P23

シリコーンオイルの表面張力の温度・電場依存性

Temperature and Electric Field Dependence of Surface Tension of Silicone Oil

○松野千映 [1], 矢野大志 [2], 西野耕一 [3],

○**Chiaki MATSUNO[1], Taishi YANO[2] and Koichi NISHINO[3]**

1 横浜国立大学大学院理工学府，Engineering Science, Yokohama National Univ.
2 神奈川大学工学部，Engineering, Kanagawa Univ.
3 横浜国立大学大学院工学研究院，Faculty of Engineering, Yokohama National Univ.

1. Introduction

Surface tension driven convection is a flow caused by the surface tension difference due to gradients of temperature, concentration and electric field along the free liquid surface. Thermocapillary flows caused by temperature gradient and solutocapillary flows caused by concentration gradient haves been studied under various conditions whereas electrocapillary flows caused by the gradient of electric field remain unclarified. The effect of electric field on thermocapillary flow was studied previously [1,2] with a view to developing techniques for controlling thermocapillary convection. Those previous studies used silicone oils, as working fluids and the surface tension effect was expressed as a body force term acting on a very thin layer on the surface of liquid in numerical analysis [3].

The present study focuses on the effect of temperature and the electric field on the surface tension of silicone oil. A series of surface tension is analyzed and expressed as a function of temperature and electric field so that the expression can be incorporated into the numerical analyses of thermocapillary convection controlled by the applied electric field.

2. Experiment

Surface tension of silicone oil is measured by the surface tensiometer while changing temperature on the surface and magnitude of applied voltage at the same time. **Fig.1** shows the schematics of the experimental equipment. The surface tensiometer based on the Wilhelmy method for the static surface tension is used where, the width w and thickness t of the platinum plate are w = 24.0 mm and t = 0.20 mm, respectively. The upper electrode has a thin slit for plate insertion into the liquid. The test fluid is 5 cSt silicone oil (KF-96L-5cs) with dielectric constant $\varepsilon_s = 2.60\varepsilon_0\{1 - \alpha(T - T_0)\}$, where ε_0 is the permittivity of vacuum, $\alpha = 2.86 \times 10^{-3}$ 1/K and $T_0 = 25\,C°$. The silicone oil is kept in a cylindrical container of diameter D = 40 mm and depth d_s = 3.0 mm. The distance between upper and lower electrodes is changed as d_0 = 7.8, 8.6, 12.8 mm. Voltage is applied in the range of 0 V to 600 V in increments of 50 V.
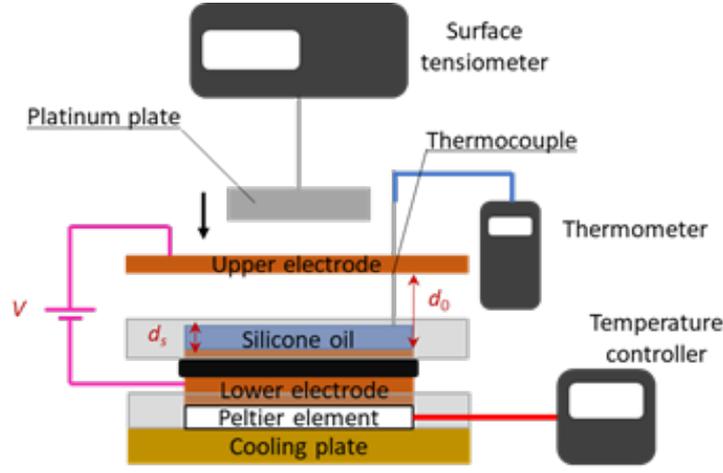
Fig.1 The schematics of the experimental equipment.

3. Result and discussion

The measured surface tension deceases linearly with temperature of free surface T and decreases quadratically with applied voltage V. The temperature coefficient of surface tension σ_T obtained from measured surface tension $\sigma_{obs.}$ is $\sigma_T = -8.28 \times 10^{-2} \pm 0.115 \times 10^{-2}$ mN/m regardless of the applied voltage. Therefore, it can be assumed that the effects of the temperature and of the applied voltage on surface tension are independent with each other. The decrease of the surface tension due to applied voltage depends not only on V but also on the distance between the electrodes d_0. The result suggests that the decrease in surface tension due to applied voltage is caused by the action of electric charge at the gas-liquid interface. From the model of gas phase and liquid phase between parallel plate electrodes, the electric surface charge density ρ_e at the gas-liquid interface is expressed follows

$$\rho_e = D\varepsilon_0\left(\frac{1}{\varepsilon_s} - \frac{1}{\varepsilon_a}\right) = \varepsilon_0\left(E_s - E_a\right) = \varepsilon_0 \frac{\varepsilon_a - \varepsilon_s}{\varepsilon_a d_s + \varepsilon_s d_a}V \tag{1}$$

Here ε is the permittivity, E is the electric field, D is the electric flux density, d is the phase thickness, and subscripts a and s refer to air and silicone oil, respectively.

