Patrick Cotter
Flow Vis Spring 2013

Team Project #1: Boo Bubbles

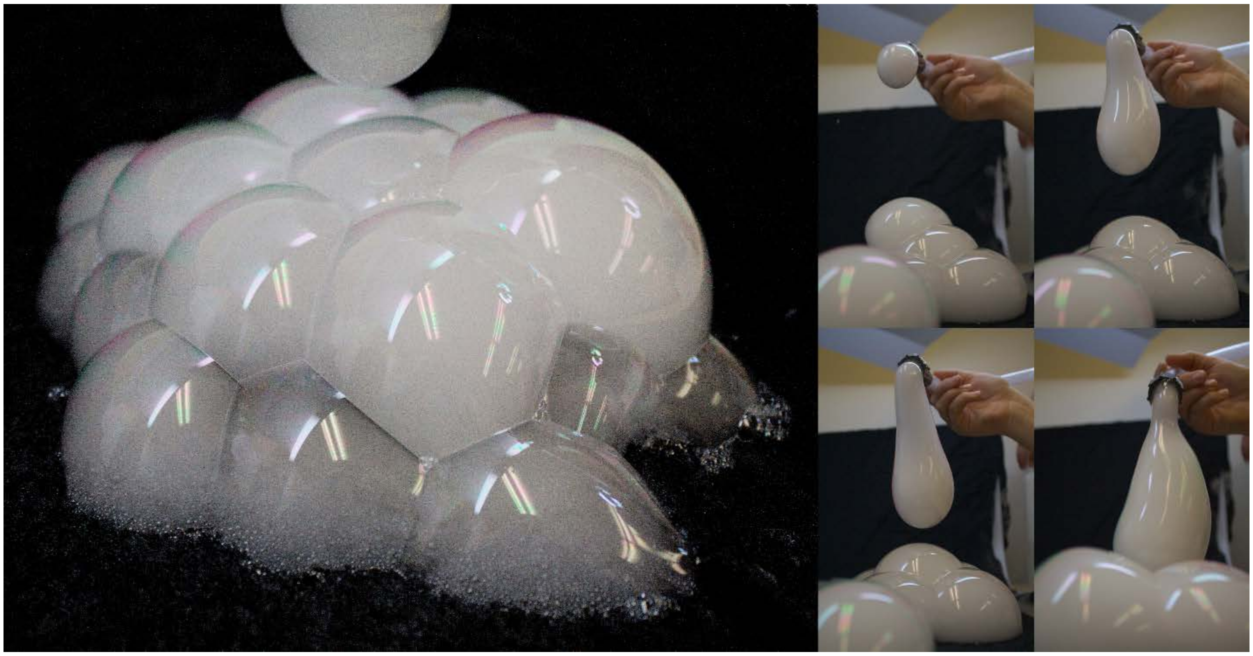

Figure 1: At left, bubbles filled with sublimated carbon dioxide gas from dry ice form a cluster. At right, the process of bubble formation can be seen

Above in Figure 1 is my submission for the first team project in the Flow Visualization course at the University of Colorado Boulder. The team consisted of myself, Matt Bailey, Elizabeth Crumb, Jon Horneber, and Shea Zmerzlikar. We chose to replicate a phenomenon called "boo bubbles" that we had seen online. I was hoping to photograph a single bubble bouncing off of a pile of bubbles but instead ended up with the capture of a pile of bubbles you see above along with a sequence depicting bubble formation. The physics of the stacking of bubbles is quite interesting and will be described in more detail later in this report.

The apparatus used will now be explained in further detail. A hole was made in a cylindrical container near the top. A hose

Figure 2: Container fabricated to create bubbles

was attached to this hole and the container was filled with water. A bowl was filled with a water and dish soap mixture. Dry ice was added to the cylindrical container full of water and the lid was placed on the container. The end of the hose was then dipped in the soap and water solution and the pressure from the dry ice sublimating in the water forced CO_2 through the soap film, forming bubbles. This setup is shown in Figure 2 above.

Soap bubbles are the result of a soap film attempting to reach a configuration with the lowest surface area. Furthermore, when two soap bubbles merge, they do so in such a way that still minimizes surface area. When 3 bubbles merge, the borders then always meet at 120 degree angles. When 4 bubbles merge, the borders always meet at about 109.47 degrees. This comes from $\arccos\left(-\frac{1}{3}\right)$, otherwise known as the tetrahedral angle. In general, soap films such as the one being photographed here are governed by Plateau's Laws. Besides the 2 conditions about the intersections of bubbles stated above, these laws say that soap films are formed of entirely smooth surfaces and the mean curvature of a single surface is always constant. This means that the soap film will always be formed of smooth, spherical bubbles. Because of these laws, namely the ones governing the angles of bubble intersections, you can observe a hexagonal pattern in the bubble borders in the photo at the beginning of this report. The main force at work here is surface tension. This is what maintains the form of the bubbles and causes them to form in the first place.

Here the visualization technique is the use of the CO_2 vapor to fill the bubbles. This milky, white vapor provides a nice backdrop which I believe makes it easier to see the borders of the bubbles where they intersect. As stated before, this vapor is a result of dry ice sublimating rapidly in water. We did find that the temperature of the water had an effect on how thick the vapor was. When warm water was placed in the cylindrical container, the vapor was thick and opaque. The water would cool down over time, causing the vapor to become thinner and more transparent. We replaced the water with warm water many times during the course of the photo shoot. Another challenge was getting the bubbles to sit on the surface in the photograph. The black surface is a sheet of velvet-like, synthetic material. At first, this material would pop the bubbles on contact. However, once the velvet became wet with soapy water, the bubbles would stick to the surface and remain for some time. Also, a higher concentration of soap in the water/soap solution seemed to make the bubbles last longer as a result of higher viscosity. By the end, we were working with about a 1:2 ratio of soap to water.

The lighting for this image didn't prove much of a challenge, as the shutter speed could be fairly slow. The photos were taken against the aforementioned black velvet background under three cylindrical, fluorescent bulbs. Some group members also utilized a magnifying fluorescent desk lamp, but I deemed this unnecessary. A flash was neither used nor necessary.

This photo was taken with a Canon EOS Digital Rebel XS camera at a resolution of 3888 x 2592. The field of view here is about six by six inches and the photo was taken from a distance of about one foot. The settings on the camera were as follows:

- Shutter Speed: 1/250 second
- Aperture: F/4.5
- Focal Length: 29 mm
- ISO Speed: 800
- Flash: No
- Exposure Bias: 0

In post processing I adjusted the contrast curve and brightness to try and make the bubble borders as visible as possible and have nice contrast between the white bubbles and the black background. I did not change much, because whenever I did I ended up with a lot of noise. The final image is far noisier than I would like, I believe it was a result of the high ISO used to capture the image.

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Overall, I do like this image. It is interesting to see such a regular hexagonal pattern in the borders of a random pile of bubbles. I enjoyed learning about the physics of bubbles in the course of doing this report and the engineer in me loves that there is such a defined set of rules for something so seemingly random. I think my image successfully shows the physics outlined in this report, however I wish that it wasn't so noisy. If I were to go back and take this image again, I would make better use of the setting on the camera and certainly shoot at a lower ISO. An idea I have to further develop this idea is to explore the behavior of smaller bubbles. I think it would be interesting to form a uniform layer of bubbles on the surface of water and overlay lines showing the exact angles that are formed at the intersections. Overall I really enjoyed this project, and I hope you do as well.