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Influence of an interfacial heat release on nonlinear convective flows in a laterally heated two-layer system

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HIGHLIGHTS

- Specific nonlinear oscillatory regimes have been found.
- The presence of the interfacial heat release can change the sequence of bifurcations.
- The region of oscillations is observed in a finite interval of the Grashof number values.

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ABSTRACT

The influence of the interfacial heat release on nonlinear convective flows, developed under the joint action of buoyant and thermocapillary effects in the 47v2 silicone oil–water system, is investigated. The system filling a closed cavity is heated from the lateral wall. The wide range of the modified Grashof number values, corresponding to heat sources and heat sinks at the interface, is considered. It is shown that the presence of the interfacial heat release can change the sequence of bifurcations and lead to the appearance of specific oscillatory regimes in the system.

1. Introduction

The stability of convective flows in systems with an interface has been the subject of an extensive investigation (for a review, see [1,2]). Several classes of instabilities have been found by means of the linear stability theory for purely thermocapillary flows [3–6] and for buoyant–thermocapillary flows [7–10]. For the most typical kind of instability, hydrothermal instability, the appearance of oblique waves moving upstream has been predicted by the theory and justified in experiments [11–13]. However, two-dimensional waves moving downstream have also been observed in experiments [14]. The change of the direction of waves' propagation can be caused by the influence of buoyancy [7].

Most of the investigations have been fulfilled for a single liquid layer with a free surface, i.e., in the framework of the one-layer approach. Recently, Madruga et al. [15,16] studied the linear stability of two superposed horizontal liquid layers bounded by two solid planes and subjected to a horizontal temperature gradient. The analysis has revealed a variety of instability modes. The nonlinear wavy convective regimes in two-layer systems have been described in [17].

There are various physical phenomena that can be the origin of a heat release on the interface. For example, interfacial heat release accompanies an interfacial chemical reaction (see, e.g., [18]) and the occurrence of evaporation [19]. It is known that the presence of a constant, spatially uniform heat release or consumption at the interface can lead to the appearance of an oscillatory instability [20]. Oscillations in [20] have been obtained in a two-layer system *heated from below*. Different types of boundary conditions—periodic boundary conditions and rigid, heat-insulating lateral walls, have been considered in [20]. The simulations in [20] have been performed for a single (negative) value of the modified Grashof number, determined by the interfacial heat release.

In the present paper, the influence of the interfacial heat release on nonlinear convective regimes, developed under the joint action of buoyant and thermocapillary effects in the 47v2 silicone oil–water system, is studied. The two-layer system is heated from *the lateral wall*. The wide range of the modified Grashof number values, corresponding to heat sources and heat sinks at the interface, is considered. It is shown that the presence of the interfacial

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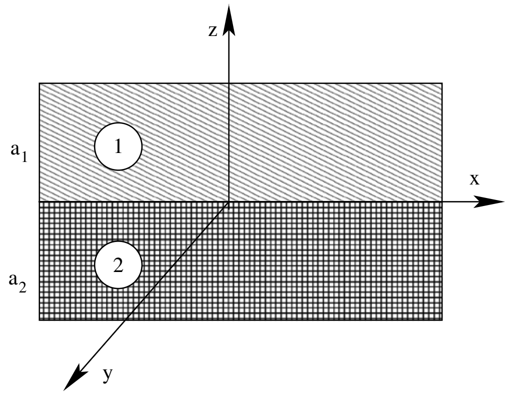

Fig. 1. Geometrical configuration of the two-layer system and coordinate axes.

