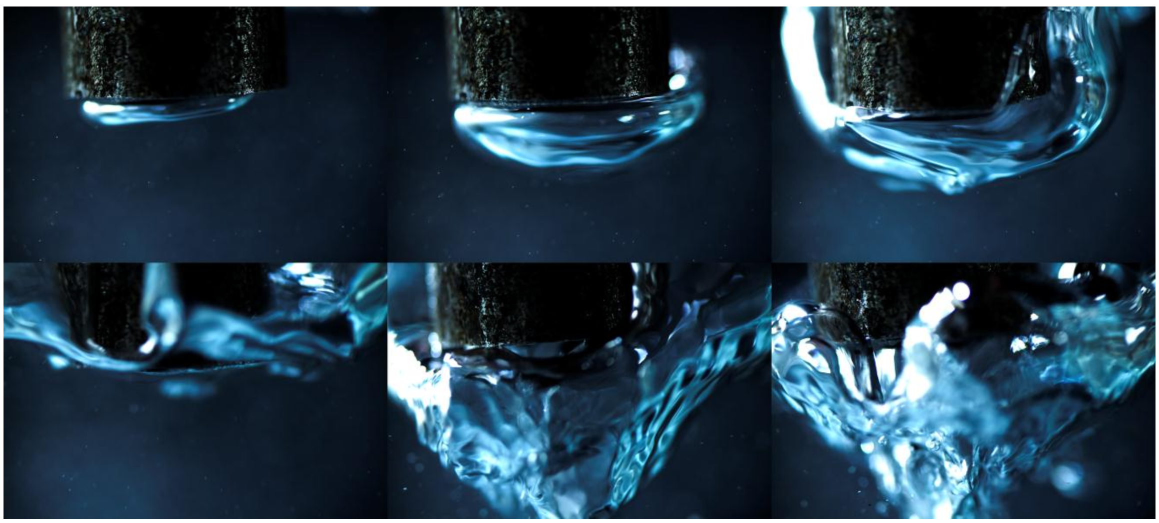
Tubular Flow



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Purpose:

This image was captured for the second team project for the class titled *Flow Visualization.* The group worked on the project in the Durning laboratory located in the basement of the engineering center at the University of Colorado at Boulder. Using a porous steel pipe and a fish tank filled with water, bubbles were blown just below the surface of the water in an effort to see the behavior in an underwater gas pocket as time progresses. This image was realized with the specific help of Elizabeth Crumb, Shea Zmerzlikar, Patrick Cotter and Jon Hornebrener; all students at the University of Colorado.

Apparatus:

The set-up to capture the image was a relatively easy one. It included two lamps, a hollow steel tube, and a 50 gallon fish tank filled with water. In figure 1, you will see the placement of each of these objects in order to capture the specific image. Placing the tube at a depth of an inch in the fish tank, breath was exerted through the steel tube at a constant rate. Simply put, the image shows the series of gas bubble formations and their explosive expansion upwards as the bubbles exit the tube.

