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Bouncing behaviors of suspension liquid drops on a superhydrophobic surface

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Abstract This paper reveals three patterns of bouncing behaviors of suspension drops containing calcium carbonate ($CaCO_3$) powder on a superhydrophobic surface with the aid of a high-speed camera. In transmission electron microscopy (TEM) observation, the particles of $CaCO_3$ are shaped like sticks whose equivalent diameters are about 700 nm. Unlike a pure water drop, dense suspension drops cannot be pinched off at the bounce on the superhydrophobic surface due to a high effective viscosity, whereas the equilibrium contact angle appears to be almost identical in all kinds of droplets.

Liquid viscosity can be obviously increased by a suspended matter. For a suspension of identical rigid spherical particles, in the case of steady straining motion of the suspension in which all trajectories in the vector $\boldsymbol{r}$-space come from infinity and the suspension has isotropic structure (Batchelor and Green 1972), the stress behavior can be represented (to order c^2 where c is the volume fraction of the spheres) in terms of an effective viscosity μ^* as $\mu^*/\mu \approx 1 + 2.5c + 7.6\ c^2$.

Figure 1 shows scanned images of calcium carbonate ($CaCO_3$) powder with a density of 2,700 kg/m^3, together with the frequency distribution of area equivalent diameter of the particles, observed through transmission electron microscopy (TEM). The particles of $CaCO_3$ are observed to be shaped like sticks (not spheres) whose lengths are about 2 μm and diameters are about 100 nm. By zooming-in on a stick particle and captured image in the red rectangular of the bottom left of Fig. 1, it can be observed that the stick particle is made of numerous microscopic spherical particles having diameter of about 10 nm.

Figure 2 shows three kinds of millimeter-scale sessile drops having volume of V_B = 30 μL on a superhydrophobic surface: deionised (DI) water drop (zero suspension) and $CaCO_3$ suspension drops with 1.0 wt% and 10 wt%0 $CaCO_3$ powder, respectively. The contact angles were approximately measured by zooming in the photograph for each drop and found that the contact angle $\theta_c = 134°$ for the DI water, θ_c = 137° for 1.0 wt% $CaCO_3$, and θ_c = 141° for 10 wt% $CaCO_3$. For reference, the above-mentioned formula would estimate the effective viscosity of the $CaCO_3$ suspensions as $\mu^* \approx 1.01\ \mu$ for 1.0 wt% $CaCO_3$ and $\mu^* \approx 1.11\ \mu$ for 10 wt% $CaCO_3$, although the $CaCO_3$ suspensions do not exactly fulfill the assumptions (they are not shaped like spheres as mentioned above). Figure 3 shows a video sequence of bouncing behaviors of those suspension drops on the superhydrophobic surface from the onset of the impact. The suspension drops produced from a syringe were freely released at the height of 23 mm from the surface. The experimental results were recorded with a high-speed camera whose frame rate was 1,330 frames/s with

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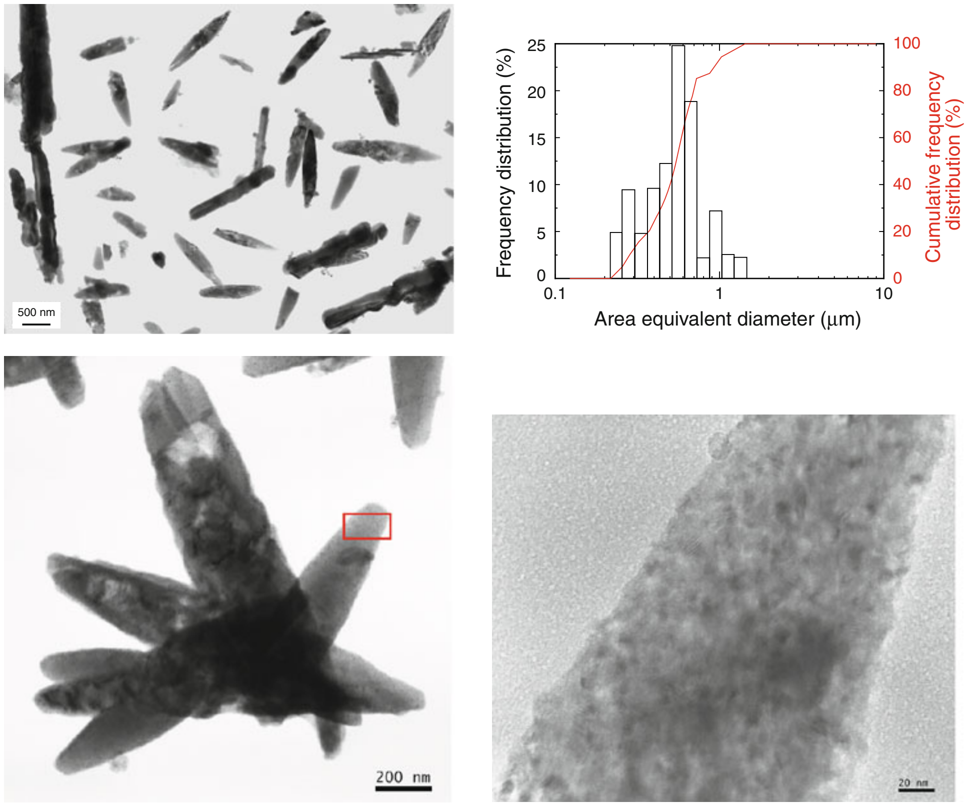

