CONVECTIVE INSTABILITIES IN A FERROFLUID WITH A VISCOELASTIC CARRIER FLUID

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Ferrofluid convection has applications e.g. in high-power capacity transformer systems, where the ferrofluid is used as core material as well as a coolant in the transformer. To activate convective cooling, one has to know the critical concentration gradient, where convection sets in. The first study on the convective instability of a magnetic fluid heated from below in the presence of a uniform vertical magnetic field was realized by Finlayson [1]. Actually, he discussed the linear stability problem for both cases, shear free and rigid horizontal boundaries. Recently, using nonequilibrium thermodynamics, a complete set of equations to describe ferrofluid convection in an external magnetic field has been derived [2]. This description is made in terms of a binary mixture, where the magnetophoretic effect, as well as magnetic stresses, have been taken into account in the static and dynamic parts of the ferrofluid equations. Moreover, studies on the stationary convection in Oldroyd viscoelastic carrier liquids were performed [3].

In the present work, Rayleigh-Benard convection in a magnetic viscoelastic liquid is studied. The stability thresholds for both, the stationary and the oscillatory convection, have been determined. We systematically investigate the role of the various effects (and their mutual interplay) for the instability and bifurcation behavior. In particular, for oscillatory instabilities nonlinear magnetic and nonlinear viscoelastic properties are taken into account. Two different boundaries conditions for the velocity field were analyzed, the so-called fee-free and rigid-rigid ones. In addition, we have provided analytical formula for the oscillatory convection. For weakly viscoelastic fluids the critical Rayleigh number for the oscillatory convection is much higher than that for the stationary one, while for high Deborah numbers the oscillatory instability always precedes the stationary instability. We have also calculated the range of parameters where the codimension-2 bifurcation appears. In the case of rigid-rigid boundary conditions, the convection thresholds are calculated numerically by the spectral method. The technique of collocation points (Gauss-Lobato) as described in [4] was used.

Due to the presence of various destabilizing effects, i.e. buoyancy and magnetic forces, and of additional relaxation channels due to the Oldroyd model, the discussion of the stability curves becomes rather intricate. An oscillatory instability, whose critical frequency is a rapidly varying function of the Deborah number, is competing with the stationary one. As a result, the codimension-2 bifurcation line, separating those two instabilities, strongly depends on the structure of the Oldroyd model and its relaxation times.

The oscillatory instability is only possible for a Deborah numbers above a certain lower limit; in addition, the relaxation time of the stress, has to be larger than the retardation time (of the strain rate). For large Deborah numbers the critical values show a distinctive asymptotic behavior. In particular, the critical wavevector tends to the value of the stationary case. The oscillatory threshold reaches a constant value that is smaller than the stationary one and is proportional to the ratio of the two Oldroyd time scales. Finally, the critical frequency goes to zero with one over square root of the Deborah number.

Acknowledgments
D.L. acknowledges financial support from FONDECYT 11080229, Millenium Scientific Initiative, P06-022-F, Financiamiento Basal para Centros Cientificos y Tecnologicos de Excelencia CEDENNA and Convenio de Desempeno UTA Mineduc.
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