International Communications in Heat and Mass Transfer 38 (2011) 468–473

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Surface tension driven convection in viscoelastic liquids with thermorheological effect ☆

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ARTICLE INFO

Available online 8 January 2011

Keywords:
Convection
Bénard–Marangoni
Viscoelastic liquids
Variable viscosity
Thermorheology

ABSTRACT

Oscillatory onset of convection is studied numerically for Rivlin–Ericksen, Maxwell and Jeffreys liquids by considering free–free and rigid–free isothermal/adiabatic boundaries. The effect of variable viscosity parameter is shown to destabilize the system. The problem reveals the stabilizing nature of strain retardation parameter and the destabilizing nature of stress relaxation parameter, on the onset of convection. The Maxwell liquids are found to be more unstable than the one subscribing to the Jeffreys description whereas the Rivlin–Ericksen liquids are comparatively more stable. Rigid-free adiabatic boundary combination is found to give rise to a most stable system, whereas the free isothermal free adiabatic combination gives rise to a most unstable system.

1. Introduction

Rayleigh–Bénard–Marangoni convection problems in constant viscosity Newtonian liquids have received widespread attention due to their implications in heat transfer and in other engineering applications (see Chandrasekhar [1]; Platten and Legros [2]). In practical problems, many a time, non-Newtonian liquids are used as working media, especially the viscoelastic ones. In view of this several works have appeared on Rayleigh–Bénard convection in these liquids.

Vest and Arpaci [3] have studied the conditions under which thermally induced overstability occurs in a viscoelastic liquid. It is found that overstability would occur at the lowest possible adverse temperature gradient at which the rate of change of kinetic energy can balance, in a synchronous manner, the periodically varying rates of energy dissipation by the shear stresses and the energy release by the buoyancy force, assuming that stationary convection has not been initialized.

Sokolov and Tanner [4] have studied the Rayleigh–Bénard convection in a general viscoelastic liquid using an integral form of constitutive equations. It is shown that under certain conditions the liquid system is overstable. The theoretical results have been applied to a Maxwell liquid and to some real viscoelastic solutions. Siginer and Valenzuela-Rendón [5] have studied the natural convection of viscoelastic liquids.

Dávalos-Orozco and Vázquez-Luis [6] have investigated natural convection in a viscoelastic liquid with deformable free surface considering the Oldroyd's viscoelastic constitutive equation with relaxation and retardation times and with the Maxwell's model as a particular case. It is found that, for different values of the Galileo number, for relaxation times that are large enough, the curves of the critical Rayleigh numbers are lower than those of the stationary convection and those of the overstability of the Newtonian liquid with deformable free surface.

Mardones et al. [7] have studied thermal convection thresholds in viscoelastic solutions. The threshold for oscillatory motions in the Rayleigh–Bénard experiments with viscoelastic binary liquids is explicitly determined as a function of separation ratio and rheological parameters. It is shown that the critical oscillation frequency may differ by several orders of magnitude on varying separation ratio and Deborah number.

Siddheshwar [8] has studied oscillatory convection in viscoelastic ferromagnetic and dielectric liquids of Rivlin–Ericksen, Maxwell and Oldroyd types. It is found that the Maxwell liquids are more unstable than the one subscribing to the Oldroyd description whereas the Rivlin–Ericksen liquid is comparatively more stable.

Demir [9] has considered a two-dimensional unsteady Rayleigh–Bénard convective motion of a viscoelastic liquid in a square cavity. For the first time, it is shown that shear-thinning and elastic numbers have an influence in shaping the flow field and determining the heat transfer characteristics with respect to the Rayleigh numbers and their combined effect acts to increase and decrease the heat transfer as represented by the local Nusselt number.

Abu-Ramadan et al. [10] have studied chaotic thermal convection of viscoelastic liquids. The viscoelastic flow in the context of the Rayleigh–Bénard thermal convection set-up is examined using a four-dimensional non-linear dynamical system resulting from a truncated Fourier representation of the conservation and constitutive equations, for an Oldroyd-B liquid. It is found that stress relaxation and strain

☆ Communicated by A.R. Balakrishnan.

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0735-1933/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.icheatmasstransfer.2010.12.040