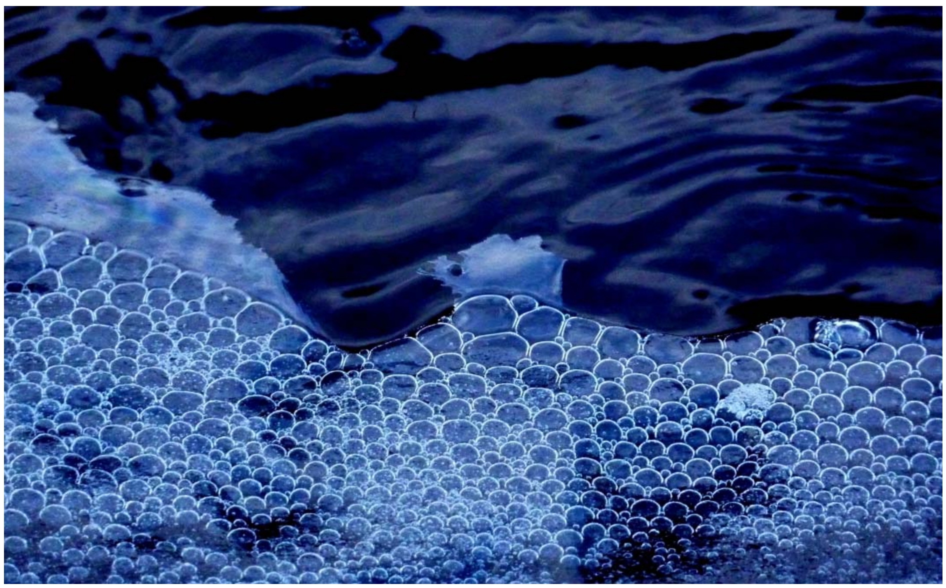
Flow Visualization: River Bubbles



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The purpose of this assignment was to "get wet" and to create a fluid phenomenon and capture it using photographic techniques. The intent was to show the phenomenon of a two phase flow revealed in the commonly known form of bubbles.

The flow apparatus consisted of nature and Tom's natural soap as shown in Figure 1. There was a patch of ice along the shore of the creek that extended between 1-1.5" into the water from the edge and was about 3mm thick. A drop of Tom's natural soap was inserted into the water right at the edge of the ice. Bubbles started appearing approximately two feet downstream, and got trapped underneath the thin but rigid piece of ice. The bubbles began to move and "breathe" with the current of the creek, got pushed up along the ice-water boundary, and did not disperse off. The bubbles had a variety of forces on them causing them to move along the surface of the ice, as shown in Figure 2. The fluid pressure is providing an upward force on the bubbles, keeping them afloat. The bubbles are bumping into one another and water is also flowing underneath causing the horizontal movement along the surface of the ice. The ice patch on the top is not only keeping the bubbles underneath it, but there is some force restraining the bubbles from dispersing off into the open flow of the creek.

