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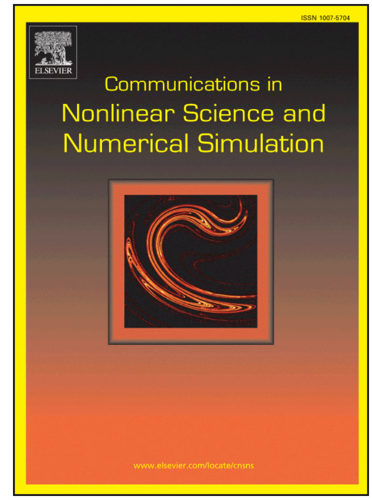

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Thermal convection in a nonlinear non-Newtonian magnetic fluid

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Abstract

We report theoretical and numerical results on thermal convection of a magnetic fluid in a viscoelastic carrier liquid. The viscoelastic properties are described by a general nonlinear viscoelastic model that contains as special cases the standard phenomenological constitutive equations for the stress tensor. In order to explore numerically the system we perform a truncated Galerkin expansion obtaining a generalized Lorenz system with ten modes. We find numerically that the system has stationary, periodic and chaotic regimes. We establish phase diagrams to identify the different dynamical regimes as a function of the Rayleigh number and the viscoelastic material parameters.

Keywords: Thermal convection, magnetic fluid, viscoelastic fluid.

1. Introduction

Convection in fluids driven by thermal gradients have been at the very origin of the field of nonlinear physics and pattern formation [1]. Very early on, investigations have been extended to e.g. binary mixture, non-Newtonian, and magnetic fluids. In such systems, new channels for dissipating energy (e.g. Soret effect), additional time scales (e.g. stress relaxation) and additional driving forces (e.g. magnetic field) lead to new phenomena at the instability thresholds and the pattern forming processes, above. Among the many examples we mention investigations of thermal convection in non-Newtonian binary mixtures [2–9], in non-Newtonian magnetic fluids [10–14], and in binary magnetic fluids [15, 16].

The technological applications of magnetic fluids [17] and their biomedical importance [18–22] is closely related to non-Newtonian properties, which are either magnetic field-induced [23–25] or due to the carrier liquid [26–32] (e.g. in blood [33–35]). In this manuscript we are particularly interested in the interplay of nonlinear non-Newtonian with magnetic properties with respect to thermal convection. Despite the black appearance of most ferrofluids, thermal convection experiments [36–47] are a valuable source to investigate the nonlinear properties of those materials.

To describe the nonlinear non-Newtonian aspects we will use a general hydrodynamic description of nonlinear viscoelasticity (PLB) [48] in terms of a dynamic equation for the (nonlinear) strain tensor. Using the standard hydrodynamic procedure including all symmetry and thermodynamic requirements, one can derive the form of the viscoelastic equations, rather than postulating them phenomenologically. PLB is applicable to arbitrarily large deformations, rotations and flows [49] and contains the solid limit, correctly. It contains as special limits typical visco-elastic models, such as Maxwell, Oldroyd, Giesekus, Leonov and KBKZ [50]. However, it overcomes the drawback of those popular models that use quasi-linear constitutive relations between stress and strain rate

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