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The Capillary Flow and Reorientation of Liquid-Gas Surface in Interior Corner under Microgravity

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Abstract

In this study, we try to investigate the capillary flow in interior corner under microgravity condition in drop tower experiments. Especially, the effect of liquid volume on the capillary flow in the container of same size is discussed. The experiments show that the reorientation of the liquid–gas surface is different for the different liquid volumes. The influence of viscosity is also studied. The experimental results show that the climbing speed is larger when the volume is larger. By measuring the angles of contact line with the edge of the container, the time range that tip location is linear with time can be determined properly. For 0.5ml and 0.12ml silicone oil, the tip location is linear with time in the final stage of the microgravity condition in drop tower experiments, and the larger viscosity will make the climbing speed smaller.

1. Introduction

The design of fluids management processes in the low-gravity environment of space requires an accurate model and description of capillary-driven flow in containers of irregular geometry. Therefore, the capillary flow and the redistribution of the fluid along an interior corner of a container have been widely discussed.

To study the capillary flow in the interior corner, the meniscus tip location L (the height of the tip from the initial tip location) versus time t is usually measured from experiments. Theoretically there are several regimes for the capillary flow[1-3]. In each regime, the flow is dominated by the capillary driving forces exceeding a certain force working against them. In the first regime, the flow is dominated by the inertia force of the initially accelerated liquid mass and $L \sim t^2$. In the second regime, it is controlled by the convective pressure loss against the capillary forces and $L \sim t$. The final regime of the capillary flow is so-called Lucas-Washburn regime with $L \sim t^{1/2}$, which is controlled by friction. Weislogel and Lichter[4] pointed out that even in the Lucas-Washburn regime, there is a third regime that the flow was observed as a constant flow with $L \sim t^{3/5}$ before the regime $L \sim t^{1/2}$.

In this study, we try to investigate the capillary flow in interior corner under microgravity condition in drop tower experiments. The influence of viscosity and the volume of liquid in container are discussed. The results show that the reorientation of the liquid–gas surface is different for the different liquid volumes.

2. Experiments

In the experiment, the container is made of PMMA [poly (methyl methacrylate)] with right-angled triangle cross section. The size of the cross section is about 33 mm * 12 mm * 35 mm, which forms three interior corners of 90, 70 and 20 degree. For this kind of container, the capillary flow with different angle of the interior corner can be observed simultaneously so as to decrease the times needed for the drop tower experiments.

The sketch-map of the instrument is shown in **Fig. 1**. One CCD camera (WAT-660D, Watec Co., Ltd.) at 25 frames per second is used to image the flow of the liquid on the right-angle side. A light source and a white screen are used to give appropriate light for the image of the liquid in container. An indicator light for microgravity is placed in an appropriate position that is viewable by CCD and does not influence the image of the flow in the container. From **Fig. 2** we can see a ruler beside the container, which is used to determine the height of the tip of the flow.

The solvent in the container is the silicone oil. In the experiments, both KF96-5 and KF96-50 silicone oil are used for the difference of the viscosity. As all the three interior corners of the container fit the Concus-Finn condition so that the liquid will flow in the three corners in microgravity condition. The drop

