INTERFACIAL CONTAMINATION CAUSED BY WATER ON MARANGONI CONVECTION IN A SILICONE OIL LIQUID BRIDGE

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Introduction

Marangoni convection in a Floating Zone has received much attention as one of basic problems in both fluid science and material science, especially under microgravity condition. To study the convective phenomena inside the Floating Zone, silicone oil is widely used for the model liquid according to the general understanding that silicone oil is transparent and resists interfacial contamination, and that its physical properties are well known. The authors have carried out an experimental study using dimethyl silicone oil for observing the flow field[2-4], and methyl-phenyl silicone oil for observing the temperature field with thermal sensitive liquid crystals[2, 3]. In the case of methyl-phenyl silicone oil, interfacial contamination caused by water in the silicone oil itself and also by water vapor in surrounding gas was found. This paper concerns the interfacial contamination caused by water on Marangoni convection driven by the interfacial tension gradient due to a temperature difference on the free interface of the silicone oil liquid bridge, and the effect of water contained in both silicone oil and surrounding gas on Marangoni convection.

1. Experiment

Figure 1 shows the final experimental setup for the observation of Marangoni convection in a liquid bridge. The liquid bridge was suspended between two coaxial aluminum disks of 15 mm diameter. The liquid bridge was 4 mm long. To attain steady state under the Marangoni convection dominant regime, the temperature difference was applied under top heating and bottom cooling conditions. Two types of silicone oil (dimethyl silicone oil (KF-96; 20 cSt) and methyl-phenyl silicone oil (KF-56; 15 cSt), supplied by Shin-etsu Chemical Co.Ltd.) were used as the model liquid. The chemical structure and physical properties of the silicone oils are shown in **Fig. 2** and **Table 1**. Spherical aluminum particles of diameter 30 μm were used as the tracer to observe the velocity field. In the early experiments, non-dehydrated silicone oil was used in surrounding air. After our finding the interfacial contamination caused by water, the following dehydration was applied. 20 vol% Molecular sieve (type 4A, manufactured by Union Showa Co. Ltd.), used as the adsorbent of water, was put into a silicone oil. Commercially available silicone oil contains 100-200 ppm of water. The 20 vol% molecular sieve is more than 100 times the theoretically required amount for the dehydration. For the surrounding gas, dry-air or dry-N_2 was used. To avoid the shear stress of gas flow, the liquid bridge was shielded by with two enclosures. The dew point of surrounding gas was measured at the exit. Under several dehydration conditions, Marangoni convection was observed using the light sheet method.

2. Results and Discussion

Figure 3 shows the schematic diagram of interfacial contamination phenomena on Marangoni convection in a silicone oil liquid bridge. In the case of methyl-phenyl silicone oil (KF-56) without any dehydration, the

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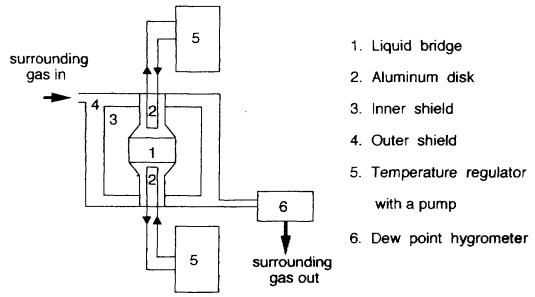
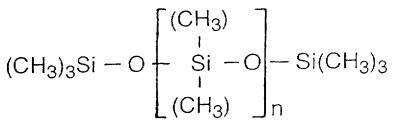
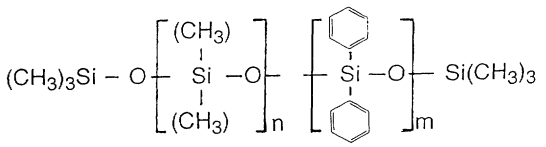


Fig. 1 Experimental set up



(a) dimethyl silicone oil (KF-96)



(b) methyl-phenyl silicone oil (KF-56)

Fig. 2 Chemical structure of silicone oil

Table 1. Physical properties of silicone oil at 25°C

			KF-96: 20 cSt	KF-56: 15 cSt
ρ	density	[kg/m^3]	9.50×10^2	9.88×10^2
μ	viscosity	[kg/m/s]	1.90×10^{-2}	1.47×10^{-2}
ν	kinematic viscosity	[m^2/s]	2.00×10^{-5}	1.49×10^{-5}
$\partial\sigma / \partial T$	temperature dependence of interfacial tension	[N/m/°C]	7.28×10^{-5}	7.02×10^{-5}
Pr	Prandtl number	[-]	2.18×10^2	2.11×10^2

stagnant region was observed near the cold disk. In addition, the interfacial velocity obtained in a humid day was less than that in a dry day, even under the same experimental conditions. It could be pointed out from the observation that Marangoni convection was suppressed by interfacial contamination caused by water in a surrounding gas. **Figure 4** shows the length of a mobile interface which means a clean interface at each dehydration condition. As the amount of water contained in both silicone oil and surrounding gas decreased, the clean interface length increased. As the temperature difference between both disks increased, the clean interface length rapidly increased. **Figure 5** shows the experimental results for the interfacial velocity at the center of the clean interface. In the case of methyl-phenyl silicone oil (KF-56), Marangoni convection was significantly affected by the dehydration conditions. In the case of non-dehydrated methyl-phenyl silicone oil, and dehydrated oil with humid gas, the interfacial velocity was suddenly suppressed at a particular temperature differ-

