω values, showing that the effect of electric field modulation and couple stresses are causing the system to stabilize. Convection occurs later in the modulated system than in the unmodulated system. **Fig. 2** depicts a plot of the critical correction Rayleigh number R_{2c} vs frequency modulation ω for different electrical Rayleigh number R_e values. In this picture, we see that the amplitude of the correction Rayleigh number R_{2c} decreases positively as the electrical Raleigh number R_e climbs. This shows that R_e decreases the stabilizing effect for low values of frequency ω. However, the same pattern is seen for high values of ω. For large values of frequency, the modulation effect vanishes.

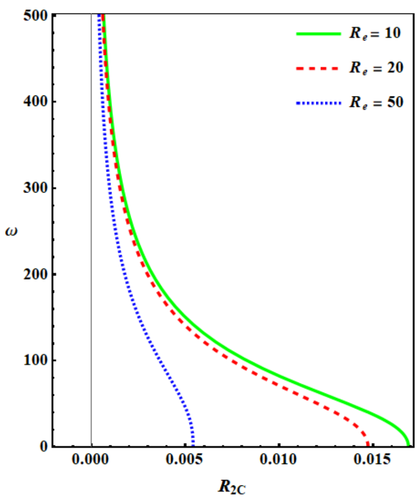

Figure 2. Variation R_{2c} vs ωfor a different value of R_e with $C_s = 0.005$ and $Pr = 5$

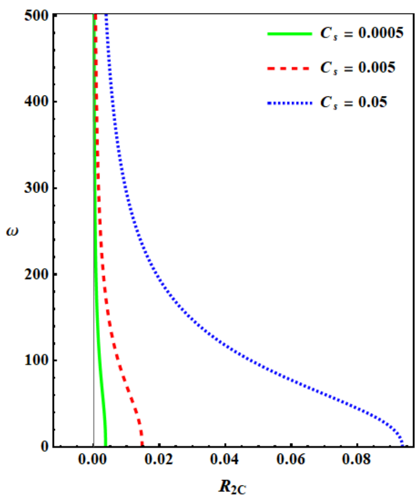

Figure 3. Variation R_{2c} vs ω for a different value of C_s with $R_e = 20$ and $Pr = 5$

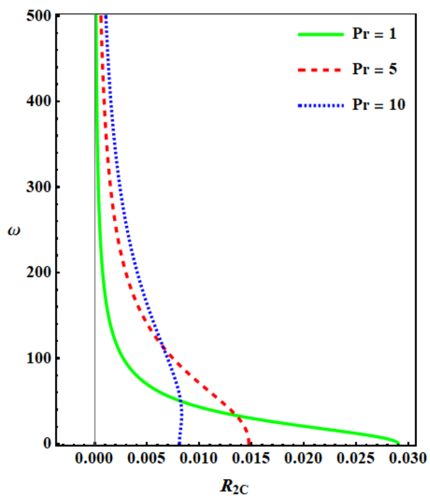

Figure 4. Variation R_{2c} vs ω for an individual values of Pr with R_e=20 and C_s =0.005

Fig. 3 depicts a plot of the critical correction Rayleigh number R_{2c} vs frequency ω for a different value of the couple stress parameter C_s. We observe from this graph that when the couple stress parameter C_s grows, so does R_{2c}, stabilizing the system. The concentration of suspended particles is represented by C_s. An explanation can be given to elucidate the impact of C_s on R_{2c} using Einstein's rule on suspension viscosity. Einstein's equation for suspended particles is $\mu = \mu_0(1 + 2.5\alpha\delta)$, where μ and μ_0 are the viscosity of the suspension and clean fluid, respectively, α is the form factor, and δ is the volume ratio of suspended particles. α equals 1 for spherical particles and exceeds 1 for other structures such as ellipsoids, rods, etc. To comprehend a change in the viscosity of a suspension with concentration, remember that the viscosity of any fluid is related to the intemperance of mechanical energy into heat inside the fluid. Other parameters influencing suspension viscosity include the viscosity of the carrier liquid, particle contact, particle stiffness or deformability, temperature, and electrical conductivity. We simply assume that the viscosity of a suspension is greater than the viscosity of the carrier liquid. For low concentrations, the assumed viscosity concentration relation holds true. In the event of larger concentrations, the Einstein relation must be supplemented with a quadratic term. Given the preceding explanation, we believe that the Prandtl numbers of fluids containing suspended particles are greater than those of fluids without suspended particles. The modulation effect, on the other hand, fades away at a high frequency. This is because the electric force adopts a mean value, resulting in the unmodulated case's equilibrium condition. As a result, in our research, we only employed a moderate value. It should be noted that the value of the Prandtl number is assumed to be larger than that of clean fluid due to the existence of suspended particles in the fluid and Einstein's connection to viscosity.

