Ice Clouds

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The image to the right, *Ice Clouds*, is a submission for the 2013 Spring Flow Visualization class for the "Get Wet" assignment. The purpose of this initial assignment was to get students thinking about different fluid flows and how to capture them for class.

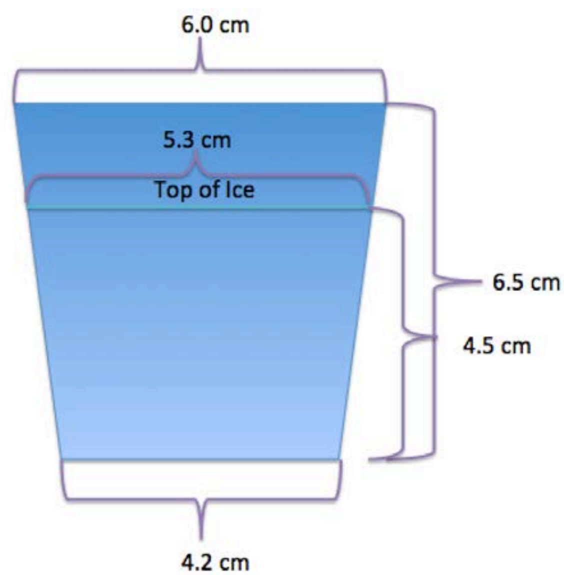
Ice Clouds is an image capturing the clouding effect commonly seen in household ice cubes. The right side of the image, that has a blurry feel to it, is the "cloud" that forms in ice cubes when impure water freezes too fast. The bubbles in the image, both in and out of the cloud, also form when water freezes too quickly. Water, especially tap water, tends to have dissolved gasses in it, such as oxygen, which contributes to the bubble formations in the ice. The bubbles in the image are pockets of air that tried to escape their frozen surroundings too late. As the temperature decreases, the amount of air that can be dissolved in water increases. However, once the freezing process begins, the water cannot retain the dissolved air and thus air bubbles are formed [1]. Most of the frozen bubbles that can be seen in the *Ice Clouds* image are approximately in the range of ½ to 3 millimeters in diameter. The air bubbles are trapped in the ice because water freezes from the outside in. Not only does water freeze from the outside in, pure water (H_20) freezes first on the outside and pushes the impurities, such as the dissolved gases and minerals found in tap water, to the center of the mold containing the water/ice combination. Different minerals found in tap water are most commonly calcium, sodium and magnesium [2]. These impurities contribute to the cloudiness of homemade ice.

The formation of bubbles in the freezing process of water has been modeled in previous work done by K.W. Lee, C.C. Huang and P.S. Wei in their paper titled, *Nucleation of Bubbles on a Solidification Front – Experiment and Analysis* [3]. The paper describes and mathematically models the conditions needed for a bubble to be formed. The condition that needs to be satisfied for a bubble to form is given by:

$$\frac{\partial \Delta F}{\partial R} \leq 0 \qquad R \geq R_c$$

Where ΔF is the change in the Helmholtz free energy and "R_c is the critical radius corresponding to the maximal change of Helmholtz free energy" [3]. For details of the experiment, analysis and results of bubble formations in ice, please refer to the paper which has been cited under *Sources [3]* at the end of this paper.

Most fluids, when in their solid form, are denser than when in their liquid state. However, water does not follow that norm. Water has an unusual property, where upon freezing, it experiences expansion, and thus has a lighter density than that of its liquid form. The additional hydrogen bonding that occurs during the freezing process can explain this behavior. When in its liquid form, Oxygen atoms have two hydrogen bonds and an average of *4.5 nearest-neighbor* water molecules [4]. When in its solid form (ice), every Oxygen atom bonds to four hydrogen atoms, which only allows for *4 nearest-neighbor* molecules [4]. It can be thought of that ice has fewer neighbors and needs to spread out (expand) more than water. This single property of water has caused people problems for a long time. A major problem seen because of this would be ruptured water pipes due to cold temperatures freezing the water inside and expanding into ice.