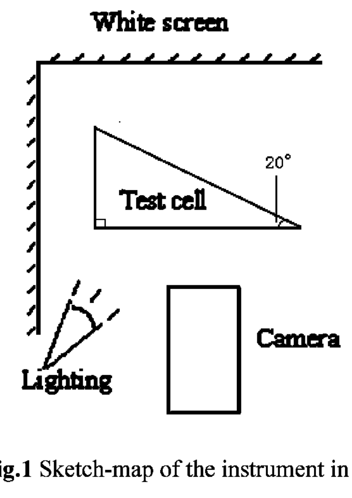

Fig.1 Sketch-map of the instrument in drop tower

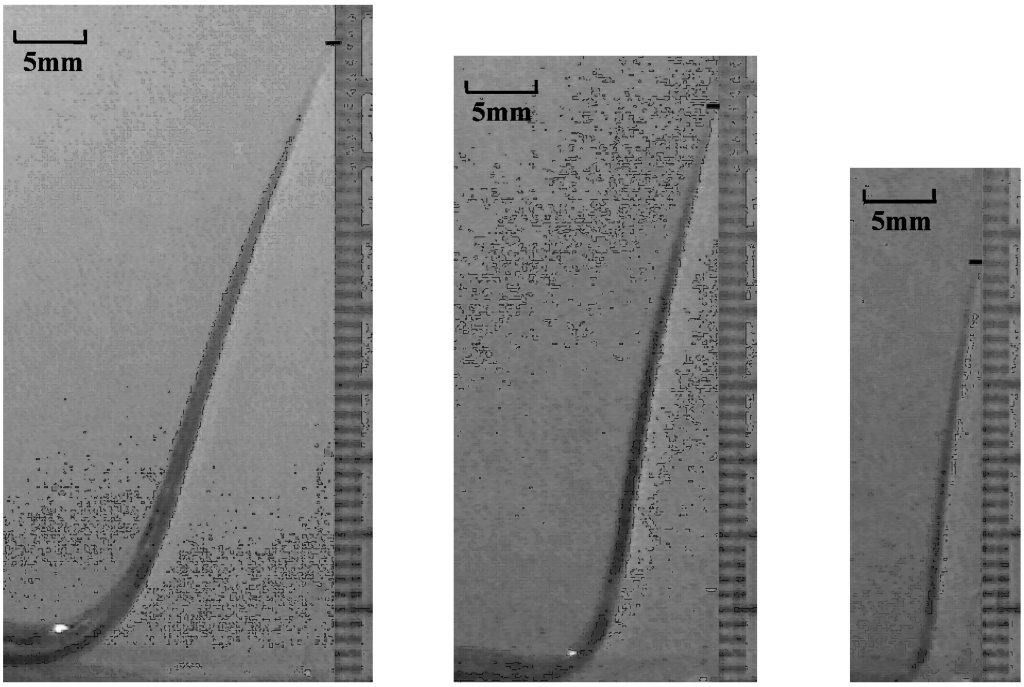

Fig. 2 Typical images of the flow of the liquid in experiments. The microgravity times are all 0.75 s. (a) 1.2 ml (b) 0.5 ml (c) 0.12 ml. "-"denotes the tip position of the contact line in the flow process.

tower experiments are performed in a dual-drop capsule system, which can give the gravity condition that $g=10^{-5}g_0$.

3. Results and discussion

In this study, we pay attention to the capillary flow on the corner of 20°, because the flow speed rate is the fastest among the different corners. The typical configurations of the liquid on the corner are given in Fig.2, which shows that the configurations of the liquid are quite different for different volumes of the liquid in the same container, even the microgravity time is the same. The angle of the contact line with the edge φ (the right side of each figure in Fig.2) is related to the dynamic contact angle. By geometrical analysis, it can be easily found that the advancing contact angle increases with the increase of the angle φ. Therefore, Fig.2 shows that the advancing contact angle is larger for larger liquid volumes, which also indicates that the speed rate of the tip location of liquid along the wall is larger.

Figure 3 shows part of the liquid-gas surface for

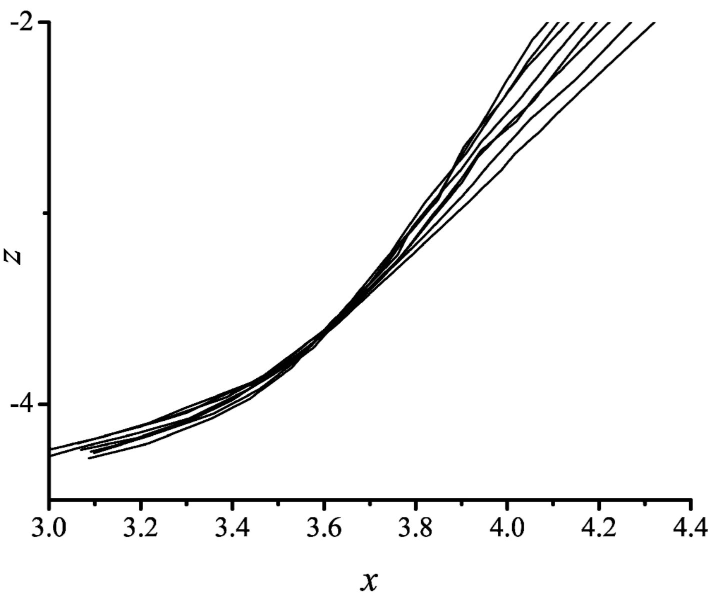

Fig. 3 The surface configuration for 1.2 ml volume of liquid for different microgravity time between 1.4 s to 1.68 s. The coordinates x and z are in cm, with an arbitrary origin.

