FLOW OBSERVATION IN TWO IMMISCIBLE LIQUID LAYERS SUBJECT TO A HOTIZONTAL TEMPERATURE GRADIENT

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Marangoni convection, driven by interfacial instability due to a surface tension gradient, has become a large problem in crystal growth on earth or in a micro gravity environment. Suppression and control of the convection phenomenon is important for the material processing. Especially in the crystal growth by LCZ or EFZ technique, wherein the melt is encapsulated with an immiscible medium, Marangoni convection could occur on the liquid-liquid interface. In the present paper, experiments were carried out with two immiscible liquid layers. Flow in a cavity subjected to a horizontal temperature gradient was visualized by applying PIV. The influence of geometrical factors on the flow was investigated.

INTRODUCTION

Because of the capability of crucibleless handling of melts, the floating zone technique is preferred for the growing of crystals. However, the FZ technique has some difficulties caused by hydrostatic forces on the diameter of the crystals, by vaporization loss at the free surface and by Marangoni convection. The restriction with size can be avoided in a micro gravity environment. A larger floating zone can be formed and there is no buoyancy driven convection, which affects much a quality of grown crystal and a size of floating zone. However, the surface tension driven Marangoni convection and volatilization are still be problems.

Marangoni convection often dominates convective motion in microgravity conditions. To control Marangoni convection, a liquid layer as an encapsulant, which has a free surface, can be put on melts. The liquid encapsulation techniques offer the possibility of overcoming above problems. The driving force, the interface tension gradient, is caused by either temperature or concentration distribution on the surface and the interface. Flow in melts can be suppressed or enhanced by choosing a liquid encapsulant with suitable physicochemical properties. Even on the earth, the liquid encapsulation technique may have a possibility of suppression and control of the convective flow in melts without the vaporization loss. The behavior of thermocapillary convection in a double-layer system[1-2] is generally much more complicated than in a single-layer system, due to a strong interaction between the motions in two contiguous layers.

In the present paper, we made experiments in a simple system with double liquid layers. To understand a convective flow in two immiscible liquid layers is very important for the liquid encapsulation techniques (EFZ, LEMZ, LEC) of the crystal growth on the ground and/or in microgravity environment. Therefore, we observed the flow behavior and investigated the combined effects of thermocapillary and buoyancy forces on flow in single and double layer systems, with changing geometrical parameters. More detailed observation was made on flow in the upside layer, which was more complicated and highly affected by experimental conditions.

EXPERIMENTS & RESULTS

Figure 1 shows our experimental apparatus, a cavity of 30 mm by 130 mm. A heater and a cooler, controlled at Th degrees and at Tc degrees, respectively, were set in a cavity at intervals of a certain distance, L. Two immiscible and incompressible viscous liquids were filled in the cavity. Natural convection flow inside the cavity was visualized by using PIV. Experimental conditions were summarized in Table 1. Temperature of the cooler, Tc, was almost fixed at 23.4 degrees and temperature of heater was varied from about 25 to about 34 degrees in each case. The vertical cross-section of the system was illuminated by a laser light sheet (Nd-YAG). A high-resolution CCD camera (1000x1000) was used to capture images of tracer particles in a flow. The velocity field was calculated by a cross-correlation method.

Effect of existence of an upper liquid layer

Effect of existence of an upper liquid layer was investigated in cases A and B at $\Delta T/L = 2.7\sim2.9$ degrees/cm. When there is no liquid layer of encapsulant (case B), the flow velocity, especially near the interface, is generally larger than in case A. A stagnant flow region, where no vector was drawn, was larger in lower layer in case A. It seemed that Marangoni convection at the liquid-liquid interface seemed to be suppressed. In case with the upper layer, flow velocity in upper layer with free surface was much higher than that in lower layer. The velocity was largest near the free surface and near the hot wall, while there is a stagnant flow region near the corner spot between the liquid-liquid interface and the hot wall. Flow in upper layer must affect flow in lower layer and the interface. Therefore, after here, we direct our attraction especially to the flow in the upper layer.

Effect of the temperature gradient

Figure 2 shows the velocity field only in the upper layer in case D with varying the temperature gradient between interfaces, Th=25.8~31.5, $\Delta T/L = 1.2\sim4.1$ degrees/cm. The vector represents a measured velocity at each point. The velocity was always largest near the free surface. Convection flow became strong with increasing the temperature gradient. Flow direction in downside area was much affected by the temperature gradient. With increasing $\Delta T/L$, the leftward flow directed upward and separated. The small clockwise vortex was appeared near the corner spot between the liquid-liquid interface and the hot wall. Though it was too difficult to measure the velocity due to the reflection, flow at the liquid-liquid interface directed rightward and the flow just above interface seemed to form counterclockwise separation vortices.

Effect of the distance between side walls

In order to investigate an effect of the different aspect ratio of liquid layer, only the distance between walls was varied, while $\Delta T/L$ and H1 were kept constant (Ma number and Ra number were constant). In this case, the velocity near the free surface and the flow pattern of the dominant circulating flow (large clockwise vortex flow) were not so affected by L. However, only in case of L=30 mm, the small vortex was observed near left bottom corner. It was thought to be caused by the difference of interaction among convection driven by the surface tension gradient at free surface, convection driven at interface and buoyancy-driven convection, i.e., the dominant circulating clockwise flow, the small but steep counterclockwise separation vortex flow above the liquid-liquid interface, and the buoyancy driven flow upward near the hot wall. It might be a kind of scale effect with a stagnant region near the corner.

