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Measurement of Dynamic Contact Angles in Microgravity

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Abstract

When the Concus-Finn condition is fitted, there will be no equilibrium configuration in the interior corner under microgravity, and the fluid will move to the walls and can rise arbitrarily high along a part of the wall. In this study, we utilize the climb of the liquid in interior corner when the Concus-Finn condition is fitted to study the dynamic contact angle under microgravity condition in drop tower. The advancing of the fluid along the edge and the receding of the fluid along the bottom side are recorded by CCD camera. The dynamic contact angle and related velocity can be obtained by analysis. This method overcomes the difficulties in controlling the velocity of the contact lines in the small time duration of microgravity condition in drop tower. And the dynamic contact angles for different velocities of silicone oil on PMMA are measured in drop tower experiments.

1. Introduction

The problem on contact line's motion and dynamic contact angle have been of interest for a long time due to many natural and industrial processes involving the flow of fluid over the solid, such as a raindrop hitting a windowpane and wetting films. The experiment conducted in the gravitation environment confirmed that the dynamic contact angle varies with the velocity of the moving contact line and there exists an intermission between advancing contact angle and receding contact angle [1,2].

A few detailed observations on the dynamic contact angle have been reported in the literature. Kwork et al.[3] studied sessile drops of 17 different liquids, including water, on FC-722 dip-coated mica surfaces, with contact angles ranging from 66 to 118 degrees. In their study, the low rate (less than 0.52mm/min advancing rate) dynamic contact angles in 1g for a sessile drop are identical to the static advancing contact angles. To study the rate dependence for advancing contact angles under reduced gravity conditions where the hydrodynamics are different, the effect of gravity on the advancing contact angle of a sessile drop has been determined experimentally by carrying out several reduced gravity and ground experiments by Ababneh et al.[4], and a difference of about 5 degree in the advancing contact angle was observed. Abel et al.[5]measured the contact angles of a drop expanded and withdrawn on another immiscible liquid in the reduced gravity environment of parabolic flights. They observed a considerable contact angle hysteresis where it should not have existed as liquid-liquid fluid systems generally do not exhibit a considerable contact angle hysteresis. It is clear from these studies that the interaction of gravity with wetting process is not yet fully understood. Even many basic problems about the dynamic contact angle for different velocities under microgravity condition, is still unknown due to the lack of experiments.

In this paper we study the dynamic contact angles for different velocities of the contact lines under microgravity condition formed by the drop tower. To overcome the difficulties in controlling velocity of the contact lines in the small time duration of microgravity condition, we utilize the capillary flow in the interior corner where the Concus-Finn condition is met. According to Concus and Finn[6], when the contact angle is smaller than the critical contact angle, there will be no equilibrium configuration in the interior corner under microgravity. So the fluid moves to the walls and can rise arbitrarily high along a part of the wall, which will form the advancing contact angle for different velocities. For different degrees of the corner angles, the velocity of the dynamic contact line will be different, which makes it possible to measure the dynamic contact angle for different velocities.

2. Experiments

A. Experimental setup

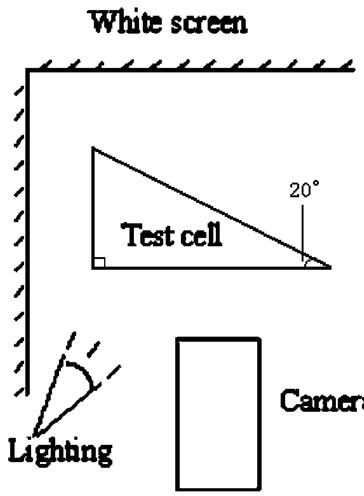

Fig.1 Sketch-map of the instrument in drop tower

The sketch map of the instrument is shown in **Figure 1**. The main components of the instrument are the container with right-angled triangle cross section and one CCD camera. The container is made of PMMA [polymethyl methacrylate] and is partly filled with silicone oil before experiments. The size of the cross section is about 33mm*12mm*35mm, which formed three interior corners of 90, 70 and 20 degree. As the contact angle of the silicone oil on the PMMA surface is quite small, 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. In different corners, the flow velocity (which is related to the velocity of the contact line) will be different in the experiment, which makes it possible to investigate the advancing contact angles with different velocities. The CCD camera was oriented to the right-angle side for recording the flow of the liquid. Besides the main components of the instrument, there is a light source and a white screen to give appropriate light for the image of the liquid in container.