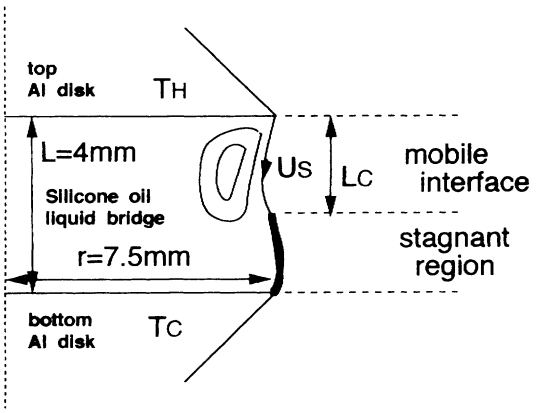


Fig. 3 Schematic diagram of interfacial contamination phenomena on Marangoni convection

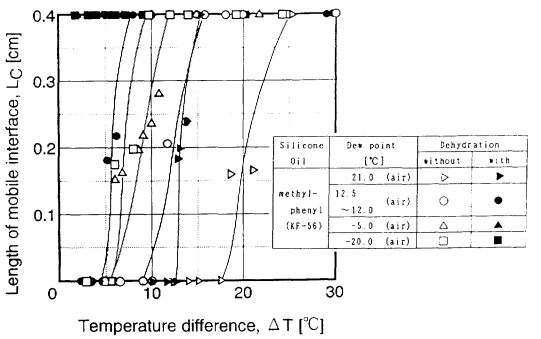


Fig. 4 Length of mobile interface

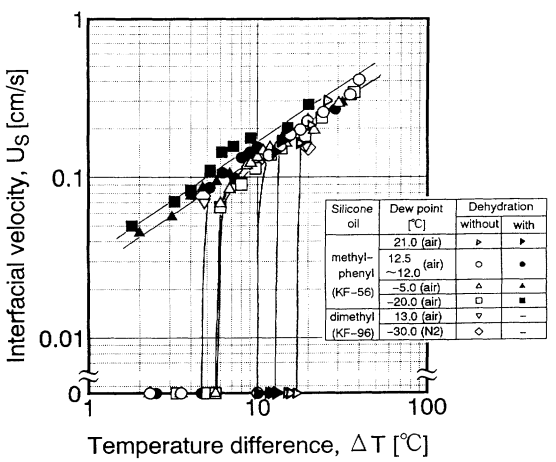


Fig. 5 Relation between temperature difference and interfacial velocity at the center of clean interface

ence. This is defined here as the critical temperature difference. When temperature difference was higher than the critical temperature difference, the interfacial velocity increased with increasing the temperature difference. In the case of dehydrated methyl-phenyl silicone oil with driest gas, the highest interfacial velocity was induced. The interfacial velocity was proportional to the 2/3 power of the temperature difference, in good agreement with our theoretical results for the Marangoni convection dominant regime with a high Prandtl number under boundary layer flow condition[4], as well as our numerical results by a finite element method[5]. **Figure 6**

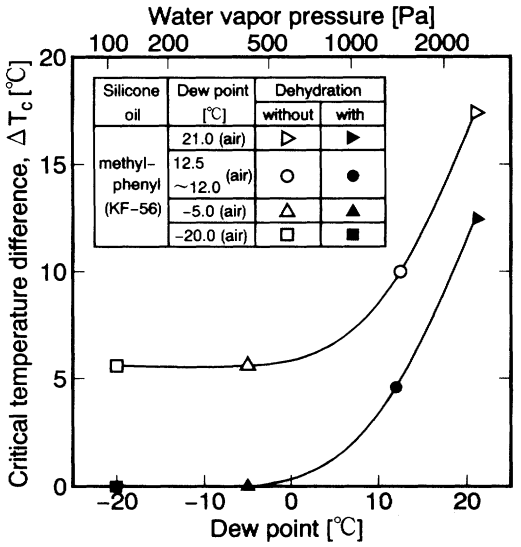


Fig. 6 Effect of dew point on critical temperature difference

shows the effect of dew point or water vapor pressure of surrounding gas on the critical temperature difference. The critical temperature difference in non-dehydrated methyl-phenyl silicone oil is higher than that in the dehydrated oil because of interfacial contamination caused by the water contained in silicone oil itself. Above the dew point –5.0°C, the critical temperature difference increased with increasing water content in the surrounding gas because of the interfacial contamination. From Figs. 4-6, methyl-phenyl silicone oil (KF-56) is very sensitive to water contained in both silicone oil and surrounding gas. To study the Marangoni convection in methyl-phenyl silicone oil (KF-56), it is necessary to pay much attention to the dehydration conditions, and to keep the dew point below –5.0°C with dehydration of the silicone oil. The detailed mechanism of this interfacial contamination caused by water is not yet clear. The great sensitivity to water in methyl-phenyl silicone oil might be related to the high solubility of water. In the case of carbon hydrate, as the number of double bonds increases, the solubility of Water increases[1]. Since methyl-phenyl silicone oil has a number of double bonds, methyl-phenyl silicone oil seems to dissolve more water than does dimethyl silicone oil.

Conclusion

It was found that Marangoni convection in methyl-phenyl silicone oil (KF-56) was suppressed by interfacial contamination caused by water contained in both silicone oil and surrounding gas. Methyl-phenyl silicone oil is so sensitive to water that it is necessary to pay much attention to the dehydration condition of both silicone oil and surrounding gas.

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Nomenclature

L	=	height of liquid bridge	[m]
L_c	=	length of mobile interface	[m]
P_r	=	Prandtl number	[-]
r	=	radius of aluminum disk	[m]
ΔT	=	temperature difference	[°C]
ΔT_c	=	critical temperature difference	[°C]
u_s	=	interfacial velocity at center of clean surface	[m/s]
μ	=	viscosity	[kg/m/s]
ν	=	kinematic viscosity	[m^2/s]
ρ	=	density	[kg/m^3]
σ	=	interfacial tension	[N/m]

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