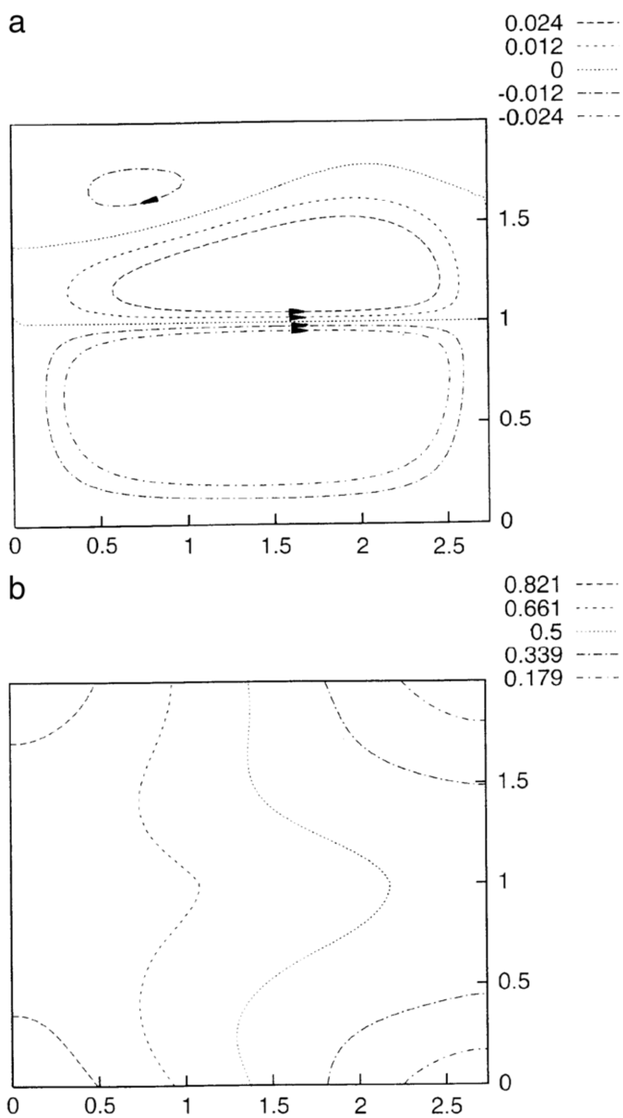

Fig. 2. (a) Streamlines and (b) isotherms for the steady state at $G = 91.9$; $K = 0.025$; $G_Q = 0$; $L = 2.74$; $a = 1$.

heat release can change the sequence of bifurcations and lead to the appearance of specific oscillatory regimes in the system.

The paper is organized as follows. In Section 2, the mathematical formulation of the problem in the two-layer system is presented. Section 2.1 contains equations and boundary conditions. The nonlinear approach is described in Section 2.2.

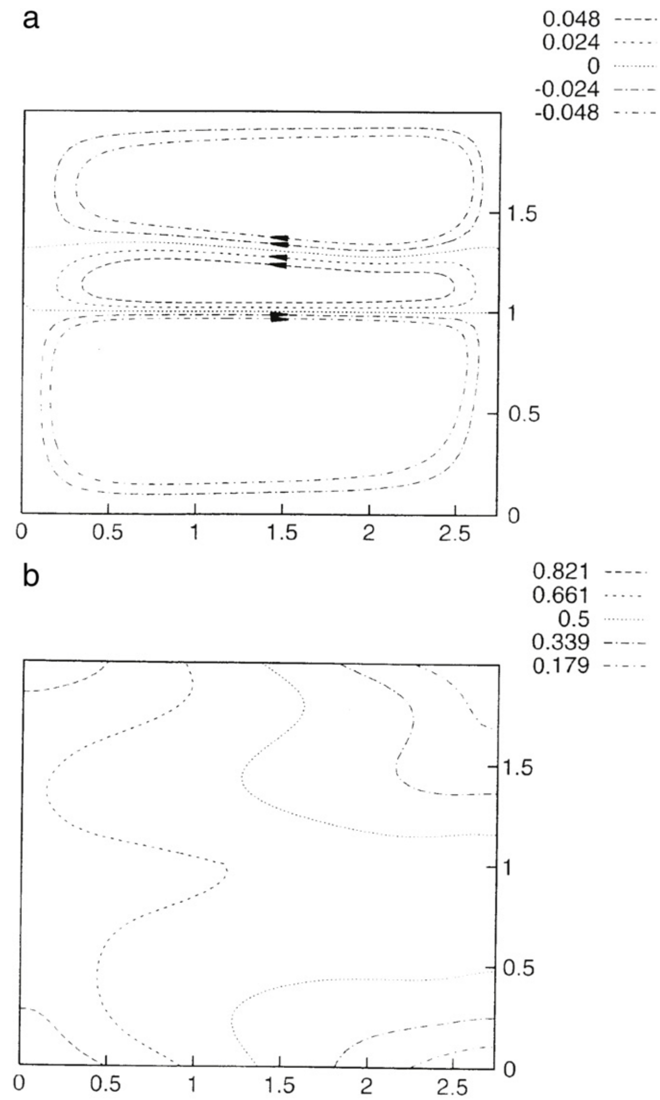

Fig. 3. (a) Streamlines and (b) isotherms for the steady state at $G = 648.8$; $K = 0.025$; $G_Q = 0$; $L = 2.74$; $a = 1$.

Numerical simulations of the finite-amplitude convective regimes are considered in Section 3. Section 4 contains some concluding remarks.

2. Formulation of the problem

2.1. Equations and boundary conditions

We consider a system of two horizontal layers of immiscible viscous fluids with different physical properties (see Fig. 1). The variables referring to the top layer are marked by subscript 1, and the variables referring to the bottom layer are marked by subscript 2. The system is bounded from above and from below by two rigid plates, $z = a_1$ and $z = -a_2$. A constant temperature gradient is imposed in the direction of the axis x: $T_1(x, y, a_1, t) = T_2(x, y, -a_2, t) = -Ax + const$, $A > 0$. A constant heat release of the rate Q_0 (Q_0 may be positive or negative) is set on the interface.

It is assumed that the interfacial tension σ decreases linearly with an increase of the temperature: $\sigma = \sigma_0 - \alpha T$, where $\alpha > 0$.

Let us introduce the following notation:

$$\rho = \rho_1/\rho_2, \qquad \nu = \nu_1/\nu_2, \qquad \eta = \eta_1/\eta_2, \qquad \kappa = \kappa_1/\kappa_2,$$
$$\chi = \chi_1/\chi_2, \qquad \beta = \beta_1/\beta_2, \qquad a = a_2/a_1.$$