Experimental study on droplets evaporation on hydrophobic surface at different tilt angles

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Abstract. Droplets evaporation exists widely in industrial manufacturing and engineering applications. Optical visualization system was used to investigate the evaporation process of deionized water droplets on fresh taro leaves with different tilt angles. The evaporation time and mode of droplets were experimental studied at different tilt angles. The results show that the time for the droplet to completely evaporate decreased as the surface tilt angle increases. During the first half of droplet evaporation process on the slant hydrophobic surface, the evaporation modes were different between the two sides of the droplet. When the droplet on an inclined hydrophobic surface evaporated to a certain volume or a certain contact angle, its subsequent evaporation behavior was similar to that of a droplet on a non-tilted hydrophobic surface.

1 Introduction

Evaporation is a common phenomenon in nature. Its physical meaning is the phase transformation process of matter from liquid to gaseous state, and it is a kind of vaporization phenomenon that occurs on the liquid surface when the vapor around the liquid is unsaturated. Sweat on the body surface, wet clothes drying, liquid splashed on the table, puddles on the ground, ponds, rivers, sea and so on will evaporate. The evaporation of droplets has attracted much attention because it widely exists in industrial manufacturing and engineering applications. Many studies have shown that there was a very important relationship between the evaporation mode of droplets and the properties of the contact floor. [1-3] At the same time, the droplet evaporation mode largely depended on the surface roughness, wetting characteristics, and interface energy.[4] Due to the limitations of experimental conditions such as the difficulty of realizing the experimental equipment and the immaturity of image processing technology, the experimental research lagged behind the theoretical simulation and numerical calculation. Through numerical simulation and theoretical analysis, some important basic equations such as diffusion equation and evaporation rate equation of droplet evaporation had been obtained.[5] Through experiments, three evaporation modes of droplets: constant contact angle (CCA), constant contact radius (CCR) and mixed (mixed) were found.[6] At the same time, two new wetting models, Wenzel and Cassie-Baxtei were proposed on the basis of Young's equation.[7] Then scholars had proposed many droplet evaporation models under different influence factors. The evaporation characteristics of small fixed droplets on horizontal and vertical substrates were numerically simulated. At present, researches of droplet evaporation focused on the evaporation of small droplets in nano scale by means of molecular dynamics. However, there was little research on the evaporation process of large droplets under the influence of gravity.

Experimental study on droplets evaporation on hydrophobic surface at different dip angles was carried out in this paper. The morphological changes and evaporation modes of droplets under the influence of different dip angles were systemmatically studied. At different evaporation stages, the influence of gravity on droplets was analyzed qualitatively.

2 experimental system and content

2.1 Experimental materials

The composition of the droplet was deionized water, and the hydrophobic surface material was made of fresh taro leaves. The structure of taro leaves under the microscope was shown in Fig. 1. The milky protrusions on the surface of taro leaves could be seen, and there were nanoscale microvilli on the surface. The hierarchical structure of this micro and nano scale composite was basically consistent with the description of the surface of natural superhydrophobic materials. [8] The average static contact angle of droplets on taro leaves measured was 158.4° (Fig.1-1c), which accorded with the criteria of superhydrophobic materials.

2.2 Experimental system

As shown in Fig.2, the experimental system was mainly composed of optical contact angle measuring instrument (including microsyringe, LED cold light source, CCD industrial camera), adjustable inclination platform and

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computer. In the experiment, the inclination angle of the contact angle measuring instrument was adjusted horizontally, the taro leaves were laid flat on the platform, the magnification and focal plane of the camera lens were adjusted, the collection parameters were adjusted, and the ambient temperature and humidity were recorded. After the droplets were placed on the surface of taro leaves with a microsyringe, the inclination angle of the platform was adjusted to the desired angle, and the computer controlled the time to take pictures.

