Formation of Bubbles

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Team Second Assignment: Flow Visualization MCEN 5151

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Introduction

The intent of this photograph was to capture the formation of soap bubbles and the resulting fluid motion on the surface. This photo was submitted for the second team assignment of the Flow Visualization class at CU Boulder. It should be noted here that this photo was created with the help of Andrew Locke and Jonathan Severns while they were visualizing buoyancy effects between air trapped in bubbles and vaporized Carbon-dioxide. The submitted photo includes this effect, however it is not the main focus of the image.

The inspiration for this image came from a lifetime love of bubbles, and wanting to learn more about their formation and surface distribution. This image also presented the opportunity to further research the equilibrium state of bubbles the forces which maintain their balance.

Flow Apparatus

The setup for this image was quite simple and was performed in the ITLL dark room. As the team was focusing on buoyancy effects, a fish tank was partially filled with water and dry ice cubes were submerged in an effort to create a bath of CO_2 vapor. The fish tank was then backed by black, non-reflective, poster board, and lit with two utility lights. This set up can be seen in figure 1 below.

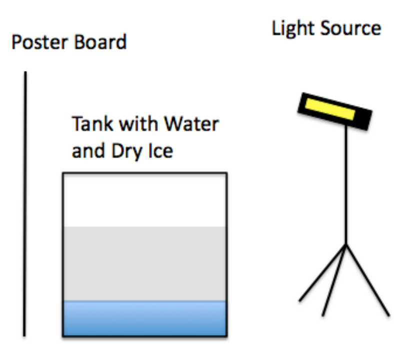

Figure 1: Experimental Set Up

The plan was that bubbles would be blown using a commercial bubble maker and then rest on top of the cloud of CO_2 from buoyancy effects. The black backdrop was used to provide contrast between the white "fog" and the bubble being examined. As this image was only concerned with the formation of the bubble the camera was placed perpendicular to the poster board, and photos were taken using only the black backdrop.

As with any experiment there were many factors which needed to be controlled during this shoot. The first of which was the size and frequency of the bubbles. This was controlled by ensuring that the team member blowing bubbles was consistent with the speed at which they would enlarge bubbles (by blowing air), and that the photographer was cautious as to capture bubbles within a certain size range. This allowed for the focus on the camera to remain roughly constant and allowed consistency in photos. The other factor which needed to be controlled was the height at which these bubbles were blown. The goal was to capture a bubble in the background (balanced on top of the "fog" cloud) with another bubble forming simultaneously. This meant that the second bubble had to be high enough so as not to interact with the broken off bubble, but low enough so that the floating bubble was still in the field of view.

So as to best visualize the phenomena multiple camera angles were explored. Angles which were two down turned lost clarity in the bubble as the bubbles are roughly clear and the "fog" is a greyish white. For this reason it was decided to photograph the phenomena directly from the side to ensure great focus and clarity of the image.

Flow Analysis

The imaged fluid phenomena is dependant on a pressure differential balanced by surface tension in the surface of the bubble. As a bubble is formed a pressure slightly greater than the surrounding atmospheric air is contained in a thin layer of fluid. So that this bubble does not just immediately expand and burst, surface tension effects pull the surrounding walls inward counterbalancing the pressure differential. The tendency for the bubble to form spheres is in order to minimize the tension on each section of the wall and can be described using Laplace's Law [1].

Before delving into Laplace's Law it is important to fully understant the free body forces acting on a bubble. In order to best visualize this the bubble can be considered to hemispheres. The top hemisphere being pulled upward by the internal pressure of the bubble, and the bottom hemisphere being pulled down from surface tension. Below in figure 2 the forces acting on these two hemispheres can be visualized.