Fig. 4 depicts the R_{2c} against ω for various Prandtl numbers Pr. When Pr increases for small values of ω, R_{2c} decreases, but increases for moderate and large values of frequencies, indicating that the effect of Pr on the electric field modulation on a couple stress fluid is to reduce the stabilizing effect for small values of ω, and to increase the stabilising effect for large values of ω.

5. CONCLUSIONS

We conclude from the research carried out that the effects of electric field modulation and couple stress fluid on the commencement of electroconvection in a dielectric fluid layer cause convection to be delayed. Depending on frequency, the electrical Rayleigh number has a stabilizing and destabilizing impact. The system stability is strongly influenced by the couple stress parameter, and the Prandtl number diminishes the stabilizing impact. At intermediate frequencies, this impact is stronger. Finally, it is discovered that electric field modulation may either stabilize or destabilize the system depending on the values of the parameters, and that it disappears for high frequency values.

ORCID IDs
Chandrappa Rudresha, https://orcid.org/0000-0002-0958-4220
Chandrashekar Balaji, https://orcid.org/0000-0002-3832-935X
Venkatesh Vidya Shree, https://orcid.org/0000-0003-1554-8258
Sokalingam Maruthamanikandan, https://orcid.org/0000-0001-9811-0117

REFERENCES

[1] V.K. Stokes, "Couple stresses in fluids", Phys. Fluids, **9**(9), 1709 (1966). https://doi.org/10.1063/1.1761925
[2] T. Ariman, "Couple Stresses in Fluids", Phys. Fluids, **10**(11), 2497 (1967). https://doi.org/10.1063/1.1762061
[3] V.K. Stokes, "Effects of couple stresses in fluids on the creeping flow past a sphere", Phys. Fluids, **14**(7), 1580 (1971). https://doi.org/10.1063/1.1693645
[4] R.C. Sharma, and S. Sharma, "On couple-stress fluid heated from below in porous medium", Indian J. Phys. **75**(2), 137 (2001).
[5] M.S. Malashetty, S.N. Gaikwad, and M. Swamy, "An analytical study of linear and non-linear double diffusive convection with Soret effect in couple stress liquids", Int. J. Therm. Sci. **45**(9), 897 (2006). https://doi.org/10.1016/j.ijthermalsci.2005.12.005
[6] M.S. Malashetty, I.S. Shivakumara, and S. Kulkarni, "The onset of convection in a couple stress fluid saturated porous layer using a thermal non-equilibrium model", Phys. Lett. Sect. A Gen. At. Solid State Phys. **373**(7), 781 (2009). https://doi.org/10.1016/j.physleta.2008.12.057
[7] S. Saravanan, and D. Premalatha, "Effect of couple stress on the onset of thermovibrational convection in a porous medium", Int. J. Therm. Sci. **57**, 71 (2012). https://doi.org/10.1016/j.ijthermalsci.2012.02.013
[8] M. Taj, S. Maruthamanikandan, and S.K. Akbar, "Effect of Chemical Reaction on Convective Instability in a Horizontal Porous Layer Saturated with a Couple-Stress Fluid", Int. J. Eng. Res. Appl. **3**(2), 1742 (2013). https://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=26C9EE742F44CA86219F8CA53B476180?doi=10.1.1.414.6306&rep=rep1&type=pdf
[9] S. George and M. Thomas, "Effect of Gravity Modulation and Internal Heat Generation on Rayleigh-Bénard Convection in Couple Stress Fluid with Maxwell-Cattaneo Law", Int. J. Appl. Eng. Res. **13**(5), 2688 (2018).
