Get Wet: Sublimation and Surface Tension

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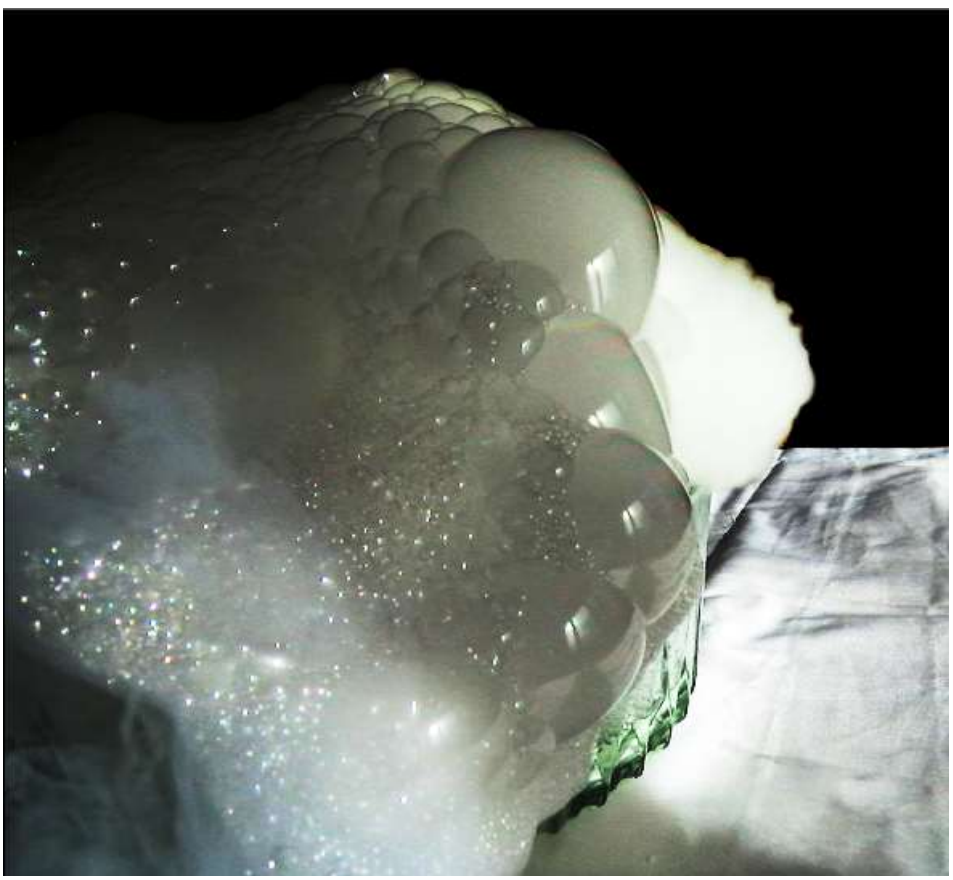

Introduction

When carbon dioxide is compressed into a solid-state form, commonly known as "dry ice," one can observe a somewhat rare physical phenomenon called sublimation. This project shows how sublimation can become a driving force for a beautiful flow observation when put under the right conditions, more specifically when solid carbon dioxide combines with liquid water and dish soap. While the dense fog in the soapy mixture behaved in a somewhat unpredictable manner, the project results told much more than what was the original focus of the flow visualization. The picture itself gives a detailed description of multiple aspects of the fluid flow, from the surface tension physics to the chemical kinetic rate, even explaining how the phase changes of the fluid affect the manner in which the flow moves.

Behind the Physics of the Flow

A lot of physics is at work in this picture, some quite obvious mixed with more subtle interactions and forces at work. The ones which are most readily recognizable are the bubbles that form from the soap creating thin films for the dense fog of the water vapor/carbon dioxide mixture to be trapped inside of before being released to the atmosphere. However, what is not pictured is the sublimation which transforms the solid carbon dioxide to a gaseous state, which in turn causes the water to condense in the air around it and create a very dense fog.

When a bubble forms from a soap film, the pressure inside of the bubble, created by the dense fog of the water and carbon dioxide, causes the soap film to create a shape which minimizes the volume needed to contain the fluid: a sphere. What creates the different size bubbles depends directly on the amount of pressure inside the bubble[1]. The flow of fog is driven mostly by the pressure that the trapped carbon dioxide creates after sublimating and rising past the water, pushing onto both the incompressible water surface and the soap film. When the pressure inside the bubble is larger than the pressure outside of it, the surface tension keeps the bubble from popping but stretches the soap to a thinner and thinner film until eventually the pressure inside the bubble is too great for the

[1]Boys, C V. *Soap Bubbles: Their Colours and the Forces Which Mould Them*. London: S.P.C.K, 1924. Print.

film to contain it, leading to the bubble collapse and allowing the fog to disperse into the surrounding atmosphere.