Figure2, Figure3, Figure4 shows a typical image recorded from CCD camera in the experiments. From these figures we can see a ruler beside the container, which is used to determine the height of the flow so as to determine the velocity of the contact line. We

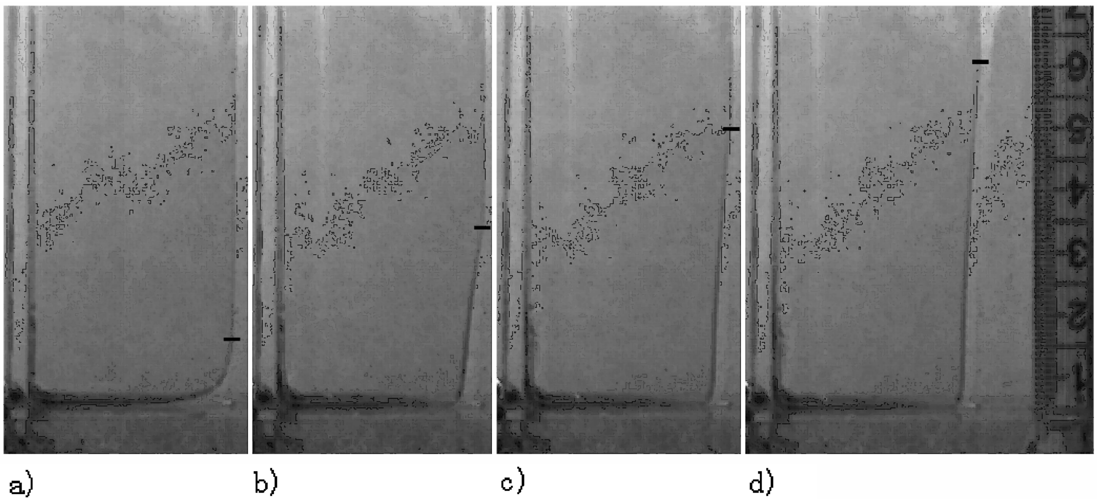

Fig.2 Typical image of the flow of the liquid at different time in experiments; volume V,0.12ml: a) 0, b) 1.0, c) 2.0,and d) 3.0 s

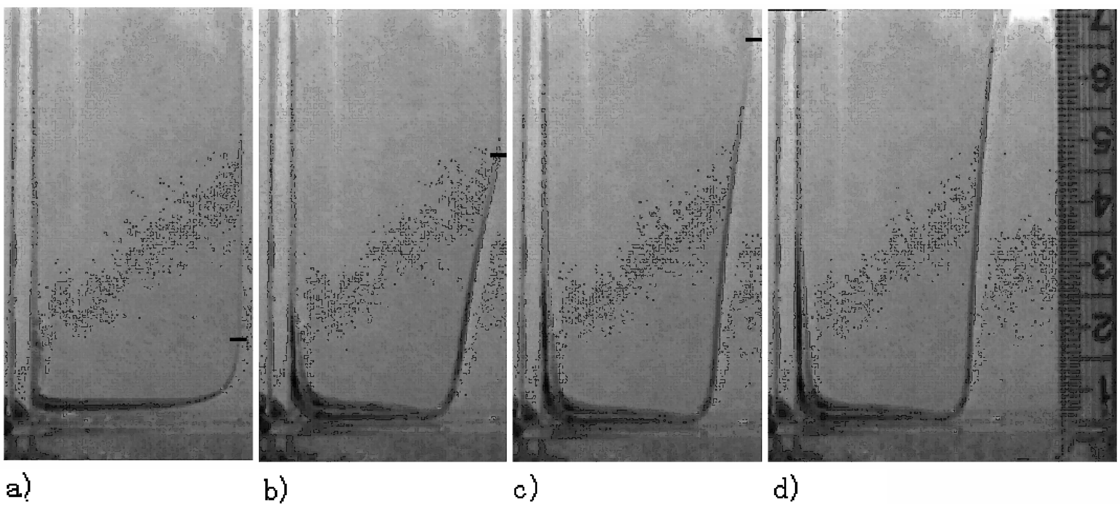

Fig.3 Typical image of the flow of the liquid at different time in experiments; volume V,0.5ml: a) 0, b) 1.0, c) 2.0,and d) 3.0 s