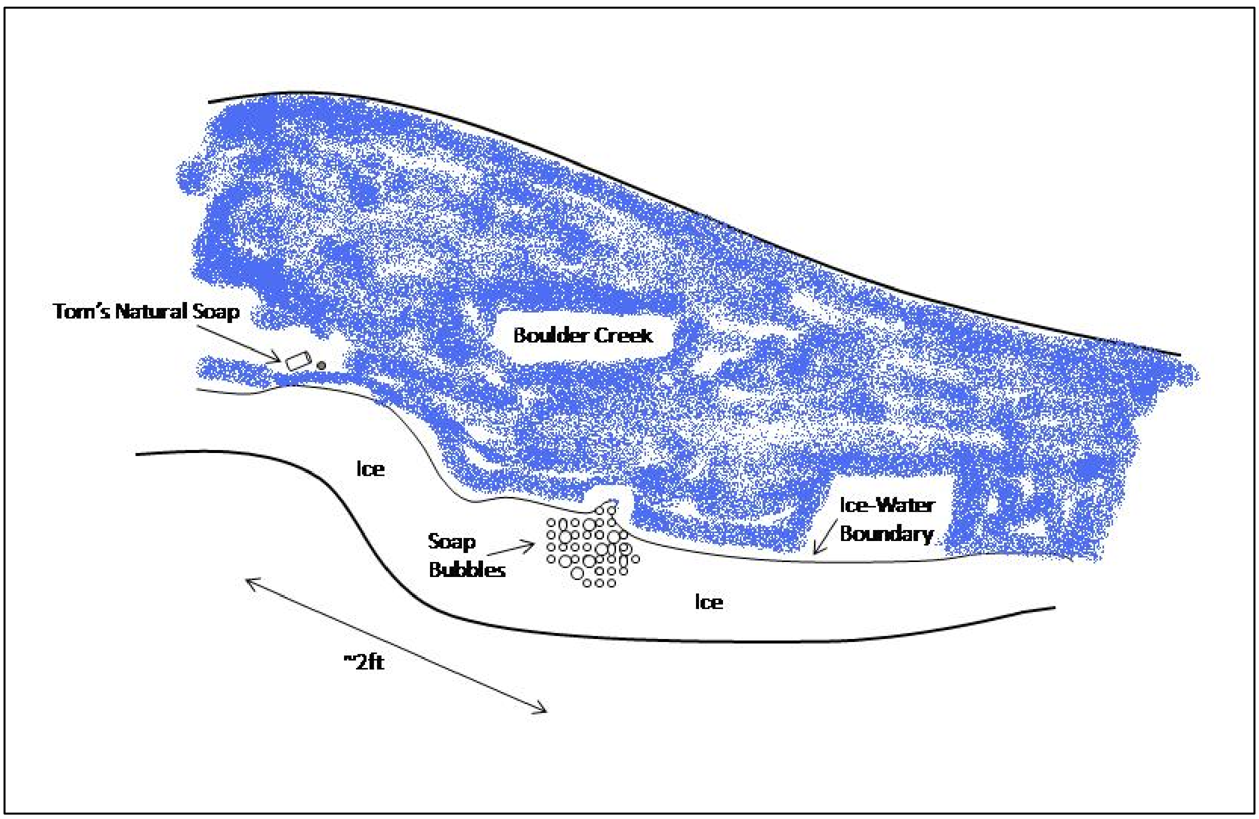

Figure 1 – Flow Apparatus

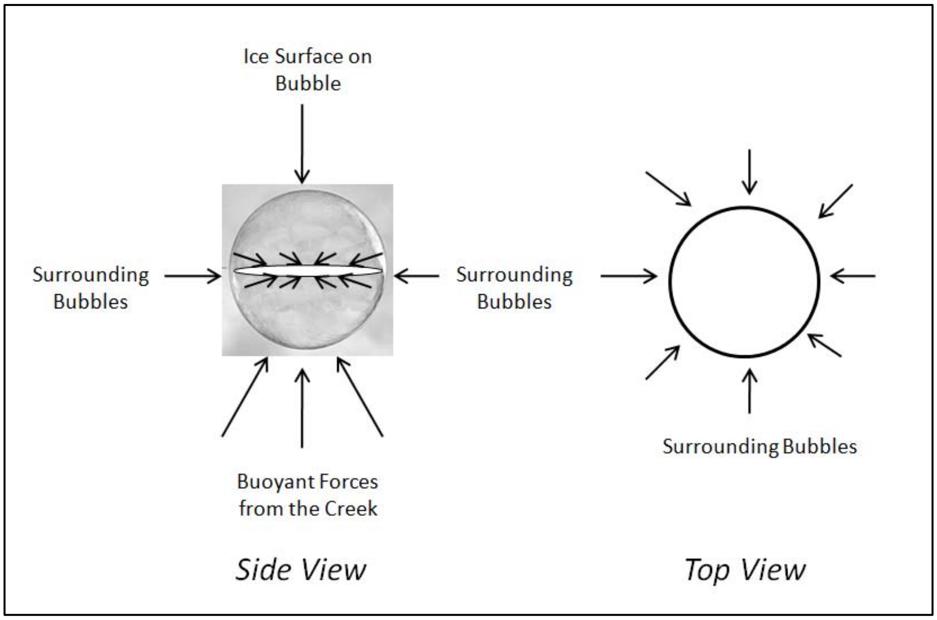

Figure 2 – Bubble Free Body Diagram

The soap bubbles formed in the first place due to surface tension. Surface tension is the result of cohesive forces in which molecules exert electromagnetic attraction on each other. The soap acted as a surfactant, which is a surface active substance whose molecules have a hydrophobic and hydrophilic part [1]. The soap decreased the surface tension to approximately one third the surface tension of pure water. The surfactant stabilized the bubble via the Marangoni effect [2]. This effect was due to the fact that surface tension gradients caused the liquid to flow away from regions of low surface tension. The soap strengthened the weak parts of the bubbles and tended to prevent them from stretching further.

