Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Physica A 345 (2005) 367–394
PHYSICA A
www.elsevier.com/locate/physa

# Thermohydrodynamic instabilities of conducting liquid jets in the presence of time-dependent transverse electric fields

M.F. El-Sayed[a,b,*], A.A. Mohamed[a], T.M.N. Metwaly[a]

[a]Department of Mathematics, Faculty of Education, Ain Shams University, Heliopolis (Roxy), Cairo, Egypt
[b]Department of Mathematics and Computer Science, Faculty of Science, United Arab Emirates University, P. O. Box 17551, Al Ain, United Arab Emirates

Received 3 January 2004; received in revised form 21 April 2004
Available online 23 July 2004

## Abstract

A novel system to study the effect of time-dependent radial electric fields on the stability of a cylindrical interface between the vapor and liquid phases of conducting fluids in the presence of heat and mass transfer is investigated. The vapor is hotter than the liquid and the two phases are enclosed between two cylindrical surfaces coaxial with the interface. The linear dispersion relation is obtained and discussed, for the periodic electric field case, and the stability of the system is analyzed theoretically and numerically. Both the nonresonant and resonant cases are considered. Using the multiple time scales method, we found that the obtained dispersion relation is the damped Mathiew equation with real coefficients. Both the frequency of the periodic electric field and the dimensions of the system are found to have stabilizing effects, while both the azimuthal wavenumber and the electrical conductivity have destabilizing effects; and the heat and mass transfer are found to have no effect on the stability of the system. The behavior of the resonance points (increased, or decreases, or a steady) corresponding to the above physical parameters are determined.


*PACS:* 47.20.−k; 47.27.Tc; 47.65.+a

*Keywords:* Hydrodynamic stability; Convection and heat transfer; Electrohydrodynamics

*Corresponding author. Department of Mathematics and Computer Science, Faculty of Science, United Arab Emirates University, P. O. Box 17551, Al Ain, United Arab Emirates. Tel.: +971-37-517-675; fax: +971-37-671-291.

*E-mail address:* m.elsayed@uaeu.ac.ae (M.F. El-Sayed).

0378-4371/$ - see front matter 
doi:10.1016/j.physa.2004.06.074

## 1. Introduction

The physical basics of electroconvection lies in the electrohydrodynamic force $\mathbf{F}_e$ per unit volume generated by an electric field $\mathbf{E}$, in a fluid of dielectric permittivity $\varepsilon$ and density $\rho$ at temperature $\tau$. This can be expressed as follows [1–5]

$$\mathbf{F}_e = q\mathbf{E} - (1/2)E^2\nabla\varepsilon + \nabla\left[(1/2)\rho E^2\left(\frac{\partial\varepsilon}{\partial\rho}\right)_\tau\right],$$

where $q$ is the electric charge density in the fluid. In this equation, the first term $q\mathbf{E}$ (the electrophoretic component) is the Coulomb force resulting from the interaction of free charge in the fluid with the electrical field and typically dominates in DC electrohydrodynamic systems. The second term is the force exerted on the fluid by a non-uniform electric field and is known as the dielectrophoretic force. It is only significant in AC electrohydrodynamic systems. The third term is the electrostriction force and relates changes in fluid density to the applied electric field and is not significant in incompressible systems such as those considered here. Electroconvection in dielectric fluids has been the subject of many previous studies [6–13]. In general the agreement between experiment and theory has been modest, owing to difficulties in modelling the generation of charge at the electrodes [14–16].

Most of the fluids in nature and in the engineering applications are time dependent. However, very little studies have been done on stability of time-dependent flows mainly due to the fact that the mathematical analysis of such problems is more difficult, since the simple method of normal modes is not applicable [17]. The linearized governing equations for such stability problems have time-dependent coefficients, due to the unsteady base flow, so that exponential time-dependence of the disturbance's dependent variables is not separable. Time-dependent forces acting on a fluid can strongly affect instability thresholds and provide an effective way to control convection in various engineering applications. Vibrations, modulations of surface temperature or surface heat flux or unsteady electric fields provide examples of periodic forcing on liquids [18–22].

The effect of time-dependent gravitational or vibration acceleration on the onset of Rayleigh–Bénard convection was investigated Gershuni and Zhukhovitsky [23]. On the other hand, the influence of vibration on convection in differentially heated infinite vertical cylinders, in a wide range of frequencies, was studied by Wadh and Roux [24]. The problem of Marangoni instability excited with a time-periodic heat flux on the free surface was studied by Gershuni et al. [25]. The dynamic excitation of thermoelectric instability in a liquid semiconductor or an ionic melt was investigated by Smorodin et al. [26]. Also, the electroconvection instability on an Ohmic non-homogeneous heated liquid subjected to an alternating and modulated electric field has been analyzed when the charge formation is produced by electroconduction [27]. The convective instability of a dielectric liquid layer with rigid high electroconductive boundaries subjected to a transverse temperature gradient and an alternating electric field with harmonic modulation is also studied by Smorodin and Velarde [28]. They studied the following two cases: (i) the onset of flow motion of an initially motionless horizontal dielectric liquid layer, and (ii) the instability of the convective base flow in