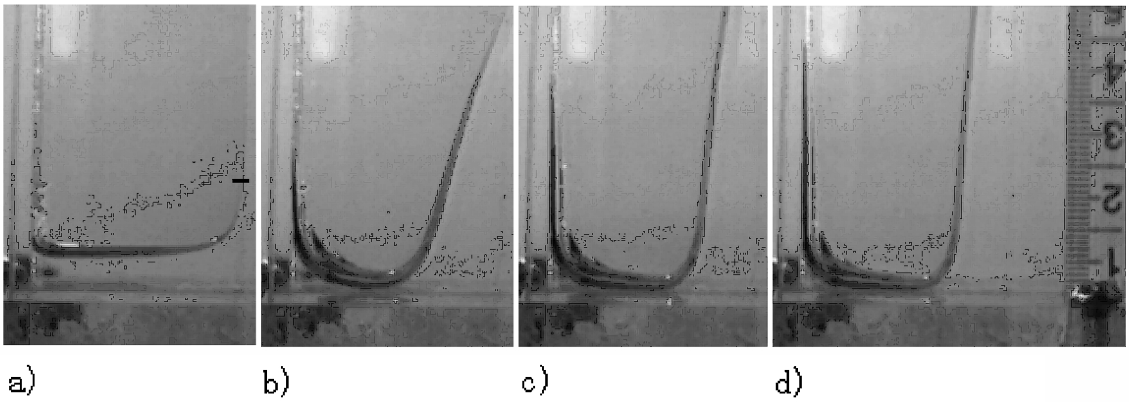

Fig.4 Typical image of the flow of the liquid at different time in experiments; volume V,1.2ml: a) 0, b) 1.0, c) 2.0,and d) 3.0 s

can also see that the velocity of contact line varies with the volume of the liquid in the container. The drop tower experiments are performed in a dual-drop capsule system, which can give the gravity condition that $g=10^{-5}g_0$.

B. Theoretical background

According to the Concus-Finn condition, when the contact angle θ is small than $(\pi/2-\alpha)$, where α is the half-angle of the interior corner, there will be no equilibrium configuration in the interior corner under microgravity. Therefore, the liquid will move along the interior corners that fit the Concus-Finn condition after gravity is diminished to microgravity condition. This behavior can help study the dynamic advancing contact angles (along the corners) in the short-time microgravity experiments. However, it is much more difficult to measure the dynamic contact angles θ than to measure the angle of the contact line with each edge of the corners of the container directly from the experiments.

In the experiment discussed in this study, we measure the angle of the contact line with the edges of the containers, which will be named as φ hereafter. And the dynamic contact angle can be determined from φ and α by some geometrical deductions.

Consider an isolated interior corner of angle 2α as depicted in **Figure 5**. The corner is partially filled with a fluid making contact angle θ with the solid surfaces satisfy the Concus-Finn condition. Part of the geometrical lines of the edge and the contact lines are shown in figure 5. In this figure, the two sides ABC and ABC' form an interior corner CBC'=2α, and CBD=C'BD=α. The lines AC and AC' are the tangent line of the contact lines on the two sides, so that the angles BAC=BAC'= φ, which can be measured directly from experiments.

If we add a plane surface DEF, which is perpendicular to the line AC as shown in figure5, we can get line FE=CE*cosφ and DE=CE*ctanα, so that tanDFE=DE/FE=ctanα/cosφ= secφ/ tanα. When the length of AD is limited to zero, the line DF will be parallel to the contact line on another imaginary surface which is perpendicular to line AC, so that the value of the angle DFE will be equal to the contact angle θ.