The surface tension is what kept the bubbles together in a spherical shape, as a sphere has the smallest possible surface area for a given volume. However, this did not explain why the bubbles remained underneath the ice, even when the current pushed them to the outer edge. Rather than dispersing out from underneath, they took the shape of the edge of the ice, and pushed together. This was due to adhesion. Adhesion is the tendency of dissimilar molecules to cling together due to attractive forces. In this case, adhesion of the molecules within the bubble to the ice was great enough to withstand not only the forces from other bubbles surrounding, but also the horizontal force of the current and the adhesion between the bubbles molecules to the water molecules in the creek.

When one bubble met another bubble, the bubbles tried to minimize surface area by sharing a common wall. The smaller bubble of the two, which had the higher internal pressure, would bulge into the larger bubble. Regardless of their relative sizes, the bubbles always met at the common wall at 120 degrees, which can be seen in the image.

No visualization techniques were used needed in order to see the soap bubbles underneath the ice. However, the photo is relatively deceiving, as it is hard to tell whether the bubbles are above or below the sheet of ice. The video added to the image and showed the true flow of the bubbles with the current of the creek. It was about 4:30PM in the afternoon when this image was shot, so there was still enough natural light and a camera flash was not necessary.

The field of view is the extent of the world that is seen at the moment the photo was taken. Given that this photo was taken under macro mode, the lens could not be assumed to focus at infinity, which complicated the calculation a little bit. The equation to calculate FOV, taking magnification into account is:

$$FOV = 2 * \arctan\left(\frac{frame\ size}{focal\ length * 2 * (m+1)}\right)$$

$$m = \frac{focal\ length}{focus\ distance - focal\ length}$$

Using the parameters described in this paragraph, the FOV on the diagonal was calculated to be 163 degrees. The distance from the ice to the lens that lent to the best focus was about 12 inches, which is equivalent to 304.8mm. The digital camera used was a Panasonic DMC-ZS1. The original photo had X and Y pixel dimensions of 3648 and 2736 respectively. The photo was cropped down to 2244 in the Y direction. Both X and Y had a resolution of 180 with the resolution unit being inches. This gave an X and Y frame size of 20.27 in by 12.47 in, which is 23.8 in on the diagonal. Converting this gave a frame size of 604.5mm. The focal length used was 39.7mm. The shutter speed was 10/1250 sec, with an F-stop of f/4.7, a max aperture value of f/3.2 and an ISO speed rating of 1600. Besides cropping, the only other alteration to the photo was an increase in contrast using Picasa.

The image revealed a few neat fluid phenomena. There was adhesion between the molecules of the ice and the bubble surface that trapped the bubbles underneath the surface, despite the downward current of the water in the creek. There was interaction between the bubbles themselves; collisions that caused them to merge together, and separate as the moved. There was also a gradient in the velocity of the creek, causing the bubbles to move at different speeds in an overall downstream direction. The dark appearance of the water gave good contrast to the soap bubbles underneath the ice, the bubbles added nice texture, and the reflection on the water added depth. However, the video was needed to reveal the dramatic back and forth, almost “breathing” motion of the bubbles. A still image did not do this motion justice. The intent was fully met with the image made, and the motion of the bubbles remains intriguing. In developing this idea further, the variables in the system, such as water velocity, or the amount and size of the bubbles could be controlled to more clearly understand the physics.

References

1. *Heifer*. 2003. Web. 5 Feb. 2010. <http://www.bubbleology.com/Hydrodynamics.html>.
2. *Science Daily*. Web. 5 Feb. 2010. <http://www.sciencedaily.com/articles/s/soap_bubble.htm>.Hipschman, Ron. "When Bubble Meets Bubble."
3. *Exploratorium*. 1995. Web. 4 Feb. 2010. <http://www.exploratorium.edu/ronh/bubbles/bubbles.html>.