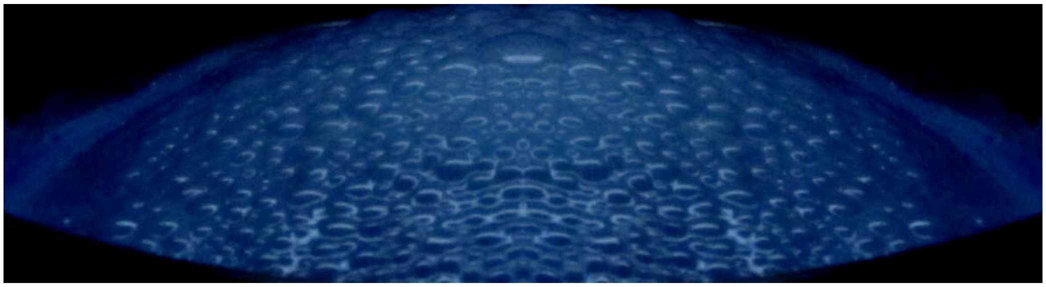
Sreyas Krishnan
4/11/2012
Flow Visualization
Team Photo #2



For Team Photo #2, I decided to capture a phenomenon that occurs fairly often but is also one that people take for granted or do not notice. This phenomenon is the boiling of milk. My initial goal was to show the patterns that were created on the surface of the milk (on the 'curd') after four minutes under maximum stove heat, however I noticed something more interesting and unusual about milk than most boiling fluids. When boiling a pot of water, the bubbles burst at the surface while steam rises and floats away. However, when boiling milk, the bubbles instead build up on top of each other until they completely fill the pot. Ultimately, the final product looks visually and texturally intriguing.

The flow apparatus is a ten-inch diameter and five-inch deep stainless steel pot that is placed on an initially cool stove. Then, approximately 1 cup of whole-milk is poured into the pot, and the stove temperature is immediately increased to the 'high' setting. This milk will form a somewhat thin layer on the bottom of the pot. At this time, food dyes can be applied to the milk in order to affect the final color of the milk in the image. This food dye will not affect the color of the bubbles or the steam physically, but since both of these things are translucent, it will affect the final color saturation of the image if the light source is directly above the pot. For my particular image, I chose to use blue dye because it appears to give the image an eerie glow. After approximately 4 to 5 minutes, the milk will boil and bubbles will fill the pot. This is when the picture should be taken, and the stove heat should be immediately cutoff in order to prevent overflow.

After some research, I found that the bubbles, which are defined as thin-walled, three-dimensional liquid shapes (usually spherical) that enclose another fluid, are formed in a process called cavitation. This occurs when the local pressure of a liquid drops below the vapor pressure. The most common way to achieve this is by raising the temperature of the liquid. There are a number of equations that can potentially be used to describe their formation, including the Rayleigh-Plesset equation (equation 1). However, not enough information is known about this particular set up to use this equation to develop any relevant values[2].

$$R\ddot{R}+\frac{3}{2}\dot{R}^2=\frac{1}{\rho}[p_g-P_0-P(t)]-4\nu\frac{\dot{R}}{R}-\frac{2\sigma}{\rho R} \qquad (1)$$

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In the case of milk, it begins boiling at a temperature of approximately 100 degrees Fahrenheit, which is nearly identical to water[3]. Once the milk reaches this temperature, cavitation begins to occur as the liquid part of the milk begins to evaporate in the form of steam, and bubbles form. However, the most fascinating part of this flow is that these bubbles do not burst, but rather, build on top of each other and stick. The explanation for this lies in the proteins in the milk. The proteins contained in the milk actually form a reinforcing layer on each bubble. Additionally, the fat content has an effect on the bubbles as well. Whole-milk tends to form bubbles quicker because of its high fat content, which is an important consideration for this experiment. Once the milk is cooled down, a thin layer of coagulated fat, known as curd, is seen on the surface[1].

The lighting for this photo was a fluorescent lamp held directly above the pot. In order to capture the phenomenon, the picture was taken from the front at a slightly downward angle, and only about six to twelve inches away from the pot. The whole visualization can be safely reproduced in a kitchen.

A Canon Powershot SX130 IS was used to take this photo and 1/1600 exposure time was used. This prevented any smudging or streaking while the bubbles moved. Then, in order to maximize the brightness of the image, f/4 and ISO-1600 were used instead of flash. The focal length was 5 mm and max aperture was 3.53. The final resolution was 2684 x 720 pixels showing a field of view of about 10 inches by 3 inches. Heavy editing techniques were applied in order to optimize the aesthetics of the image. Aside from an increase of contrast and slight decrease in brightness, the curves were altered to bring out the blues and the image was mirrored about largest bubble in order to make the image symmetric.

Overall, this image turned out great, and I'm very happy with the results. Perhaps a brighter light source and tripod could have further improved the results and allowed for less post-processing. Next, I would like to try this with other household fluids, like orange juice, or combinations of other household fluids to see how the results are affected. The introduction of moving air could yield good results as well.

Works Cited

1. Krampf, R. (n.d.). *Nicholas Academy*. Retrieved April 10, 2012, from http://nicholasacademy.com/scienceexperiment249milkbubbles.html

2. Lohse, D. (2003, February). *Bubble Puzzles*. Retrieved April 10, 2012, from Physics Today: http://physicstoday.org/journals/doc/PHTOAD-ft/vol_56/iss_2/36_1.shtml

3. University of Illinois at Urbana-Champaign. (n.d.). Retrieved May 5, 2012, from http://van.physics.illinois.edu/qa/listing.php?id=1451

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