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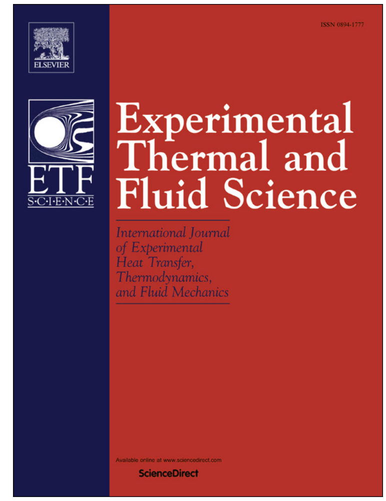

A peculiar bifurcation transition route of thermocapillary convection in rectangular liquid layers

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A peculiar bifurcation transition route of thermocapillary convection in rectangular liquid layers

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Transition routes of thermocapillary convection are complex and diversiform in rectangular layers. In general, three types of transition routes were observed in thermocapillary convection, including quasi-periodic bifurcations, period-doubling bifurcations and tangent bifurcations. The tangent bifurcation is a peculiar type of bifurcations, which often appears accompanied with other types of bifurcation sequences. In our experiments, a detailed research on tangent bifurcations of thermocapillary convection in rectangular liquid layers was conducted through the measurement of single-point temperature oscillation in liquid. There are different tangent bifurcation series for various of experimental conditions, including different Prandtl numbers of silicone oil and different aspect ratios. It has certain occasionality for appearance of the tangent bifurcation, mainly in the experimental condition of Prandtl number of silicone oil equal to 16 (1cSt) or Prandtl number equal to 25 (1.5cSt). Chaotic characteristics of bifurcations are investigated by the method of phase-space reconstruction, maximum Lyapunov exponent and permutation entropy.

thermocapillary convection, temperature oscillation, transition route, tangent bifurcation, chaotic characteristic

1. Introduction

The thermocapillary convection is driven by non-uniformity of surface tension, which comes from non-uniformity of surface temperature [1]. Thermocapillary–buoyancy flow is the main form of natural convection. Transition between the steady and the oscillatory states involves a nonlinear instability process [2]. A bifurcation is a complex structure in the nonlinear system. Deep investigations of this nonlinear phenomenon are of great benefit to understand the nonlinear behavior. In the past few decades, this classic physical phenomenon has attracted many researchers' interest. In general, there are three types of bifurcations in chaotic dynamics: period-doubling bifurcations, quasi-periodic bifurcations and tangent bifurcations. These bifurcations have been found in various convection including Rayleigh-Bénard convection and thermocapillary convection. Gollub and Benson [3] have done the experiment on Rayleigh-Bénard convection and research transition routes from laminar to turbulent flow. They observed four routes to non-periodic motion, including quasi-periodic motion at two frequencies-phase locking or entrainment, period doubling bifurcations of a periodic flow, quasi-periodic motion of three generally incommensurate frequencies, and the process of intermittent non-periodicity by varying the geometrical aspect ratio, Prandtl number, and mean flow. Mukutmoni [4] has reported the numerical study on bifurcation sequences in Rayleigh-Bénard convection. He investigated the counter-intuitive transition route: steady state – periodic – quasi-periodic – steady state. Bucchignani [5, 6] has detected three different bifurcation sequences, but only identified two individual mechanisms for the transition to the non-periodic motion: the subharmonic cascade and the quasi-periodicity with three incommensurate frequencies. Yok-Sheung Li, et al [7] reported the numerical results about the transition to chaos in double-diffusive Marangoni convection in a rectangular cavity with horizontal temperature and concentration gradients. They found that the supercritical solution branch takes a quasi-periodicity and phase locking route to chaos while the subcritical branch follows the Ruelle–Takens–Newhouse scenario. Transient intermittency in the supercritical branch is observed and physical instability mechanisms of the subcritical branch are identified. Jia-Jia Yu, et al [8] reported a counter-intuitive transition route from a perspective of the flow field in the capillary flow. They considered that the reverse transition from the three-dimensional unsteady flow to the steady flow is the reason that the spatial complexity of the flow increases as the thermal Marangoni number increases. Hu, et al [9] have researched the liquid-bridge model of the floating half zone, and reported the experimental and numerical results of the transition process and the period-doubling bifurcation transition route in oscillatory thermocapillary convections. Peng

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