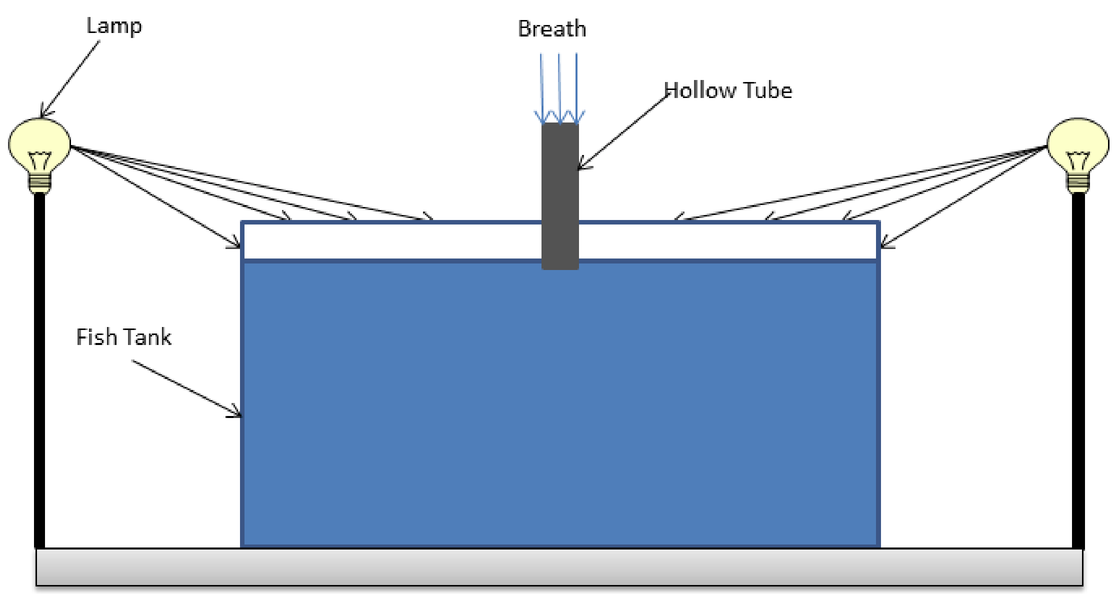

Figure 1: Flow Set-up

Flow:

The captured flow shows the first stage when the gas; which is simply carbon dioxide, just begins leaving the end of the tube. Following this initial stage, the underwater bubble expands as more carbon dioxide exudes from the tube tip.

Eventually the gas begins to rise in the water as the initial bubble separates and expands out around the end of the tube [1]. The last two frames show the interference between this first bubble formation and the new bubble formations. The wake from the previous gas bubbles leaving the tube collide with the new gas bubbles leaving the end of the tube and create a turbulent bubble formation as the old bubbles begin to rise around the old bubbles.

The reason for the stage as described in the previous paragraph include the surface tension of the water, the density of the gas in relation to the water it's being blown into and the force at which the gas is being forced into the water. I will first note that the average human can exert a pressure of approximately 12 psi with a very hearty blow. Taking into account the diameter of the tube as 1 inch, we can first calculate the force of the air coming out of the end of the tube:

$$F = PA = 12\,psi * \pi * (.5\,in)^2 = 9.43\,lbf = 41.95\,N$$

If we say that this force is approximately the force experienced at the surface of the water where the bubble exits the tube, and use the diameter of the tube to be the distance over which this force is exerted; we can calculate the necessary surface tension to withstand this situation and compare it to the actual surface tension of water [2]. As a note, standard units will be used from here on:

$$\gamma = \frac{F}{d} = \frac{41.95\,N}{.013\,m} = 3.23\,\frac{kN}{m}$$

Water at room temperature has a surface tension of 71.97 mN/m. This value is 4 orders of magnitude less than the surface tension required to rebound the force exerted through the tube [3]. This is the reason for the rapid expansion and formation of the gas bubble through the end of the tube. Since the water doesn't possess the tension forces to rebound the force of the breath through the tube, the bubble is created as the gas breaks the surface of the water and becomes trapped in a pocket. Now that we know the reason for the bubble formation we can move on and comment about the rapid release of the gas back to the surface of the water. The density of carbon dioxide is as follows:

$$\rho_{CO2} = 1.98\,\frac{kg}{m^3}$$

And the density of water is:

$$\rho_{H2O} = 1000\,\frac{kg}{m^3}$$

Due to the drastic differences in density, the gas bubble rises rapidly once it exits the end of the tube. This is the reason for the expansion around the tube between the third and fourth sections of the image. The bubble exits the tube and is immediately drawn upward by this density difference. The last thing to comment on is the turbulent wake appearance in the last two images. This has to do with the rapid expansion of the bubble once it is released out of the tube as well. As the bubble expands around the tube, the succeeding bubble interferes immediately with it and causes the first bubble to rise around the bubble currently exiting the tube.

Visualization Technique:

The main visualization technique used to capture this series was the macro lens on the camera. It was important to maximize the zoom on the lens in an effort to make the 1 inch tube fill as much of the photo frame as possible. Since it is nearly impossible to focus on the moving bubbles, the lens was first focused on the end of the tube and since the bubble emanated from that same point, they in turn became in focus. One of the more important techniques was to ensure that the first bubble formed in the series was captured before the turbulent wake was created by the following bubbles. This was done by capturing 6 frames in approximately one second. That is to say that the six frames viewed in the image occurred within approximately one second. There was a set of two halogen lights used to illuminate the photo, one on either side of the tank directed towards the center.

