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A New Approach to Measure Contact Angle and Evaporation Rate With Flow Visualization in a Sessile Drop

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A NEW APPROACH TO MEASURE CONTACT ANGLE AND EVAPORATION RATE WITH FLOW VISUALIZATION IN A SESSILE DROP

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The contact angle and the spreading process of sessile droplet are very crucial in many technological processes, such as painting and coating, material processing, film-cooling applications, lubrication, and boiling. Additionally, as it is well known that the surface free energy of polymers cannot be directly measured for their elastic and viscous restraints. The measurements of liquid contact angle on the polymer surfaces become extremely important to evaluate the surface free energy of polymers through indirect methods linked with the contact angle data.

Due to the occurrence of liquid evaporation is inevitable, the effects of evaporation on the contact angle and the spreading become very important for more complete understanding of these processes. Based on the laser shadowgraphic system used by the present author [1, 2], a very simple optical procedure has been developed to measure the contact angle, the spreading speed, the evaporation rate, and to visualize inside convection of a sessile drop simultaneously.

It is of interest to note that evaporation can induce Marangoni-Bénard convection in sessile drops [3]. However, the impacts of the inside convection on the wetting and spreading processes are not clear. The experimental methods used by previous investigators cannot simultaneously measure the spreading process and visualize the convection inside. The present work provides the solution for the first time.

The inside convection and the drop profile data can be synchronously recorded through the CCD camera I and II. CCD camera I would also precisely record the real-time diameter of the sessile drop which is essential for determination of both spreading speed and evaporation rate. As it is well known that a sessile drop takes the shape of a spherical cap provided its mass is sufficiently small, for example, less than 1 mg [4-6]. The sessile drop on the glass slide can be taken as a thin plano-convex lens with a focal length, f, which can be expressed as

$$f = \frac{R}{n-1} \tag{1}$$

where R is the curvature radius of the spherical cap, n is the refractive index of the liquid. By a simple geometric relationship as shown in Fig. 1,

$$f = \frac{d(s+p)}{d+D} \tag{2}$$

where d is the base diameter of the sessile drop, s is the distance from the center of the drop base to its image on the front surface of the mirror, p is the distance between images of the drop center on the mirror and on the screen, D is the diameter of the drop image on the screen. Both d and D are time dependent due to the spreading and the evaporation, which can be accurately measured through the direct photo-shadowgraphic system. It is obvious that as the function of time, the curvature radius of the liquid spherical cap can be then determined by the data of d and D:

$$R(t) = (n-1)(s+p)\frac{d(t)}{d(t)+D(t)} \tag{3}$$

The contact angle can be calculated as

$$\theta(t) = \arcsin\frac{d(t)}{2R(t)} \tag{4}$$

The evaporation rate can also be determined from the data of d and D. According to a simple geometric relationship, the instant volume of the sessile drop can be written as