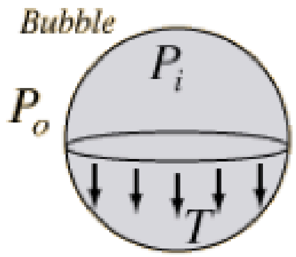

Figure 2: Forces in a Bubble [1]

It turns out that the pressure differential can be related to the force of surface tension by the following equation:

$$P_i - P_o = \frac{4T}{r_{bubble}} \tag{1}$$

There are a total of 4 surface tension forces as two surface contribute to each (the inside and outside surfaces of the film) and there are 2 hemispheres. These forces account for the bubble retaining its shape, but why is it a sphere?

Pascal's principle states that the pressure at all points inside a bubble must be equal. However there is another relationship at play inside a bubble. As a pressure vessel (bubble) increases in radius the wall tension must also increase in order to contain the same pressure [2]. This relationship is known as Laplace's Law. As the radius increases the tension at the surface of the bubble must also increase to create the same downward force and thus put the bubble in equilibrium. This can be visualized in figure 3
As θ increases (i.e. the radius gets larger) the tension must grow in order to create the same downward force and balance out the bubble.

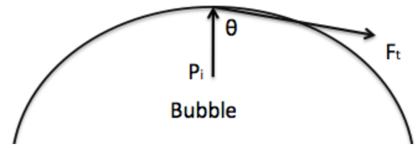

Figure 3: Free Body Diagram

In order to counterbalance this effect the entire pressure vessel wants to pull itself into a sphere. This equalizes the tension throughout the bubble and produces and equilibrium state.

Bubbles are used in many practical applications as well. The use of bubbles in medicine is becoming an increasingly positive idea. Using micro bubbles injected into a patients bloodstream can give contrast in ultrasound imaging [3]. This type of application can lead to better diagnosis and even in some applications is being used to cross the blood brain barrier.

Visualization Technique

In order to visualize the scene best the lighting, angle, and focus needed to be perfected. Using a non-gloss black backdrop allowed for a good light sink while still allowing for illumination of the bubble. This back drop allowed the team to use two work lights from different angles and eliminate shadows in the scene. Focus was kept a rough constant and only the size of the bubbles were changed. The angle was chosen to be perpendicular to the back drop in order to get good contrast in the image.

Photographic Technique

The heavy amount of light and speed at which the bubbles were being blown required the perfect camera settings. The image was taken with a CANON Rebel EOS xsi with a shutter speed of 1/100 s, f-stop of f/3.5, ISO of 800, and an EF-S60mm f/2.8 Macro USM lens. The macro lens was used to provide great detail in the image while maintaining a very small distance from the phenomena. The lights were dimmed slightly with the use of paper and the help of the team. All of these factors contributed the the image submitted.

Conclusion

The published image was meant to give insight into the workings of bubbles and their formation. The focus on a forming bubble with a fully formed bubble in the background gave just this. This image also served to educate myself of the physics which govern and shape bubbles, in which I would say I succeeded.

There were some small issues with the image that in the future I would like to resolve. As the bubble has a glossy surface the reflection of my team mate (Jonathan Severns) was clearly visible in the top section. While this may have been corrected with Photoshop, my ability to do so was slightly lacking.

Overall, I am very proud of this image and think that it shows my developing photographic abilities with focus framing and fluid visualization.

Bibliography

1. "Surface Tension and Bubbles." Surface Tension. N.p., n.d. Web. 9 Apr. 2013. http://hyperphysics.phy-astr.gsu.edu/hbase/surten2.html
2. "Wall Tension/Laplace's Law." Pressure and Surface Tension. N.p., n.d. Web. 14 Apr. 2013. ¡http://hyperphysics.phy-astr.gsu.edu/hbase/ptens.html¿
3. Posterna, Michiel. "ScienceDirect Article Suggestions." ScienceDirect.com. Institute for Medical Engineering, n.d. Web. 10 Apr. 2013. http://www.sciencedirect.com/science/article/pii/S1350417706001519
4. "American Physiological SocietyAdvances in Physiology Education." Feeling Wall Tension in an Interactive Demonstration of Laplace's Law. N.p., n.d. Web. 12 Apr. 2013. ¡http://advan.physiology.org/content/36/2/176.full¿