WATER DROPLETS ON A SUPERHYDROPHOBIC SURFACE (FLOW VISUALIZATION FALL 2016)

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ABSTRACT

This paper describes the art and physics of the interaction between a superhydrophobic surface and water droplets. The experiment was performed for the Flow Visualization course at the University of Colorado at Boulder for the Fall 2016 semester. The project was performed as a team (Team 2) that includes: Sierra Castillo, David Leng, and Kate Gresh. On October 11, 2016 Team 2 met at the Integrated Teaching and Learning Laboratory at the University of Colorado at Boulder. Images were taken of water droplets dyed with food coloring on a non-manufactured superhydrophobic surface.

The superhydrophobic surface was created by S. Castillo using a glass plate surface and isopropyl alcohol. The glass was coated with the isopropyl alcohol, and then it was placed under the high heat conditions of a flame to produce the superhydrophobic surface.

The image was taken using a Nikon D3200 camera. The focal length was 32.0 mm. The ISO was 1600, aperture was 4.8, and the exposure was 1/8 sec. Post-processing was performed using Photoshop and included rotation, cropping, saturation and color adjustments, and editing to remove white border edges.

INTRODUCTION

The first team image for the Flow Visualization course at the University of Colorado at Boulder was completed using a digital single lens reflex (DSLR) camera. The images taken were focused on the fluid interaction between water droplets dyed with food coloring and a superhydrophobic surface made with a glass plate and isopropyl alcohol. The images show how the fluid interacts on a superhydrophobic surface that prevents dispersion and the puddle effect typical for water resting on a surface.

Creating a Superhydrophobic Surface

In order to create a superhydrophobic surface, the following items are needed [Ref 4]:

-Isopropyl alcohol (90%)
-Small dish (ceramic)
-Lighter
-Glass plate
-Ceramic plate
-Safety glasses

The process involves a flame, so safety glasses are recommended. The following steps were taken:

1. Fill the dish with a small amount of isopropyl alcohol.
2. Light the dish on fire.
3. Holding the glass from the bottom, wave it over the flame to begin coating it in the soot from the flame. Note: The glass used was thin, so to avoid cracking it we held the glass over the flame for 1 min and let allowed to cool for 10 min.
4. Repeat the process until the glass is black (about 4-5 min). During the cooling cycles, the glass was placed on the ceramic plate to avoid damaging the table the setup was resting on.
5. Finally, cool the glass to room temperature (approximately 15 min). The coated glass is now a hydrophobic surface (See Figure 1 and Figure 2).

Figure 1: Superhydrophobic Surface (Soot Coated Glass) With a Single Water Droplet - Created by Team 2

Figure 2: Team 2 Image Showing the Superhydrophobic Surface – D. Leng

Fluid Physics

Fluid interaction with a hydrophobic surface is an area of current research studies. Team 2 chose to investigate the fluid physics interaction, and visually captured the unique fluid phenomena for the first team project. The wetted surface interactions with the fluid is well demonstrated in the image with the hydrophobic surface and water droplet clearly showing a well formed droplet with a greater contact angle. The wetted surface interaction with the fluid on the non-hydrophobic surface clearly shows a smaller contact angle between the water droplet and glass plate surface, which produced a puddle effect.

The contact angle (θ) on a wetted surface is given by Young's Equation (1805) as [Ref 1]:

$$\text{Cos}\ \theta = (\gamma_{SV} - \gamma_{SL}) / \gamma_{LV}$$

γ_{SV} = Solid Surface Energy
γ_{SL} = Solid-Liquid Interfacial Energy
γ_{LV} = Liquid Surface Tension

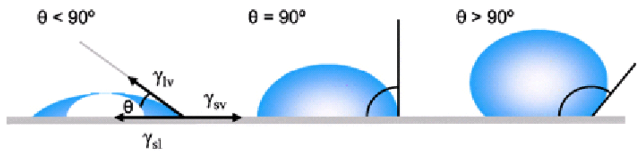

Figure 3: Contact Angles – Formed by sessile liquid drops on a smooth homogenous solid surface [Ref 2]

The contact angle (θ) on a rough surface is defined by Wenzel's Equation where roughness is determined by the roughness factor and has a value greater than one [Ref 3]:

$$r = A_{rough} / A_{flat}$$

r = Roughness Factor
A_{rough} = Area of the rough surface
A_{flat} = Area of the flat surface

The contact angle (θ) on a rough surface is given by Wenzel's Equation [Ref 4]:

$$r\ \text{Cos}\ \theta = r\ (\gamma_{SV} - \gamma_{SL}) / \gamma_{LV}$$

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A hydrophobic surface exhibits and fluid interaction with a contact angle greater than 90 degrees [Ref 2]. Superhydrophobic surfaces exhibit contact angles greater than 150 degrees with water, as shown in Figure 5 [Ref 2]. Fully wetted surfaces exhibit a contact angle of 0 degrees with water and show a puddle, as shown in Figure 2 [Ref 2].

The two parameters which varied and are shown in the images, include the Solid Surface Energy and the Solid-Liquid Interfacial Energy. The parameters determined the contact angle of the droplets with the surface. The liquid surface tension (γ_{LV}) for all droplets is negligibly the same with all droplet compositions consisting of water and food dye.

As shown in Figure 4, the Solid Surface Energy (γ_{SV}) varies with half of the plate having higher surface energy after being treated to create the hydrophobic surface. The greater contact angle of the droplets on the treated surface are shown with the edges of the droplets well formed and the droplet form being elliptical to spherical varying on volume size. As expected, the droplets on the non-treated surface as shown in Figure 3, lack form with height, giving the appearance of a puddle, and the contact angle is very small.

As shown in Figure 4, the Solid-Liquid Interfacial Energy (γ_{SL}) is consistent throughout the diameter of the majority of the droplets due to being placed on a surface with a single surface energy. A few droplets were placed at the boundary of the hydrophobic surface and non-hydrophobic surface. These droplets exhibit similar contact angles consistent with the surface in which they contact. The treated surface shows a lower solid-liquid interfacial energy and larger solid surface energy as displayed with a greater contact angle.

Figure 4: Superhydrophobic Surface and Non-Hydrophobic Surface Boundary

Figure 5: Team 2 Image Showing the Superhydrophobic

Surface – S. Castillo

Photographic Technique

The photographic technique included the following equipment:

-Nikon D3200 DSLR Camera

The photographic settings used for the original image (Figure 6) were:

-Focal Length: 32.0 mm
-ISO: 1600
-Exposure: 1/8 sec
-Aperture: 4.8
-Mode: Manual
-Image Size: 6016 x 4000
-Resolution: 240 Pixel per Inch

Figure 6: Team 2 Original Image – K. Gresh

Post-processing included: rotation, cropping, saturation, and color adjustments and use of editing tools to remove white border edges (Figure 7). The final image size is 5608 x 2183. The final resolution is 240 pixels per inch.

Figure 7: Team 2 Edited Image – K. Gresh

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