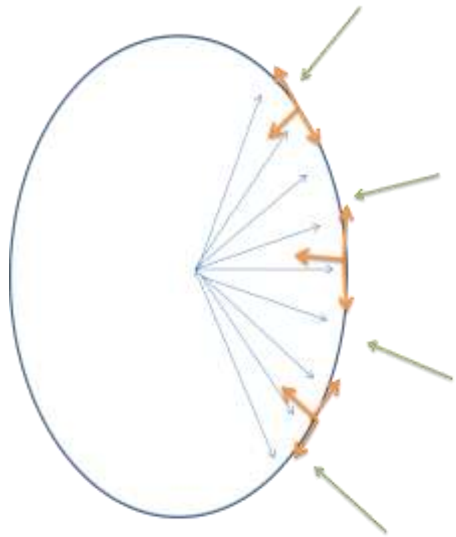

Figure 1: When the pressure overcomes the surface tension of the soap and air outside the bubble, the result is a collapse of the soap film and a dispersion of the fog.

One way to determine the pressure that was required to cause the bubble to burst is by using the Laplace Pressure Equation[1]:

$$\Delta P \equiv \gamma \left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

$$R = Radii\ of\ curvature, \qquad \gamma = Surface\ Tension$$

To give a sense of scale, the bowl is 4 inches tall, allowing the radii of curvature for the elipse to be approximately 2.5 cm and 5 cm. Assuming the surface tension of soap film is about 25 mN/m[2], that gives a pressure difference of about 1.5 Pascals. Once the pressure inside this particular bubble reached 1.5 Pascals above the local atmospheric pressure, the bubble popped and allowed the fog to disperse into the atmosphere. As the equation shows, in order for the smaller bubbles to pop, a much bigger pressure difference was required, which explains why the larger bubbles would pop before the smaller ones would. The direction in which the fog diffused was distributed in an outward direction perpendicular to the bubble surface. This explains why the flow of the fog was shaped very

[1] Weaire, D L, and Stefan Hutzler. *The Physics of Foams*. Oxford: Clarendon Press, 1999. Print.

[2] Zimmerman Jones, A. (n.d.). Experimental Surface Tension Values. *Experimental Surface Tension Values*. Retrieved February 7, 2011, from http://physics.about.com/od/physicsexperiments/a/surfacetension_5.htm

similarly to the surrounding bubbles right when it popped. The fog flowed in this manner and then would disperse into the atmosphere.

Set Up

The apparatus for this project is quite simple but not very controlled in terms of exact quantitative measurements for the system. A gallon-size serving bowl was used to hold the 1.5 pounds of dry ice, which varied in piece sizes from about 8 cubic inches to as little as 0.125 cubic inches, along with some grain-size pieces used from the shavings off the bag which the dry ice came in. The water and soap were pre-mixed at a ratio of about 2 cup of water to every teaspoon of concentrated dish soap. A white tablecloth was set underneath the bowl and out toward the window to create a little more reflection of the natural sunlight coming in through the glass door.

The glass door allowed the sunlight to enter, with the picture taken at 1:12 PM with very little cloud cover, allowing a great amount of light into the picture. Originally the intention was to have no cover of the sunlight and allow the bubbles to be fully exposed. However, due to the limit of the door size, a shadow was cast upon the side closest to the camera. However, instead of taking away from the picture, it instead enhanced the view of the individual bubbles and allows a more detailed shape of the bubbles. Using a Casio Exilim EX-H5, an aperture of f/4.8 gave a good field of view to see the flow as it progressed from the early stages of the fog formation to a more matured flow rate as the dry ice began to reduce in size. The camera was set at an ISO value of 200, shutter value of 4 seconds, a focus length of 15 cm and was shot at a distance of about 22 inches from the middle of the bowl. This simple set up allowed the focus to be on the fog flow. This particular camera gives a 12.1 megapixel output, with a final picture size of 1200 x 1200 pixels after cropping.

Not very much photo editing was required for this because the original picture provided quite a bit of information with the appropriate exposure and aperature. Even though the background needed to be removed from the original picture, the original background did not hinder the overall picture, but instead helped to produce a higher contrast picture. While the shadow in front of the subject area created a hard visualization of the bubbles, with a sharper contrast on the photo editor (PhotoPlus) using color curves, the shadow actually helped to provide a contrast between the white fog and the soapy film over them to show separation between the individual bubbles. The overall picture is simple but the high contrast provides a good example of sublimation rates with a non-uniform dry ice surface area reduction.

Result

The image shows a great deal about how a pressure-driven gas expansion leads to a uniform flow into the surroundings, moving from a solid-state carbon dioxide block to a gaseous mixture of water vapor and carbon dioxide. What I like the most about this image is the deep contrast between the fog inside the soap film and the surroundings, along with the perfect timing to create a great visual of this flow. One aspect of the picture which is not particularly pleasing to me is the choice on the shooting distance since it is somewhat blurred around some of the bubbles in the immediate foreground and somewhat in the background.

Overall the picture fulfilled my intent of capturing a pressure-driven flow originating from sublimation and a temperature difference to create a dense enough fog to visualize this. The biggest question I have after taking the picture is why the bubbles were so diverse in pressure difference considering the proximity of each of the dry ice pieces in the water solution. This project could go further by exploring the importance of surface exposure on the dry ice to the water and how this affects the pressure of the carbon dioxide being released, or even in how temperature of the water affects the rate at which the bubbles are produced, which would explain more about the exact relationship temperature has in this phenomenon.