CONCLUSIONS

The flow in two immiscible liquid layers was observed with changing geometrical parameters. With the liquid layer as an encapsulant, flow in the lower layer was suppressed. The velocity field in upper layer, which could affect the flow in lower layer, was measured by applying PIV technique.

REFERENCES

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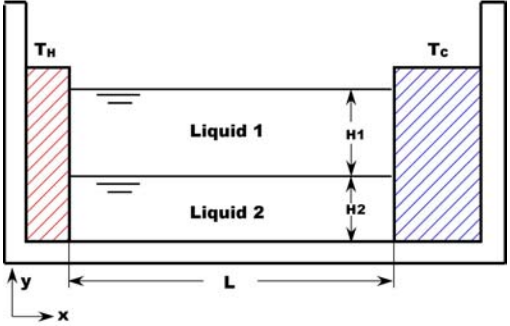
Table 1 Experimental conditions

case	H1 (mm)	H2 (mm)	L (mm)
A	10	10	20
B	0	10	20
C	5	10	20
D	15	10	20
E	10	10	10
F	10	10	30

Fig.1 Schematics of the experimental apparatus



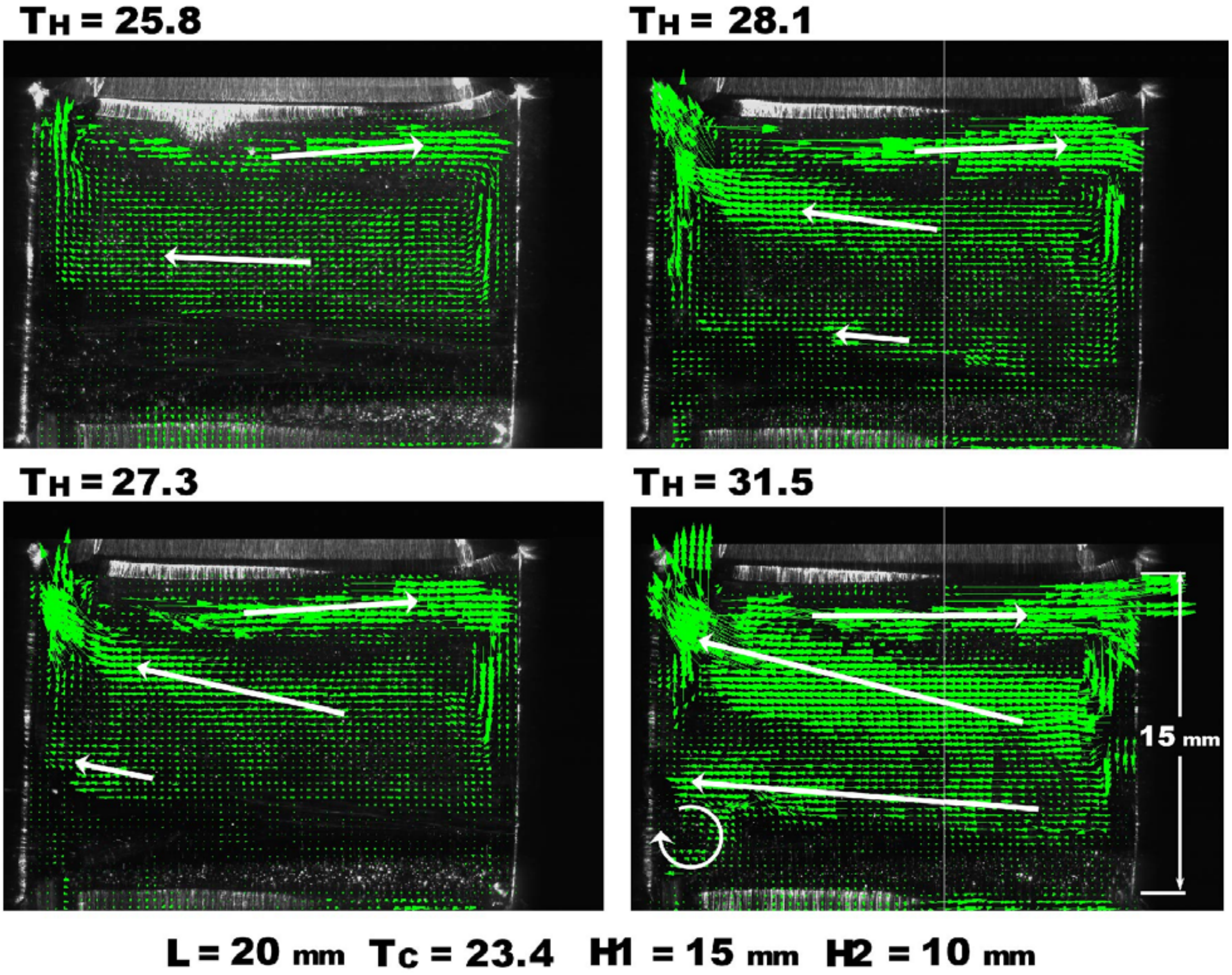


Fig. 2 Visualized flow patterns in Silicone oil layer with varying temperature, Th.