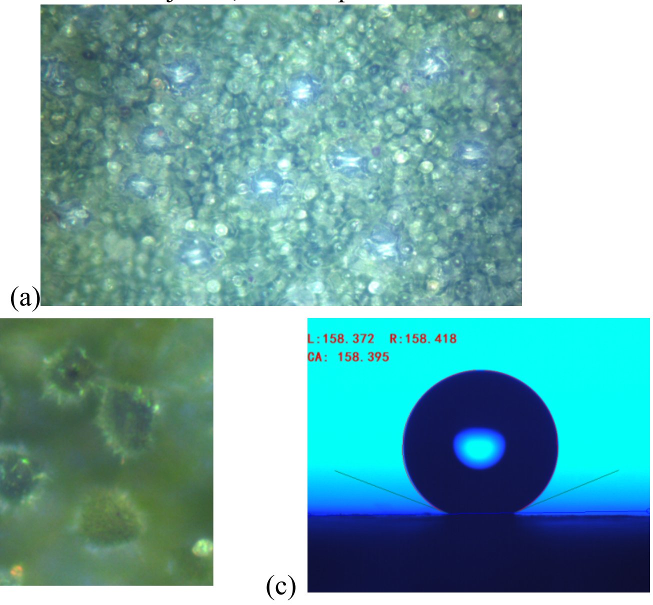

Fig. 1. The surface of taro leaves

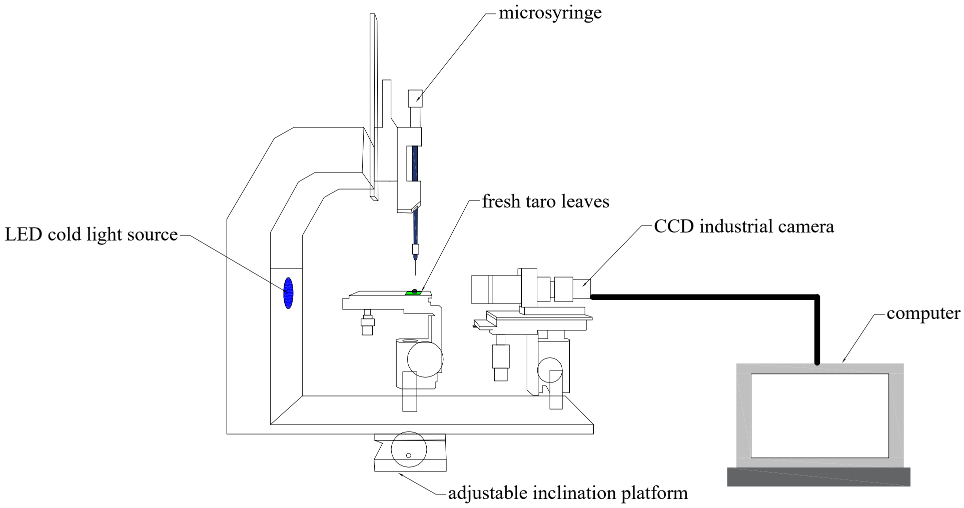

Fig. 2. Experimental system

3 Experimental results and analysis

3.1 Evaporation process of droplets

The initial volume of the droplet was 7 μL±1μL, and a picture of the droplet was taken every 10 seconds. Three groups of experiments were carried out, and the tilt angles of each group were 0°, 30°and 60°, which were recorded as a, b and c respectively. The experimental conditions are shown in Table 1.

As shown in Fig.3, in the pictures separated by 12min, it could be seen that all three groups of droplets could maintain a spherical crown during evaporation. With the passage of time, the contact line continued to decrease, and the shape was getting closer and closer to the circle. The shape of group a with an inclination angle of 0° was basically similar in the process of evaporation, the volume change was the smallest among the three groups, and a round droplet could be seen in 48min. In the process of evaporation, the right contact angle of group b with an inclination angle of 30° was obviously decreasing, and the volume of group b was faster than that of group a, and the droplets would no longer be seen in 48min. The shape change of group c with an inclination of 60° was similar to that of group b in the process of evaporation, the right contact angle was close to the left contact angle, and its volume changed most obviously, which was the fastest among the three groups, and the droplets could no longer be seen during 48min. From the 36min, it could be seen that the volume relationship of the three groups of droplets was a>b>c.

