学位論文要約（博士（理学））

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論文題名：Convection dynamics and hydrodynamic instability in complex fluids 複雑流体における対流ダイナミクスおよび流体力学的不安定性（英文）

本文

Macroscopic flow induced by temperature gradient and density difference is one of the phenomena which can be usually observed in natural phenomena and industrial processes. Especially, the non-equilibrium phenomenon accompanied by hydrodynamic instability and thermal convection are related not only to fluid mechanics but also to various fields such as physical oceanography, meteorology, geophysics (mantle dynamics) and astrophysics. In this thesis, we consider the thermal convection and hydrodynamic instability.

Consider that heating the bottom of a fluid column produces a density gradient. Once the fluid's thermal buoyancy overcomes its viscosity, thermal convection will occur. This is specifically called Rayleigh-Bénard convection and dynamical properties of convection have been investigated experimentally and theoretically. Generally, convection is governed by the non dimensional Rayleigh number. The conductive motionless state is unstable and Rayleigh-Bénard convection universally starts when Rayleigh number *Ra* exceeds a critical value, and exhibits a sequence of transitions from steady convection to chaos-turbulence as *Ra* increase. For example, hexagonal pattern formation is observed in the form of roll patterns with a small Rayleigh number.

We experimentally studied convection dynamics near the steady regime in a gelatin solution near a reversible sol-gel transition point where viscosity strongly depends on temperature. Physical gels are regarded as having highly functional properties: they are able to sustain their shape due to elastic polymer chain networks. The polymer network of physical gel bonds via weak interactions such as hydrogen bonding, and the physical gel reversibly transforms from an elastic gel (solid) state to a fluidity sol (liquid) state by changing temperature. Thus, viscosity changes significantly with a small change in temperature. In the Initial stage, a roll convection is observed, however, the roll pattern is not stable over time. A domain without flow (Transient stagnant domain, TSD) is transiently formed in an upwelling near the upper surface and the mode of heat transfer in the fluid changes repeatedly between convection and conduction over time. We observed that this phenomenon occurs repeatedly. Furthermore, we also observed transient stagnant domain in thermally driven convective flow in diluted Golden Syrup, which is not a viscoelastic fluid. Here, Golden Syrup is a simple viscous liquid, while gelatin solution is a complex fluid with viscoelastic properties. This suggests that the origin of the dynamical changes that accompany the transient stagnant domain formation is not the viscoelasticity of liquids. Furthermore, we noticed that working fluids in previous research are two component systems.

It is known that Rayleigh-Bénard convection in a two component fluids is more complex than that in single component fluids. Rayleigh-Bénard convection in two component fluid systems such as salt solution and ethanol-water mixture is called double-diffusive convection. In a binary fluid system, a concentration gradient is induced by the Ludwig-Soret effect in response to an externally imposed temperature gradient. Generally, the density of the mixture depends on the concentration; RBC is thus strongly affected by the concentration gradient. If the denser component moves to the hot boundary by the Ludwig-Soret effect, the concentration gradient becomes stable. Therefore, the critical Rayleigh number is larger than that for a pure fluid system. Meanwhile, when the denser component moves to the cold boundary, this means that the Ludwig-Soret effect enhances the buoyancy forces; the critical Rayleigh number becomes much smaller than that for a pure fluid system. Investigations of convection considering the separation ratio in two component systems include both experimental and theoretical works. The effect of the concentration gradient by the Ludwig-Soret effect is described by a parameter known as the separation ratio. Very little experimental work has been done on the convection dynamics of two component systems with dynamical asymmetry. Therefore, we investigated convective dynamics in two component systems near the critical Rayleigh number using several different fluids. We found that a TSD is formed in mixtures of fluids with a large viscosity difference. However, a TSD is not formed in one component fluids. We also show that TSD formation is not as closely related to the Ludwig-Soret effect as previously believed. We conclude that it is, in fact, the viscosity difference between the two components of the fluid mixture that is crucial for TSD formation. We hope our results stimulate further discussion regarding the physics of convection and non-equilibrium phenomena with dynamical asymmetry.

We also performed research on hydrodynamic instability phenomena. A particular example of this occurs when a heavy fluid lies over a lighter fluid in a constant gravitational field, causing fluctuations at the interface to occur gradually and generating macroscopic flow; this is called a Rayleigh-Taylor instability. The method for creating unstable initial conditions is to employ a partition between the two fluids. These partition removal methods also disturb the fluid interface at the instant the partition is withdrawn due to viscous effect and fluid displacement, and the artificial flow induced by the removal of the partition may dominate the initial growth of the instability. Another method can initiate rotation for an entire experimental system from a stable state, but this is inappropriate for low viscosity fluids. When two liquids are miscible, this experiment is doubly unfeasible, as it is not possible to prepare a stable state to begin with. We propose a new experimental method for preparing a static initial interface despite an unstable state under gravity, which can be used to observe the early stages of an instability using the physical gel. At the beginning of the experiment, the sample is uniformly heated to above the sol-gel transition temperature using a strong light, irradiating the back of the sample cell. The gel in the layer transforms into a sol state, and a Rayleigh-Taylor instability arises. We demonstrate that our method can investigate the effect of different boundary conditions and initial conditions by combining heating via the light and a heat insulating material. Our method enables the realization of static initial condition and arbitrarily complex boundary conditions, the most crucial factors for flow dynamics. We thus hope that our method will be able to realize further experimental research into the fluid instability phenomenon, particularly the fluid dynamics associated with instabilities.

We thus believe that our results and methods stimulate further discussion regarding the fluid instability phenomenon and the physics of convection and open a new avenue in the field of fluid dynamics.