Fig. 1 TEM observation of calcium carbonate ($CaCO_3$) powder. *Left* TEM images, *top-right* particle size distribution, *bottom-right* zooming in the image of the red rectangular in the *bottom-left* figure

the shutter speed of 250 μs for the resolution of 1,024 × 1,260 pixels. After released, the drops freely fell due to gravity and then impacted on the hydrophobic solid surface. During a drop falling, a small satellite droplet (so-called residue of the main drop) was observed following the main drop (Fig. 3, left). At the impact the drop deformed to a pancake shape (see the second column from left of Fig. 3) and dissipated the energy due to the surface tension. After bouncing of the drops, pinched-off of the DI water and dilute suspension drops (Fig. 3, top two rows) were observed (see the second column from right of Fig. 3), whereas the non-dilute (dense) suspension drop ($CaCO_3$ 10 wt%) remained the original drop without pinched off. The pinched-off droplet is smaller in the DI water experiment due to the lower viscosity, and consequently, reaches the highest position in the three kinds of droplets, as shown in the rightmost column of Fig. 3.

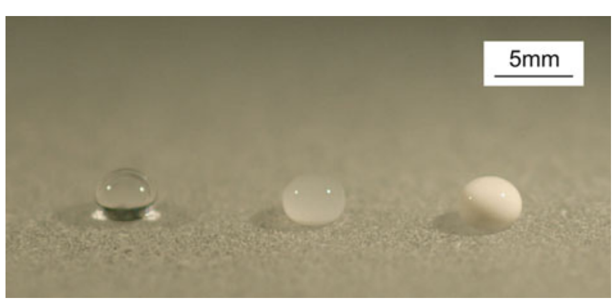

Fig. 2 Three kinds of suspension droplets of V_B = 30 μL fending off a hydrophobic surface. *Left* DI water, *center* $CaCO_3$ 1.0 wt%, *right* $CaCO_3$ 10 wt%

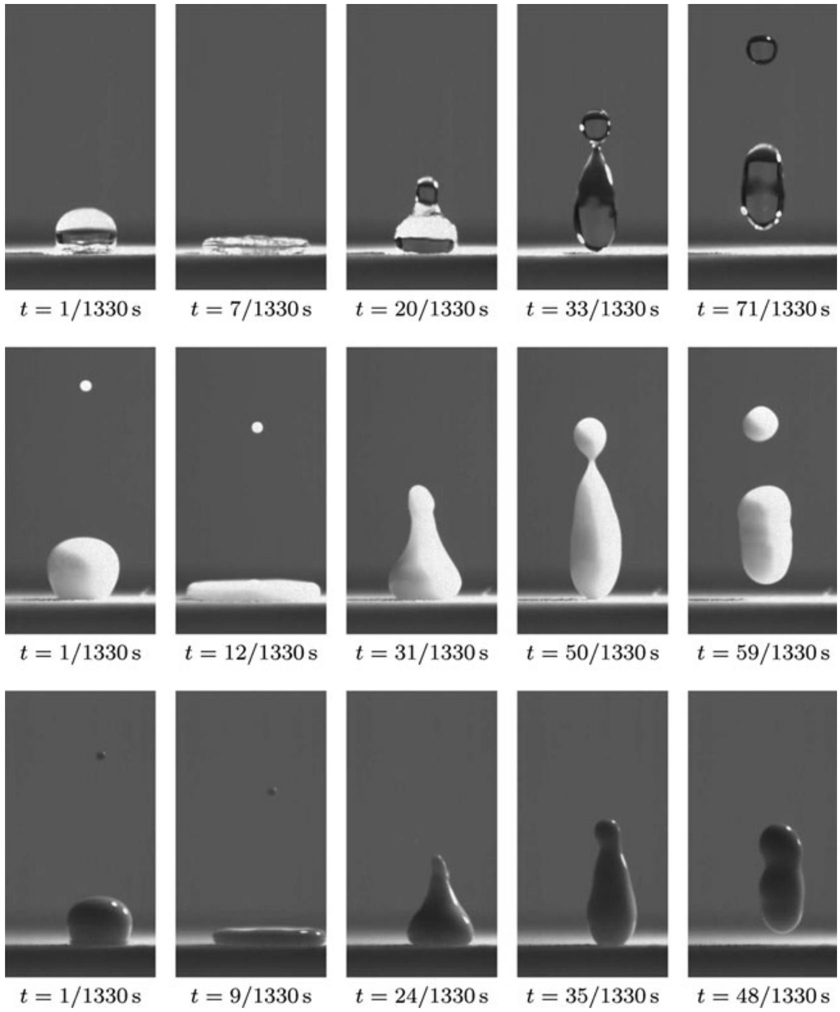

Fig. 3 Bouncing behaviors of three kinds of suspension droplets of V_B = 30 μL on a hydrophobic surface. *Top* DI water, *middle* $CaCO_3$ 1.0 wt%, *bottom* $CaCO_3$ 10 wt%

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Reference

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