Table 1. Experimental conditions

Inclination angle（°）	Temperature（℃）	Relative humidity（%）
0	28.8	59.3
30	28.0	60.5
60	27.9	61.9

The data of the left and right of the whole droplet evaporation process and the average contact angle were obtained by processing the photos taken for 10 seconds, and the data were drawn as a line chart as shown in Fig.4. From Fig.4, we would found that the values of the left and right contact angles in the initial state of group were almost the same, and were basically the same in the process of change. The change of contact angle fluctuated in a small range, and changed little with time before 2000 s, and was sawtooth as a whole. The fluctuation range of the droplet contact angle began to increase after 2000s, and the overall change with time was obvious. The contact angle began to decrease rapidly after 2430s, and evaporated in the next 30s.

In the initial state, the right contact angle of group b and c was basically the same as the three contact angles of group a, both of which were about 160°, but the right contact angle and average contact angle of group b and c were obviously smaller than those of group a. The left and right contact angles of group C were slightly larger than those of group b, and this law also exists in a certain time range after that, and the average contact angles of the two groups were basically the same. In the whole process of evaporation, the change rule of the average contact angle of group b and c was similar to that of group a. Before 1220s, the average contact angle of the two groups was basically the same as that of group a before 2000s, but the difference was that the left and right contact angle gradually approaches to the average contact angle from the upper and lower sides of the y-axis direction with time. The three lines intersect at 1220s, and then the fluctuation become larger, and the contact angle began to rise and drop to a small extent. Finally, in group b, it began to decrease rapidly at 1640s in group c, and evaporated in 50s and 80s, respectively.

3.2 Analysis of evaporation process

Combined with the actual pictures, the whole evaporation process of three groups of droplets could be divided into two stages.

In group a, the contact angle changed little before 2000 s, and the contact line decreased continuously. Therefore, it could be considered that the evaporation of droplets during this period was a constant contact angle evaporation mode, which was the first stage.

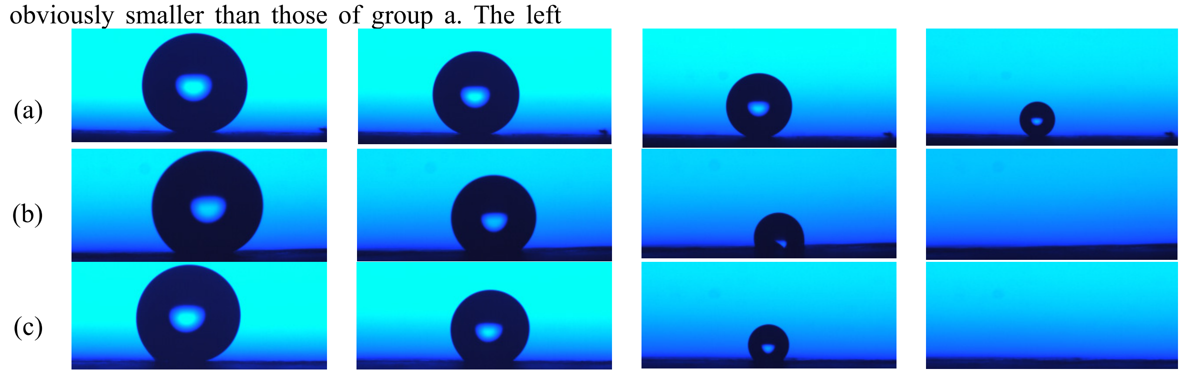

Fig.3. Evaporation process of liquid droplets at different dip angles

In the second stage, the contact line of the droplet decreased with time, but the change of the contact angle fluctuated greatly, after 2000s. At the same time, the left and right contact angle began to become asymmetrical. The difference fluctuation began to increase (Fig. 5a), pinning and de-pinning effect became obvious. There was the abrupt change of contact angle. And it could be considered that the evaporation of droplets during this period of time was a mixed mode. Although the contact line remained stable and the contact angle decreased rapidly within 30 seconds after 2430s. For the time of occurrence of this phenomenon was relatively small for the overall time, this period of time was also classified as the second stage.

Because of the influence of different degrees for gravity component, there was a great difference in the left and right contact angle of the initial state between group b and group c. The inclination angle of group c was larger, so the difference between the left and right contact angle of group c was larger than that of group b. Then, the volume of droplets decreased due to the evaporation process, and the influence of gravity on droplets became weaker. So the difference between the left and right contact angles became smaller (Fig.5 b and c). The contact angle lines would intersect at 1200s. And this whole process was in the evaporation first stage.