1.2 ml volume of liquid from microgravity time 1.4 s to 1.68 s. It can be seen from Fig.3 that there is a point on all the surfaces for different microgravity time 1.4 s to 1.68 s, and this position is the constant height position described by Weislogel and Lichter[4]. However, for 0.12 ml and 0.5 ml volume, we haven't found obvious constant height position for the liquid-gas surface. This result shows that the reorientation of the liquid-gas surface under microgravity condition are different for 1.2 ml volume liquid and <0.5 ml volume liquid. From the experiments, we can see that the liquid almost get to the three corners thoroughly and almost no liquid remains on the bottom soon after the microgravity condition for <0.5 ml volume liquid, while for 1.2 ml liquid, there is liquid on the bottom for rather a long time. Therefore, the flows for <0.5 ml liquid on the corner of 20° is more like the spread of a constant droplet, which makes the difference of the flow for <0.5 ml and 1.2ml liquid volumes.

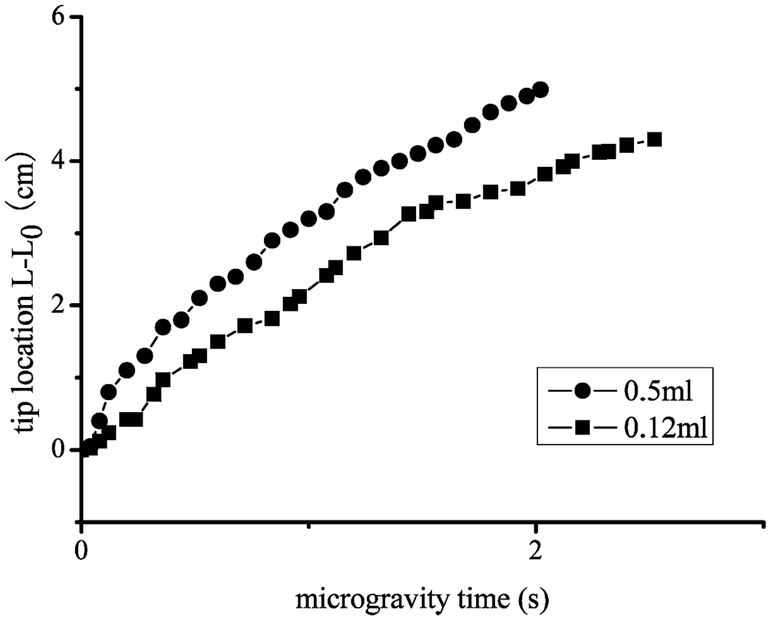

Fig. 4 The comparison for the tip location of 0.5 ml liquid with 0.12 ml liquid. L_0 is the position of the tip at microgravity time 0.