[10] R. Sumithra and S. Venkatraman, "Darcy-Benard Marangoni Convection in a Composite Layer Comprising of Couple Stress Fluid", Int. J. Appl. Eng. Res. **15**(7), 659 (2020). https://www.ripublication.com/ijaer20/ijaerv15n7_07.pdf
[11] M. Takashima, and A. K. Ghosh, "Electrohydrodynamic Instability in a Viscoelastic Liquid Layer", J. Phys. Soc. Japan, **47**(5), 1717 (1979). https://doi.org/10.1143/JPSJ.47.1717
[12] R.C. Sharma, and K.D. Thakur, "On couple stress fluid heated from below in porous medium in hydromagnetics", Czechoslov. J. Phys. **50**(6), 753 (2000). https://doi.org/10.1023/A:1022886903213
[13] S. Maruthamanikandan, "Convective instabilities in Newtonian ferromagnetic, dielectric and other complex liquids", PhD Thesis, Bangalore University, Bangalore, India, 2005.
[14] N. Rudraiah, B.M. Shankar, and C.O. Ng, "Electrohydrodynamic stability of couple stress fluid flow in a channel occupied by a porous medium", Spec. Top. Rev. Porous Media: An International Journal, **2**(1), 11 (2011). https://doi.org/10.1615/SpecialTopicsRevPorousMedia.v2.i1.20
[15] I.S. Shivakumara, M. Akkanagamma, and C.O. Ng, "Electrohydrodynamic instability of a rotating couple stress dielectric fluid layer", Int. J. Heat Mass Transf. **62**(1), 761 (2013). https://doi.org/10.1016/j.ijheatmasstransfer.2013.03.050
[16] S. Maruthamanikandan, and S.S. Nagouda, "Convective Heat Transfer in Maxwell-Cattaneo Dielectric Fluids", Int. J. Comput. Eng. Res. **3**, 347 (2013). https://cutt.ly/AVrcoGi
[17] S.S. Nagouda, and S. Maruthamanikandan, "Rayleigh-Bénard Convection in a Horizontal Layer of Porous Medium Saturated with a Thermally Radiating Dielectric Fluid", IOSR J. Math. **11**(3), 01 (2015). https://www.iosrjournals.org/iosr-jm/papers/Vol11-issue3/Version-3/A011330110.pdf
[18] O.L. Andreeva, and V.I. Tkachenko, "Analytical Solution and Neutral Curves of the Stationary Linear Rayleigh Problem with Rigid or Mixed Boundary Conditions in Cylindrical Geometry", East Eur. J. Phys. **2**(4), 52 (2015). https://periodicals.karazin.ua/eejp/article/view/5118/4672
[19] O.L. Patochkina, Yu.G. Kazarinov, and V.I. Tkachenko, "Physical model of the dependence of the Nusselt number on the Rayleigh number", ZhTF, **66**(11), 23 (2016). (in Russian).
[20] S. Tarannum, and S. Pranesh, "Effect of Gravity Modulation on the Onset of Rayleigh-Bénard Convection in a Weak Electrically Conducting Couple Stress Fluid with Saturated Porous Layer", Int. J. Eng. Res. **5**(01), 2016. https://cutt.ly/7VrvvJY
[21] B.M. Shankar, J. Kumar, and I.S. Shivakumara, "Stability of natural convection in a vertical dielectric couple stress fluid layer in the presence of a horizontal AC electric field", Appl. Math. Model. **40**(9–10), 5462 (2016). https://doi.org/10.1016/j.apm.2016.01.005
[22] S. Myson, and S.S. Nagouda, "Convective instability analysis of couple-stress dielectric fluid saturated anisotropic porous medium with radiation effect", Multidiscip. Model. Mater. Struct. **16**(5), 1019 (2020). https://doi.org/10.1108/MMMS-08-2019-0149

