Interferometric Observation of Phase-Change Phenomena Under Reduced Gravity

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Introduction

AN experimental setup for visualizing the behavior of liquid in phase-change processes under reduced gravity was developed and boarded on KC-135. A Jamin interferometer with a small number of optical components was used as a means of observing temperature distribution in the liquid. The phase change of succinonitrile from liquid to solid and that of Freon-11 from liquid to vapor were observed in an experimental cell. In this Note, the results obtained under a reduced-gravity condition are described, and the effects of reduced gravity on phase change are discussed.

Experimental Setup

The experimental cell was composed of an upper block and a lower block, both made of copper, and an observing window made of quartz glass. A bellows was installed on the top of the upper block to absorb volume change during phase change. A sheet heater was attached to the upper block so as to control the temperature of the block. A Peltier cooler was installed between the lower block and the support of the cell to control the temperature of the lower block. In the case in which the Peltier cooler was operated in the normal mode, heat was removed from the block. On the other hand, when it was operated in the reversed mode, in which the current was supplied in the opposite direction, heat was supplied to the block. Chromel-alumel thermocouples were inserted into the blocks to control the temperature. The observing window was assembled between the two blocks, and the sample was placed in the enclosure. The inner dimensions were 10 mm in height, 5 mm in the direction longitudinal to the laser beam, and 8 mm in the horizontal direction.

Figure 1a shows the principle of the Jamin interferometer used for noncontact measurement. He-Ne laser light was expanded to a parallel beam with a diameter of 6 mm. The beam was split into a probe beam and a reference beam by the first prism and recombined by the second prism. The probe beam passed through the experimental cell and the reference beam the uniform field. The optical path length of the probe beam was changed by the refractive index of the sample[1,2] contained in the experimental cell. The fringe pattern was formed by the interference of the two beams. As a result, two-dimensional information on the distribution of the refractive index in the sample was obtained.

Although the Jamin interferometer provided the interferometric null, a couple of fringes existed when the experimental cell was kept in an isothermal state, as shown in Fig. 1b. Hence, the finite fringe method was used, and the obtained pattern needed to be corrected to determine the temperature distribution. But this condition provided the information on the reversal of the temperature profile by the bent of the fringes.

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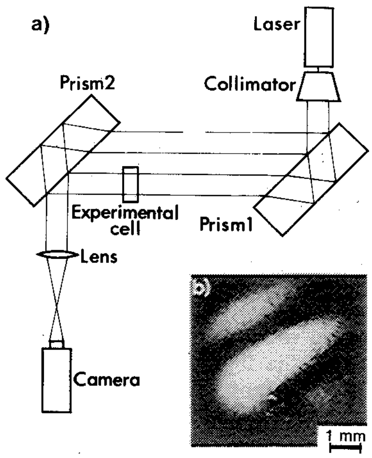

Fig. 1 Jamin interferometer and its initial fringe.

Result and Discussion

Solidification Experiment on Succinonitrile

We distilled purchased succinonitrile with a purity of 98% beforehand. The sample was melted and kept at 60°C, just above the melting point, by means of the heater and the Peltier cooler. When the reduced-gravity period started, solidification was initiated by cooling the lower block with a constant power of 5 W, which produced a stable system with negative density gradient (lower density in higher position) where the buoyancy convection did not occur. Under the reduced-gravity condition, it took 15.3 s to initiate solidification from the start of cooling. By contrast, it took 11.9 s on the ground. As a result, more supercooling and a wider supercooled region, which could be seen in a greater number of fringes in the adjacent region of the lower block under reduced gravity (Fig. 2a), was formed before the nucleation in reduced gravity. By analyzing the interference fringes, we found that the temperature of the liquid at the bottom was 2°C lower than that in normal gravity at the initiation of solidification. The lower heat-transfer rate and the lower heterogeneous nucleation rate seemed to be the main reasons.

At the beginning of the solidification process, the solid-liquid interface advanced quickly[3] in both cases of reduced- and normal-gravity conditions. Latent heat was released at a rapid rate, but it was absorbed by the supercooled region. As the interface advanced with the release of the latent heat, a layer with a reversed temperature gradient appeared, as shown in Figs. 2b and 2b′. The region below the bent of fringes corresponded to this reversed layer, where discharged heat accumulated. The temperature gradient of this reversed layer was steeper in the case of Fig. 2c′ than in the case of Fig. 2c.

The advancing velocity of the interface became very small after the phase shown in Figs. 2c and 2c′. Especially in the case under reduced gravity, the interface was almost stopped or further remelted although the recession was insignificant. This was due to the existence of the reversed layer. The advancing velocity was larger at first, then smaller in reduced gravity than in normal gravity. The reason was a lower rate of heat removal from the layer to the upper region of liquid by the smaller buoyancy force.

Heating Experiment of Freon-11

The upper block was kept at 20°C and the lower one at 15°C by the Peltier cooler. When the reduced-gravity period started, a sequencer turned the switch to heat the lower block with 7.6 W. Periodic flow was induced on the ground. By con-

