Measurement of Surface Tension Coefficient of Liquid by Saturation Height Method

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[Experimental Principle]

Between two adjacent parts of a liquid's surface, the force that pulls each other within a unit length is called the surface tension coefficient, in mN/m unit. Surface tension causes the liquid surface to shrink to reduce surface energy. For droplets on solid surfaces, the shape is determined by the surface tension, gravity, and the effective surface energy of the solid. When the volume is small, the droplet shape is dominated by surface tension. As large volume , the shape is dominated by gravity.

Draw the gas-liquid interface tangent line at the gas, liquid, and solid three-phase intersection point. The angle between this tangent line and the solid-liquid boundary θ(figure 1) is defined as *contact angle*. θ<90°, the surface is a *hydrophilic surface*; θ>90°, the surface is a *hydrophobic surface*. Solid surfaces are always rough, so treating the solid-liquid interface as a horizontal straight line is based on an apparent (macroscopic) perspective. Similarly, the contact angle is also apparent, and its measurement does not take into account the rough structure of the solid surface.

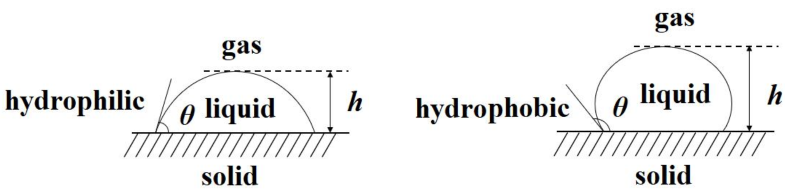

Fig. 1. Droplets on different infiltrating solid surfaces

On the solid surface, as the droplet volume increases, the height of the droplet will gradually increase to a saturation value (gravity will limit the height increase). Research show that the surface tension coefficient of the droplet is related to the saturation /maximum height as follows, both on the hydrophilic surface and the hydrophobic surface:

$$\gamma = \frac{\rho g {H_{max}}^2}{4\sin^2\left(\frac{\theta}{2}\right)} \qquad (1)$$

Here，γ - surface tension coefficient，ρ - droplet density，g - gravitational acceleration，H_{max} - Maximum droplet height，θ – contact angle。Measured density, maximum height and contact angle, the surface tension coefficient can be calculated by formula (1).

It should be pointed out that there are many methods for measuring surface tension, among which, the saturation height method is usually not used as a conventional method for surface tension measuring because of its low measurement accuracy. However, the method is suitable for home experimental training because it can be used without complex instruments.

[Experiment Content]

Measure the surface tension coefficient of water (tap water, mineral water, or purified water). The density of water is approximately 1 g/cm3, and the gravitational acceleration is about 9.8 m/s2. The surface tension coefficient can be calculated by measuring the saturation height and the contact angle of water droplets. Students good ability can also measure other liquids, relevant parameters can be queried online.

[Experimental Procedure]

1. Choosing a flat and clean solid substrate (a broad contact angle is better), drop the liquid to be tested at room temperature on it, and gradually increase the volume to observe its height increasing. The H_{max} and θ can be measured when the height is basically unchanged, with the water droplet volume in the order of 1.0 milliliter. The exact size depends on the substrate infiltration. Note that continuing to add liquid after reaching saturation height has little effect on the experiment, but the final volume should not exceed 2.0 ml as far as possible.

2. Place a regular shape object next to the droplet to be measured as a reference object, or stand a ruler next to the droplet and photograph the side view of the droplet with a mobile phone or camera (see figure 2). When shooting, the connection between the droplet and the reference should be parallel to the phone plane (ensure that the droplet side view and the reference are on the same focal plane). The phone should be perpendicular to the desktop, and the lens should be as high as the droplet. Five side views are shot in different directions around the same droplet, and each shot should comply with the above requirements.

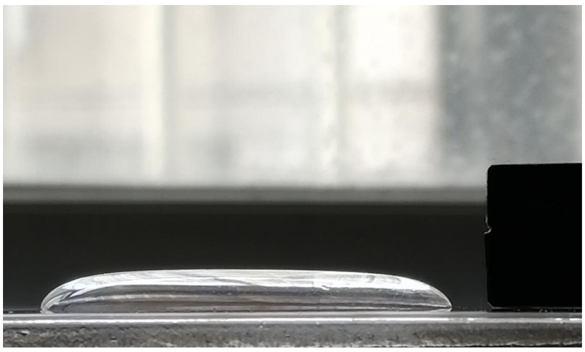

Fig.2. About 1.9 mL tap water droplet on a plastic box. (reference--cuboid on the right)

3. Export pictures, measure the contact angle with protractor or software such as Photoshop (figure 3), and measure the height with software such as Photoshop or PPT (figure 4), where the height can be calculated by using the actual size of the reference

and the ratio of droplet and reference in the picture. On each picture, droplet height and contact angle are measured once each.