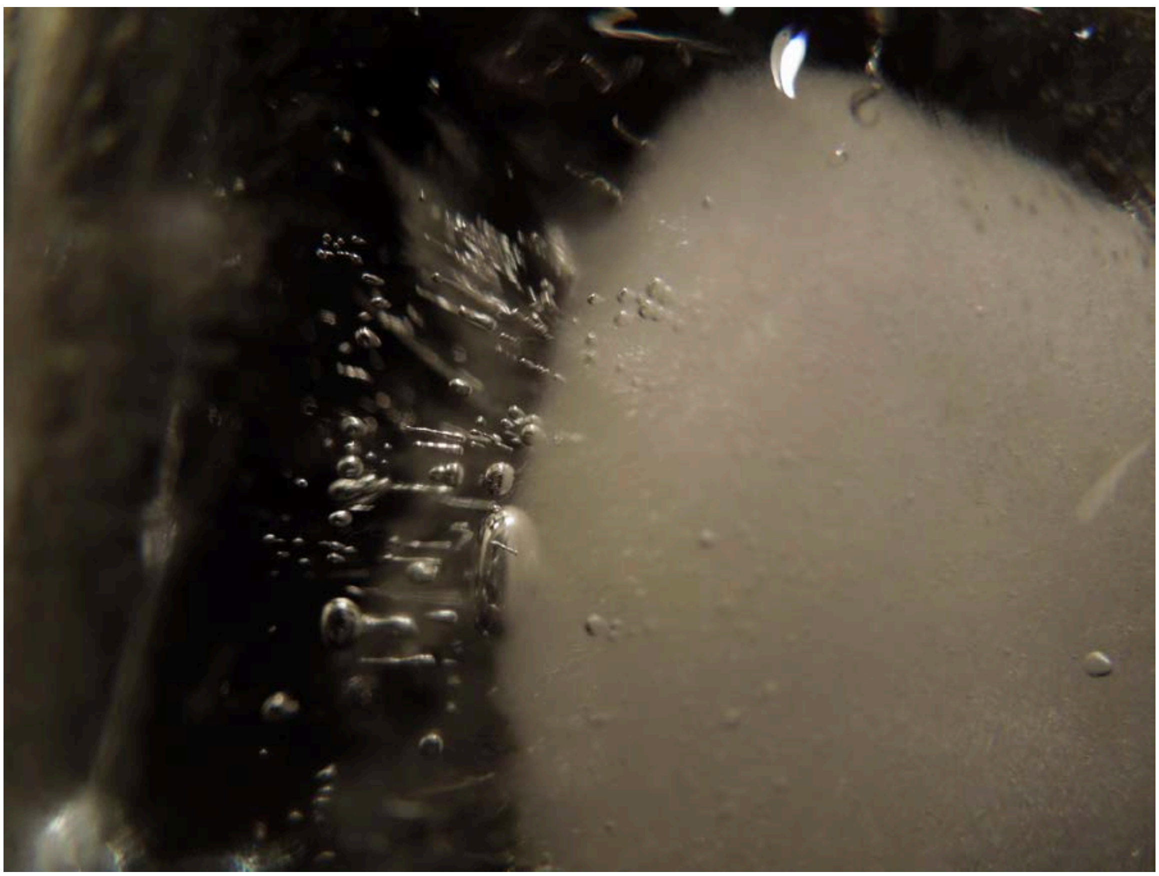


A normal ice cube (from a typical ice cube tray) was too small for the camera to focus on, so a small tupperware was used to freeze water in. The dimensions can be seen in the schematic above. The volume of ice in the tubberware was 109.012 cubic centimeters. The corresponding volume of water can be calculated easily. Assuming that the mass stays the same by the conservation of mass principle we can obtain the following equation:

$$\frac{V_{ice}}{V_{water}} = \frac{m/\rho_{ice}}{m/\rho_{water}} = \frac{\rho_{water}}{\rho_{ice}}$$

Using a density of 1,000 and 917.43 kg/cubic meters for water and ice respectively, the initial volume of water can be found to be 100.01 cubic centimeters using the above equation.

When visualizing the image, the goal was to capture the unique patterns and lines that branch out from the cloudy center of ice cubes. Tap water from the sink was used to fill ice cube trays; however they were either too cloudy or too small to take a good picture, so a small tubberware was used. Once the water was frozen, I took the ice and put it on a shiny black surface and used the lighting from a 40W incandescent light bulb overhead for the photo-taking environment. As the ice melted, water droplets formed on the outside of the ice and dripped down creating a puddle of water underneath the ice. Once water droplets formed on the ice cube, they had to be wiped off. They acted like a lens, distorting the image. Though it made for an interesting shot, it wasn't intended.



It took a lot of playing around with camera settings, lighting and the ice to capture the image I wanted. The camera used was a Nikon S8200 and it had trouble focusing on the inside of the ice. This was due to the auto focus of the camera, which wanted to focus on the outside of the ice cubes. The original image for the assignment "Get Wet", which can be seen in the image above, was shot with a shutter speed of 1/6 of a second, an aperture of f/3.3 and an ISO of 200. Unfortunately, the Nikon S8200 does not let the user manually adjust the shutter speed or the aperture; however, it does grant the user access to adjust the ISO sensitivity. A higher ISO was used to capture other photos, however, the image became blurry and a little grainy, so a lower ISO of 200 was used. The focal distance of the camera during this image was 4.5mm. The slow shutter speed was not intended and a tripod was not used. Placing both wrists on the same surface the ice cube was sitting on made a pseudo-makeshift tripod which steadied my hands for minimum motion blur. This image was then post-processed by using the program ViewNX2 by Nikon. The image was cropped and had its sharpness increased slightly to bring the large center bubble into better focus. The DHS lighting was then increased to make the image a little brighter.

The image reveals a lot behind the freezing of water, more than I was expecting. It's discernable, in the unedited version that the bubbles seem to be traveling outward from the cloud, towards to the top of the cube. I believe I fulfilled my intent for the image. If I could take this further, I would take the image with a camera where the shutter speed could be controlled. Also, for future studies, it would be neat to film water freezing, and to put some dye in there to see how the fluid moves inside the ice cube in the midst of the freezing process.

Sources:

[1] Lersch, Martin. "Ice Cubes and Air Bubbles." *Khymos RSS*. WordPress, 13 Apr. 2008. Web. 10 Feb. 2013.

[2] Eisenberg, Mark, Arik Azoulay, and Phillippe Garzon. "Comparison of Mineral Content of Tap Water and Bottled Water." *PMC: US National Library of Medicine* (2001): n. pag. Mar. 2001. Web.

[4] Wei, P. S., C. C. Huang, and K. W. Lee. "Nucleation of Bubbles on a Solidification Front—experiment and Analysis." *Metallurgical and Materials Transactions B* 34, no. 3 (June 1, 2003): 321–332. doi:10.1007/s11663-003-0078-x.

[3] Callister, William D., and David G. Rethwisch. "Secondary Bonding or Van Der Waals Bonding." *Materials Science and Engineering: An Introduction*. 8th ed. Hoboken, NJ: John Wiley & Sons, 2010. N. pag. Print.