[23] B.L. Smorodin, G.Z. Gershuni, and M.G. Velarde, "On the parametric excitation of thermoelectric instability in a liquid layer open to air", Int. J. Heat Mass Transf. **42**, 3159 (1999). https://doi.org/10.1016/S0017-9310(98)00351-2
[24] B.L. Smorodin, and M.G. Velarde, "On the parametric excitation of electrothermal instability in a dielectric liquid layer using an alternating electric field", J. Electrostat. **50**, 205 (2001). https://doi.org/10.1016/s0304-3886(00)00036-x
[25] B.L. Smorodin, "The Behaviour of Low Conducting Liquid in Modulated Electric Field", in: *Proc. 14th lnternational Conf. Dielectr. Liq.*, (IEEE, Graz, Austria, 2002). pp. 425–428, 2002. https://doi.org/10.1109/ICDL.2002.1022783
[26] L. Bozbiei, B. Borts, Y. Kazarinov, A. Kostikov, and V.I. Tkachenko, "Experimental Study of Liquid Movement in Free Elementary Convective Sells", Energetika, **61**(2), 45 (2015). (in Russian)
[27] O.L. Andrieieva, B.V. Borts, A.F. Vanzha, I.M. Korotkova, and V.I. Tkachenko, "Stability of a Viscous Incompressible Conducting Liquid Layer of a Cylindrical Shape in an Inhomogeneous Temperature Field and a Magnetic Field of a Vacuum Arc Current Through It", PAST. **3**, 91 (2021). https://vant.kipt.kharkov.ua/ARTICLE/VANT_2021_3/article_2021_3_91.pdf
[28] C. Rudresha, C. Balaji, V. Vidya Shree, S. Maruthamanikandan, "Effect of Electric Field Modulation on Electroconvection in a Dielectric Fluid-Saturated Porous Medium", Journal of Mines Metals and Fuels. **70**(3A), 35 (2022). https://doi.org/10.18311/jmmf/2022/30665
[29] S. Maruthamanikandan, N.M. Thomas, and S. Mathew, "Bénard-Taylor ferroconvection with time-dependent sinusoidal boundary temperatures", J. Phys. Conf. Ser. **1850**(1), 012061 (2021). https://doi.org/10.1088/1742-6596/1850/1/012061

ВПЛИВ МОДУЛЯЦІЇ ЕЛЕКТРИЧНОГО ПОЛЯ НА ПОЧАТОК ЕЛЕКТРОКОНВЕКЦІЇ В ПАРНІЙ НАПРУЖЕНІЙ РІДИНІ

Чандраппа Рудреша, Чандрашекар Баладжі, Венкатеш Відья Шрі, Сокалінгам Марутаманікандан
Факультет математики, Інженерна школа, Президентський університет, Бенгалуру, Індія

Досліджено проблему конвективної нестійкості в горизонтальному діелектричному парному напруженому шарі рідини з модуляцією електричного поля. Горизонтальний діелектричний верхній граничний шар охолоджується, а нижній граничний шар піддається ізотермічним граничним умовам. Для обчислення критичного числа Релея та відповідного хвильового числа використовується метод регулярних збурень на основі малої величини модуляції. Міцність системи характеризується коригувальним числом Релея, яке розраховується як функція теплових, електричних параметрів, параметрів напруги пари та частоти модуляції електричного поля. В цьому дослідженні деякі з добре відомих висновків розглядаються як окремі випадки. Показано, що початок конвекції можна прискорити або відстрочити належним налаштуванням різних контрольних параметрів. Результати цього дослідження мають потенційні наслідки для керування електроконвекцією за допомогою залежного від часу електричного поля.

Ключові слова: конвекція, парна напруга, діелектрична рідина, електричне поле, модуляція