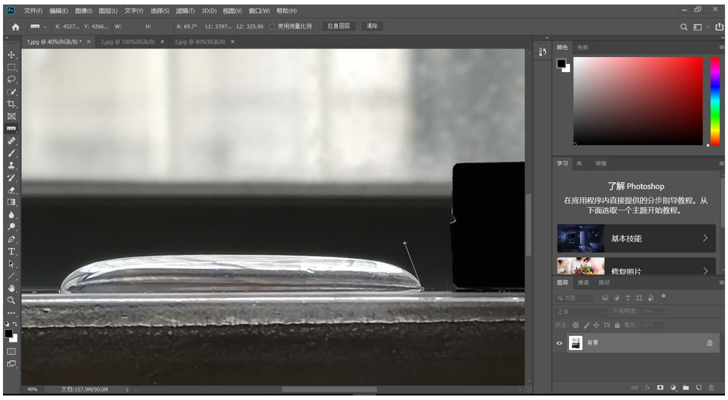

Fig.3. Measure the droplet's right contact angle by Photoshop

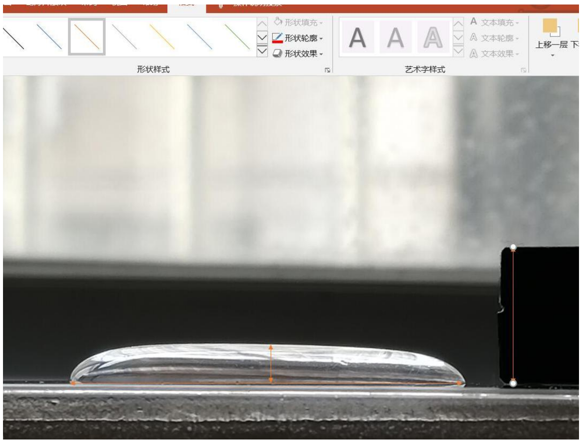

Fig.4. Measure the height of droplet and reference by PPT

4. Substitute the measured contact angle θ and maximum height H_{max} into formula (1) to calculate the surface tension.

5. Replace the base (different contact angles) and repeat the above steps.

[Data process]

1. If a vernier caliper or micrometer is not available, the size of the reference can be measured with a ruler. Choose as large a frame as possible to minimize the impact of measurement errors.

2. Measure both the left and right sides contact angles and use the average value for calculation. If the left and right contact angles are different greatly, it is likely that the surface properties of the solid are not uniform, and it is necessary to change the position or the base to add the liquid again.

3. Calculate the average value and uncertainty of contact angle (the average of left and right contact angle obtained from each picture is the result of one measurement) and saturation height of 5 measurements, the optimal value and uncertainty of water's

surface tension coefficient. It take no account of type B uncertainty of $H_{\max}$ and θ in calculation.

4. Inquire the surface tension value of water at the experimental temperature online (e.g., 72.8 mN/m at 20℃) as the theoretical value to calculate the relative error. If the relative error is greater than 20%, the experiment needs to try again.

Calculation of uncertainty and relative error:

BASE1：

BASE2：

[Experiment report requirements]

WORD document, should contain (not limited to) the following:

1. Experimental conditions and material description: temperature, substrate, liquid to be tested, reference, shooting equipment, etc.

2. Diagrams of experimental apparatus on different substrates , diagrams of software interface for height and contact angle measurement

3. Data table.

4. Uncertainty and relative error calculation

5. Result discussion and error analysis

<table>
<tr><td rowspan="2" colspan="2">Base
Value</td><td colspan="5">BASE1：____________</td><td colspan="5">BASE 2：____________</td></tr>
<tr><td>Pic.1</td><td>Pic.2</td><td>Pic.3</td><td>Pic.4</td><td>Pic.5</td><td>Pic.1</td><td>Pic.2</td><td>Pic.3</td><td>Pic.4</td><td>Pic.5</td></tr>
<tr><td colspan="2">Maxium height（mm）</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Average of maxium height（mm）</td><td colspan="5"></td><td colspan="5"></td></tr>
<tr><td rowspan="3">Contact angle</td><td>Left (°)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Right(°)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Avg (°)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Average of contact angle</td><td colspan="5"></td><td colspan="5"></td></tr>
<tr><td colspan="2">Surface tension coefficient（mN/m）</td><td colspan="5"></td><td colspan="5"></td></tr>
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