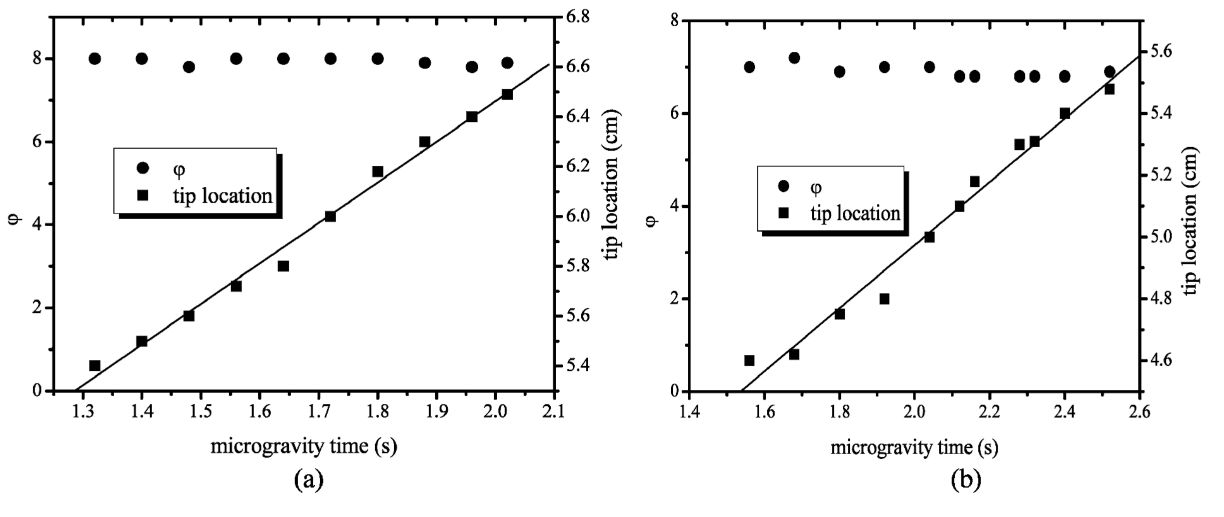

Fig. 5 The tip location and related angle of the contact line with the edge φ with microgravity time. (a) volume: 0.5 ml (b) volume: 0.12 ml

The comparison of the tip location for microgravity time for 0.12 ml and 0.5 ml volume of liquid is shown in **Fig. 4**. The result of figure4 shows that the tip location is larger when the volume is larger.

It also seems that the location is linear to time in the final stage of the microgravity condition in drop tower experiments from figure4. To confirm this, the tip location with time and the measured angle of the contact line with the edge φ in the final stage of microgravity condition are shown in **Fig. 5**. This figure shows that φ is almost the same, which means that the advancing contact angle and the speed of the tip is the same so that the tip location is linear with time.

The influence of the viscosity on the climbing of the liquid in interior corner is also studied in this study. As the volume of the liquid affect the tip location, we compare the results of KF96-5 and KF96-50 silicone oil for the same volume (0.12 ml). The result is shown in **Fig. 6**. This figure shows that the climbing speed is smaller when the viscosity is larger.

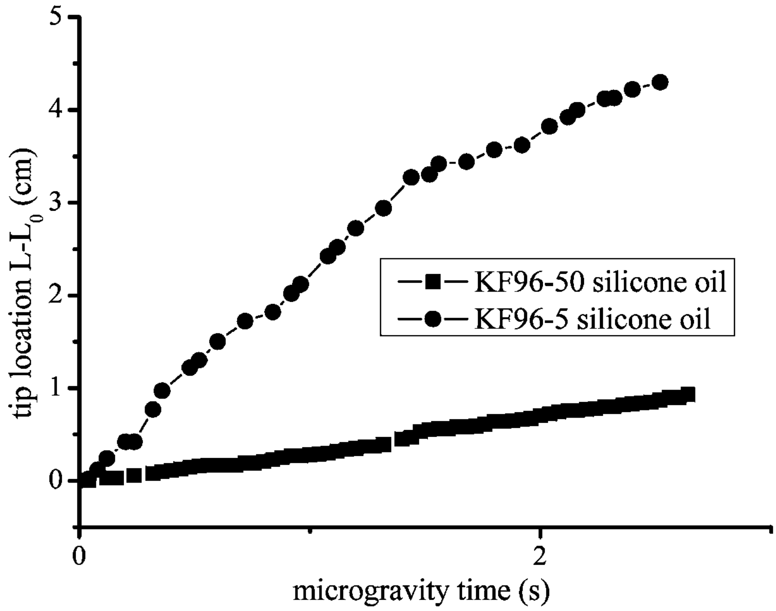

Fig. 6 The comparison for the tip location of KF96-5 and KF96-50 silicone oil for the same volume (0.12 ml). L_0 is the position of the tip at microgravity time 0.

4. Conclusion

In this paper, we have studied the climbing process in interior corner under microgravity condition in drop tower experiments. Especially, the effect of liquid volume on the capillary flow in the container of same size is discussed. It is found that there exists a constant height position for 1.2 ml liquid volume, while there is not for <0.5 ml liquid. And the reason is explained in this study. The experimental results show that the tip location is larger (so that the climbing speed is larger). And the tip location is linear with time in the final stage of the microgravity condition in drop tower experiments for 0.5ml and 0.12ml liquid volumes. For such conditions, the larger viscosity will make the climbing speed smaller.

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