In the first stage, the left contact angle of group b and c was almost stable with only little variation, while the right contact angle decreased gradually with time and the contact line was retracted at the same time. So the evaporation mode on the left side of the droplet was constant contact angle mode, but the evaporation mode on the right side was mixed evaporation mode. In group c, there was a big difference of contact angles between the left and right sides. The evaporation mode difference was also obvious than group b.

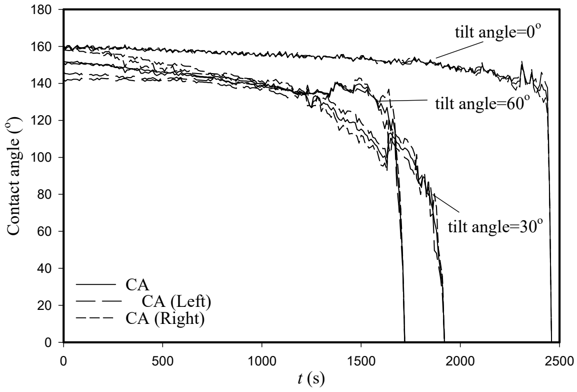

Fig. 4. The change of droplet contact angle at different tilt angles

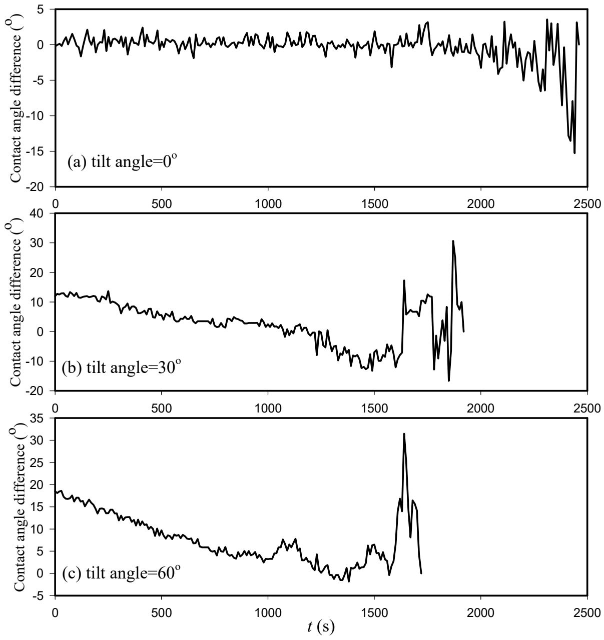

Fig.5. The difference between the left and right contact angles of liquid droplets

In the second stage, the change of droplet contact angle of group b and c after 1200s was similar to that of group a, but the time lasted longer. At the same time, the constant contact line evaporation mode of very short time also appeared in the group b and c after 1870s and 1640s.

It was worth noting that the contact angles at the demarcation points of the two stages of the three groups of experiments were all close to each other, which was about 140°.

4 Conclusions

The evaporation process of droplets on the hydrophobic surface of taro leaves at the 0°, 30°, and 60° dip angles was experimentally studied. The influence of the hydrophobic surface inclination angle on the change of the contact angle and the evaporation mode were analyzed. And the following conclusions were drawn:

(1) Under normal temperature and pressure, the left and right contact angles of liquid droplets on the slant hydrophobic surface were inconsistent due to the influence of gravity.

(2) The time required for the droplet of the same volume to evaporate on the hydrophobic surface at different tilt angles was 0°> 30°>60°.

(3) During the first half of droplet evaporation process on the slant hydrophobic surface, the evaporation mode on the side where the contact angle becomes larger under the influence of gravity was the constant contact line mode. The other side was a constant contact angle mode. And the difference between the left and right contact angle would gradually decrease during this process.

(4) When a droplet on an inclined hydrophobic surface evaporated to a certain volume or a certain contact angle, its subsequent evaporation behavior was similar to that of a droplet on a non-tilted hydrophobic surface under the same state.

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