$$V(t) = \pi h^2(t)[R(t) - \frac{h(t)}{3}] \tag{5}$$

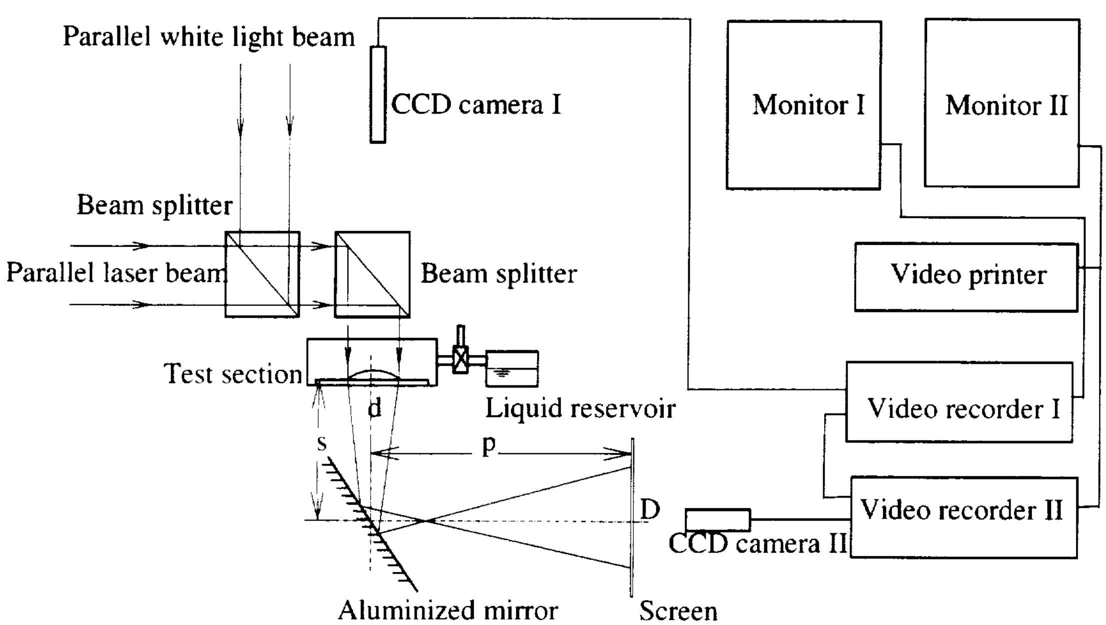

Figure 1.—Schematic of experimental setup.

Therefore, the evaporation rate is

$$\dot{V} = 2\pi h\dot{h}(R - \frac{h}{3}) + \pi h^2(\dot{R} - \frac{\dot{h}}{3}) \tag{6}$$

where

$$h = R - \sqrt{R^2 - d^2 / 4}, \tag{7}$$

$$\dot{h} = \dot{R} - \frac{R\dot{R} - d\dot{d} / 4}{\sqrt{R^2 - d^2 / 4}}, \tag{8}$$

and

$$\dot{R} = (n-1)(s+p)[\frac{\dot{d}}{d+D} - \frac{d(\dot{d}+\dot{D})}{(d+D)^2}] \tag{9}$$

As an example, Figs. 2 and 3 show the direct photography from top and the laser shadowgraphy at moment t = 4 sec., respectively, for an evaporating freon-113 sessile drop. Inside convection can be seen clearly in Fig.3.

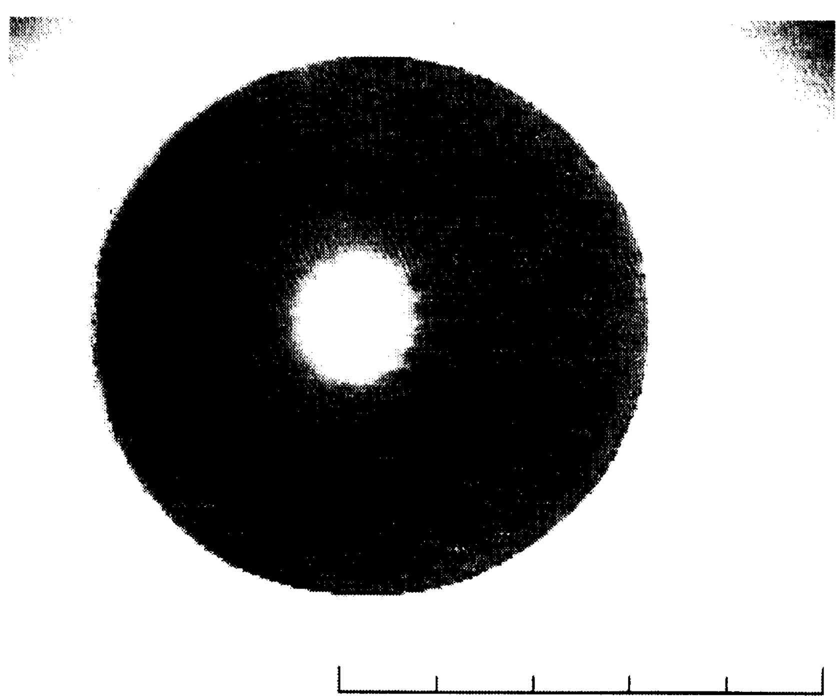

Figure 2.—Direct photography from top. d(t) = 5.72 mm at t = 4 sec.