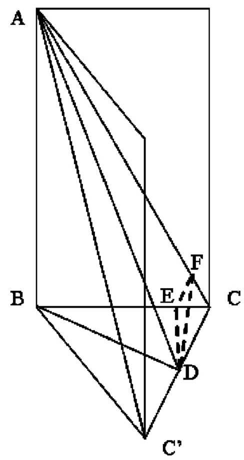

Fig.5 Schematic drawing of geometrical lines in an interior corner

Therefore, by geometry analysis, the relationship of the contact angle can be determined by:

$$\tan\theta = \sec\varphi / \tan\alpha \qquad (1)$$

where θ, φ, and α are the contact angle, the measured angle of the contact line with edge and half of the interior angle. For testing the applicability of this formula, some Surface Evolver[7] programs are used to calculate φ for different values of θ and α under microgravity condition. The numerical results also prove this formula.

3. Results and Discussion

In the microgravity experiments, the liquid in the container will climb at the interior corner, and the images can be obtained by CCD camera for different time, as shown in Figs.2-4. The principal measured quantities from the images are the tip location of the fluid in the interior corner and the angle of the contact line with edge φ. When the Concus-Finn condition is satisfied, regardless of the gravity level, a

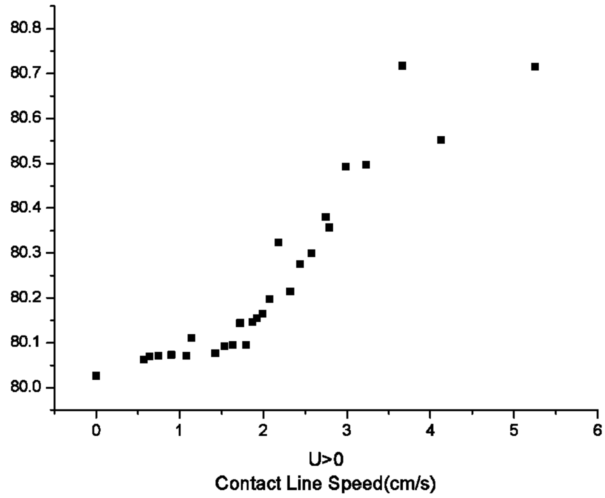

Fig.6 Typical experimental results for the dependence of the dynamic contact angle, θ, on the velocity of the contact line. When U>0 the contact line is advancing.

thin column of fluid already exists in the corner prior to the drop test[6]. The pre-existing film makes ambiguous the true tip location of the meniscus during the early stage of the drop tests. An apparent tip location was thus measured at the onset of the flow by extrapolating the apparently linear meniscus profile near the tip to the vertex of the corner. As the fluid column rises, upper portions of the corners are reached where the film is not observed and data taken in these regions needs no extrapolation. Near the tip location a tangent of the contact line on one side is put and the angle between the tangent and the edge is φ. According to Eq.(1) the dynamic contact angle θ can be calculated as α is already known. On the other hand, the relationship of the tip location with time can also be obtained, which is used to get the velocity of the contact line. The experimental results show that the volume of the liquid in the container affects the climbing velocity of tip location. So we can get different velocities of the contact line and finally get the dependence of the dynamic contact angle on the velocity of the contact line through analyzing the image of the flow of the liquid, which is shown in **Figure 6**.

It can be clearly seen from Fig.6 that the advancing dynamic contact angle is larger than the static contact angle. As the advancing velocity increases, the advancing contact angle becomes larger. The tendency of the dynamic contact angle with the contact line speed is consistent with the experimental results on the ground[1]. These results confirm that the method proposed in this study can be used to measure the dynamic contact angles with different velocities in drop tower, although the data is not so adequate that there may be some error in the measured results.

4. Conclusion

In this study, we have utilized the climb of the liquid in interior corner when the Concus-Finn condition is fitted to study the dynamic contact angle under microgravity condition in drop tower. The experimental results show that this method is appropriate to measure dynamic contact angles for different contact line velocity. And this method overcomes the difficulties in controlling the advancing or receding velocity of the contact lines in the small time duration of microgravity condition in drop tower. However, more precise data is required in future studies.

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