JASMAC

Conference of the Japan Society of Microgravity Appllication

P22

Thermal Marangoni instability in a thin film layer of variable-viscosity fluid under zero gravity field

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The Marangoni flow is a natural phenomenon observed in nature and technology processes[1,2]), which is driven by surface tension gradients along a free surface due to temperature and/or concentration gradients. The ability to control the convective motion by suppressing or promoting it is vital to achieving desired results. The two main driving mechanisms of convective instabilities in a liquid layer are buoyancy forces and surface tension forces. However, in a thin layer of liquid, the surface tension forces are dominant[3,4]). Thermal Marangoni force is the dominant driving force in a reduced gravity environment. The dynamic viscosity in most fluids is generally sensitive to temperature variations[5]), which can also influence the stability of the steady and oscillation convection of the fluids. However, silicone oil has strong viscosity variations, which is usually described by an exponential law. For some liquids, the dynamic viscosity varies linear with the temperature, and viscosity variation plays a more important role in destabilizing the liquid layer since the temperature-dependent viscosity cannot be neglected in thin film applications[6]). The study of the influence of variable-viscosity fluids on convective motions must be important since fluids possess a temperature-dependent viscosity that can influence the heat transport and the spatial structure of the fluid. Convection in fluids with variable viscosity has received considerable attention because of its importance to thin film coating processes.

The role of thermal Marangoni flow in the heat and mass transfer processes with temperature dependence viscosity, and the characteristics of the transition from steady to oscillatory, can be significantly important to understanding these phenomenons for solving thin film application problems. The study of thermal Marangoni flows involves various applications where interfacial flows are encountered, such as in lubricating and coating flows where temperature dependence viscosity is the dominant factor in order to impose uniform thicknesses of liquid layers upon solid substrates. Any small deviation in temperature could lead to the growth of instabilities that could disrupt the entire coating layer[7]). When a temperature gradient is present on the thin film layer, the spreading of liquid films becomes unstable under the thermal Marangoni force. However, variable viscosity fluids are less stable than the constant viscosity fluid. In the thin film problems with variable viscosity, the largest value of viscosity is fixed at the cold wall. Everywhere in the liquid layer, the value of viscosity is smaller. Therefore, higher velocities arise for given thermal Marangoni convection and, therefore, may expect a strong decrease of critical thermal Marangoni number for variable viscosity fluid[8]). The desire to understand the phenomena has led to numerous studies on the fluid layer with temperature-dependent viscosity.

As shown by the above literature survey, there is a lack of previous studies on thin film layers subject to the thermal Marangoni convection of variable viscosity fluid with the aim of examining spreading performance and flow pattern evaluation. Hence, in the present numerical study, we considered the effect of viscosity variation and took into dynamic viscosity as an exponential function of temperature with governing equations of overall conservation of mass, the balance of momentum, and the balance of energy. Furthermore, we will discuss both cases of constant viscosity and variable viscosity at various temperature differences to examine the lubrication performance and flow instabilities.

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