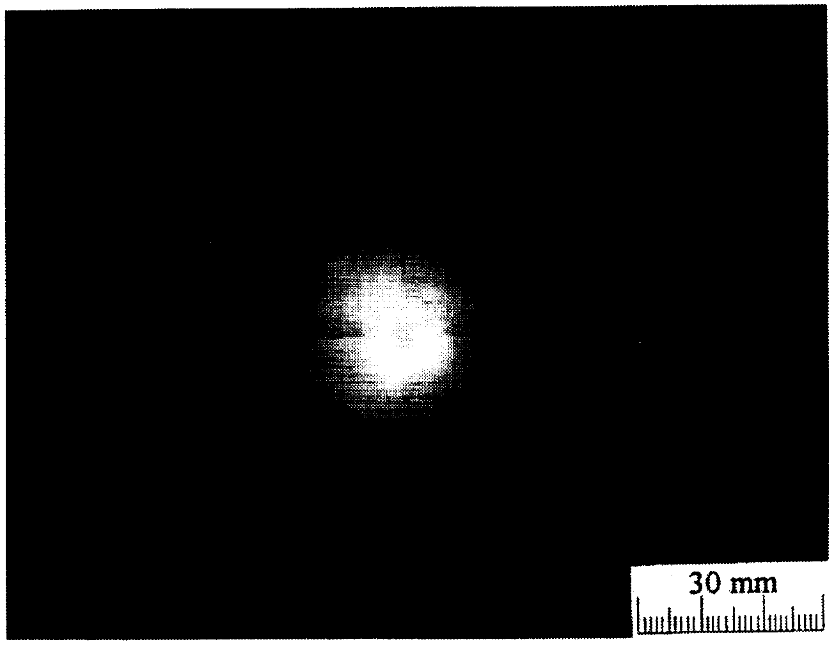

Figure 3.—Laser shadowgraphy. d(t) = 85.7 mm at t = 4 sec.

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13. ABSTRACT ***(Maximum 200 words)***

The contact angle and the spreading process of sessile droplet are very crucial in many technological processes, such as painting and coating, material processing, film-cooling applications, lubrication, and boiling. Additionally, as it is well known that the surface free energy of polymers cannot be directly measured for their elastic and viscous restraints. The measurements of liquid contact angle on the polymer surfaces become extremely important to evaluate the surface free energy of polymers through indirect methods linked with the contact angle data. Due to the occurrence of liquid evaporation is inevitable, the effects of evaporation on the contact angle and the spreading become very important for more complete understanding of these processes. It is of interest to note that evaporation can induce Marangoni-Bénard convection in sessile drops. However, the impacts of the inside convection on the wetting and spreading processes are not clear. The experimental methods used by previous investigators cannot simultaneously measure the spreading process and visualize the convection inside. Based on the laser shadowgraphic system used by the present author, a very simple optical procedure has been developed to measure the contact angle, the spreading speed, the evaporation rate, and to visualize inside convection of a sessile drop simultaneously. Two CCD cameras were used to synchronously record the real-time diameter of the sessile drop, which is essential for determination of both spreading speed and evaporation rate, and the shadowgraphic image magnified by the sessile drop acting as a thin plano-convex lens. From the shadowgraph, the inside convection of the drop can be observed if any and the image outer diameter, which linked to the drop profile, can be measured. Simple equations have been derived to calculate the drop profile, including the instantaneous contact angle, height, and volume of the sessile drop, as well as the evaporation rate. The influence of the inside convection on the wetting and spreading processes can be figured out through comparison of the drop profiles with and without inside convection when the sessile drop is placed at different evaporation conditions.

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