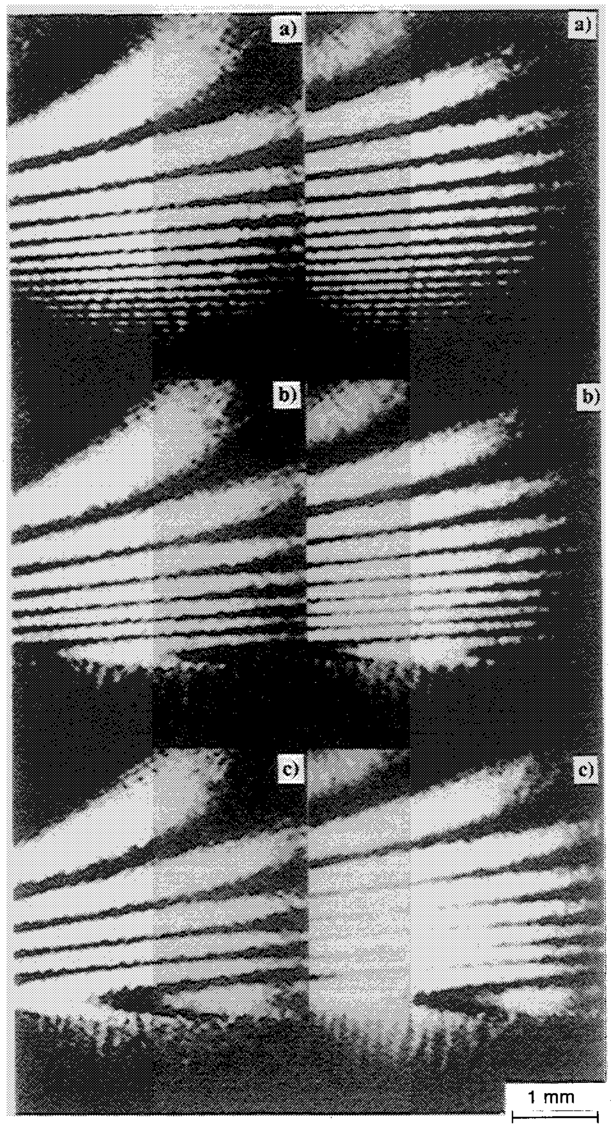

Fig. 2 Time-dependent change of interferograms in the solidification process of succinonitrile: a) 0 ms: one frame (1/60 s) before the emergence of solid; b) 100 ms; and c) 200 ms.

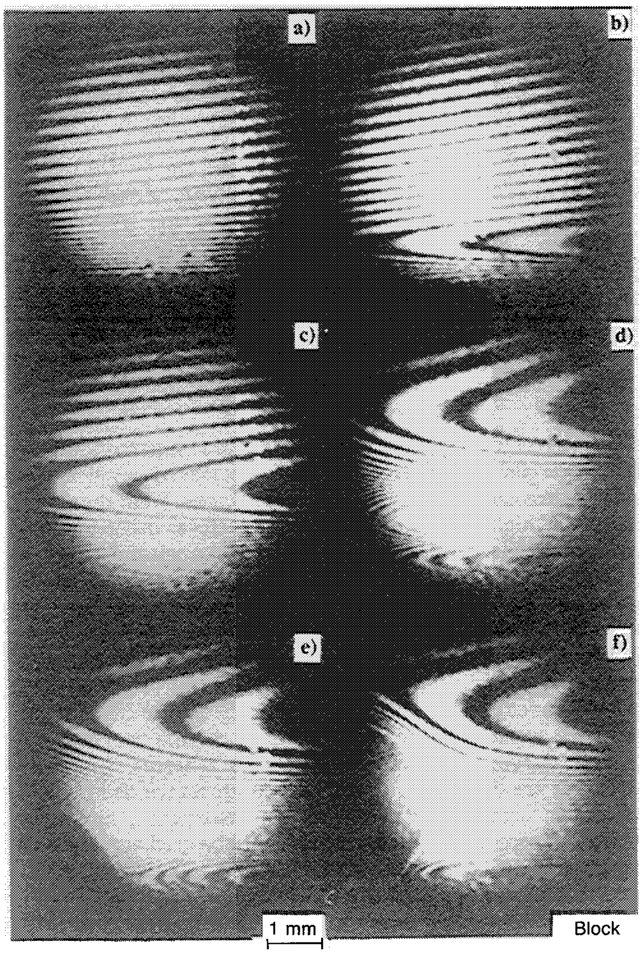

Fig. 3 Time-dependent change of interferograms in heating of Freon-11 under reduced-gravity condition: a) 0 s: start of heating; b) 2 s; c) 6 s; d) 13.2 s: one frame before the emergence of bubble; e) emergence; and f) 1/60 s after the emergence.

trast, the interferometric patterns shown in Figs. 3b–3d in reduced gravity were not disturbed.

At the onset of heating, the fringe pattern was almost in parallel, as shown in Fig. 3a. In this case, the temperature gradient produced a stable system with negative density gradient (lower density in higher position), and no convective flow took place even on the ground. After 2 s elapsed, temperature distribution changed, as shown in Fig. 3b. The bent of fringes at the lower part, corresponding to the point of inflection of the temperature profile, showed the boundary of a stable temperature-stratified layer and an unstable one. The layer below the bent had a positive density gradient and buoyancy force could be induced, even in this reduced-gravity condition. However, the characteristic thickness of this layer was less than 1 mm, and no convective flow was observed.

As the heating process continued further, the position of the bent elevated, as shown in Figs. 3c and 3d. This bent fringe pattern in the unstable stratified layer corresponded to the laminar type of convective flow. However, it should be noted that under this reduced-gravity condition, the buoyancy force in this layer was not strong enough to break into the periodic flow prevailing throughout the experimental cell.

Although convective flow was induced in the temperature-stratified layer even under the reduced-gravity condition, heat transfer from the stratified layer to the upper region was smaller than that in the ground-based experiment because of the lack of the periodic flow which occurred on the ground. Heat, as a result, accumulated in this stratified layer. In all of the cases of the ground-based experiment and the cases with heating powers of 2.3 W and 4.8 W in reduced gravity, no bubbles appeared. However, as shown in Figs. 3e and 3f, a bubble was formed in the case with the heating power of 7.6 W in reduced gravity.[4] The bubble rose due to the buoyancy in this gravity level of 0.03 g. It was found that a better microgravity condition was needed for observation of the nucleation and growth of bubbles.

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