The force per unit area at the gas-liquid interface is calculated by Maxwell stress[4], so that the force per unit length of the contact line with the platinum plate becomes

$$f_e = \frac{1}{2}\left(\varepsilon_a E_a^2 - \varepsilon_s E_s^2\right)\bar{l} = -\frac{1}{2}\frac{\bar{l}}{\varepsilon_0}\frac{\varepsilon_a \varepsilon_s}{\varepsilon_a d_s + \varepsilon_s d_a}\rho_e V = -\frac{1}{2}\frac{\varepsilon_a \varepsilon_s\left(\varepsilon_a - \varepsilon_s\right)}{\left(\varepsilon_a d_s + \varepsilon_s d_a\right)^2}\bar{l}V^2 \tag{2}$$

Here $\bar{l}$ is average length from the platinum plate to the wall of the liquid container (**Fig.2**).

When the constant term of surface tension is σ_0, the surface tension is expressed as below.

$$\sigma_{calc.} = \sigma_0 + \sigma_T T - f_e \tag{3}$$

Fig.3 shows the comparison between $\sigma_{obs.}$ and $\sigma_{calc.}$. The plotted data follow, in a good approximation, a straight line where $\sigma_{obs.}$ and $\sigma_{calc.}$ are equal. This result suggest that the Maxwell stress is the cause of change in surface tension under the applied electric field. The reason why $\sigma_{calc.}$ becomes slightly larger than $\sigma_{obs.}$ as V becomes larger could be that the nonuniformity of electric field strength due to the slit of the upper electrode is ignored in the present modelling.
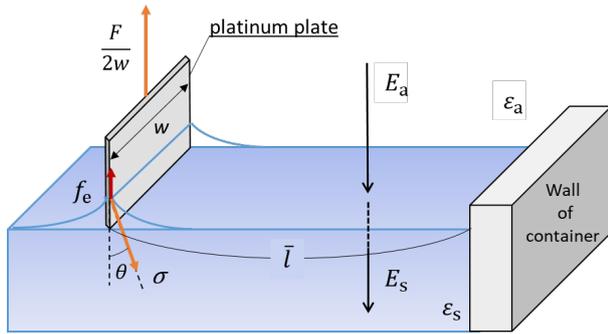
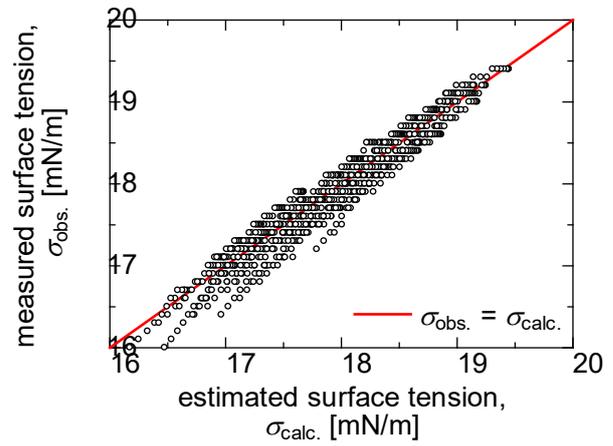**Fig.2** The force per unit length of the contact line with the platinum plate.

Fig.3 The comparison between measured surface tension $\sigma_{obs.}$ and estimated surface tension $\sigma_{calc.}$.

4. Future research plan

As a future research plan, numerical analyses of thermocapillary flow considering the effect of electric field will be conducted. The changes in thermocapillary flow will be investigated when the surface tension effect obtained from the Maxwell stress gradient at the gas-liquid interface and the electric force per unit volume acting on the liquid are applied.

References

1) M. Haga, T. Maekawa, K. Kuwahara, A. Ohara, K. Kawasaki, T. Harada, S. Yoda and T. Nakamura: J. Jpn. Soc. Microgravity Appl., **12**,1(1995), 19-26.

2) K. Casson and D. Johnson: Physics of Fluids, **14,**8 (2002), 2935-2938.

3) S. Tiwari and K. Nishino: Journal of Crystal Growth, **300** (2007), 486-496.

4) T. B. Jones: Langmuir, **18**,11(2002), 4437-4443.