Photographic Technique:

The field of view of wach image is approximately 2 inches and was taken with a Canon EOS 5D Mark II camera. The lens was approximately 3 inches from the bubbles. See Table 1 for the exposure specifications.

Table 1: Camera Settings/Specifications

Lens focal length	90 mm
Aperture	f/3.2
Shutter Speed	1/1000 sec
ISO	1600

The pixel count of the image is 5000 x 2222, the pixel count of the image remained the same in the final image. With respect to resolution, you can see that every part of the image appears to be as sharp as possible. This is to say that the resolution of not only the whole image, but each individual image appears to encapsulate every decade of resolution as discernible by the human eye. Very little was done with regards to post-processing. The only thing that was altered was the contrast. This was in an effort to make the focus more on the expanding gaseous bubble pockets as opposed to the steel tube.

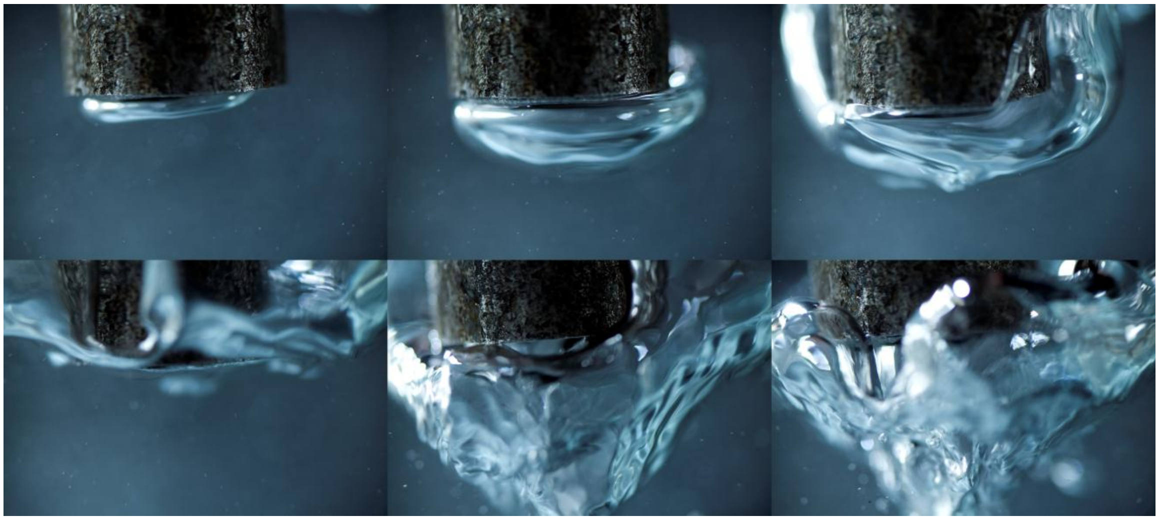

Figure 2: Original Image

Concluding Remarks:

The physics in this image are very straight forward; there is nothing overly complex and this is one of my favorite things about the picture. It is a stunning image captured with nothing but some water and a steel tube. The fluids of a gaseous substance submerged in a fluid are very well shown in this image. It shows the multiple stages of what occurs. My intent was more than realized and I am very pleased with every aspect of this image; the detail, focus and fluid capture are everything I'd hoped for. In the future, I would like to do this same experiment but use a high speed camera to capture the stages more in depth than are shown in just one image. It would be very interesting to see what is actually going on between sequences.

References:

[1] White, Harvey E. (1948). Modern College Physics. van Nostrand. ISBN 0-442-29401-8. Accessed April 4th, 2013

[2] physics.com. Website. Accessed April 4th, 2013
http://physics.about.com/od/physicsexperiments/a/surfacetension.

[3] Lange's Handbook of Chemistry (1967) 10th ed. pp 1661–1665 ISBN 0-07-016190-9 (11th ed.) Accessed April 4th, 2013