Megan Borfitz | Image-Video 1 Report

MCEN 4151-001 Flow Visualization | 28 September 2020

Acknowledgements: Christy Borfitz, Melissa Borfitz

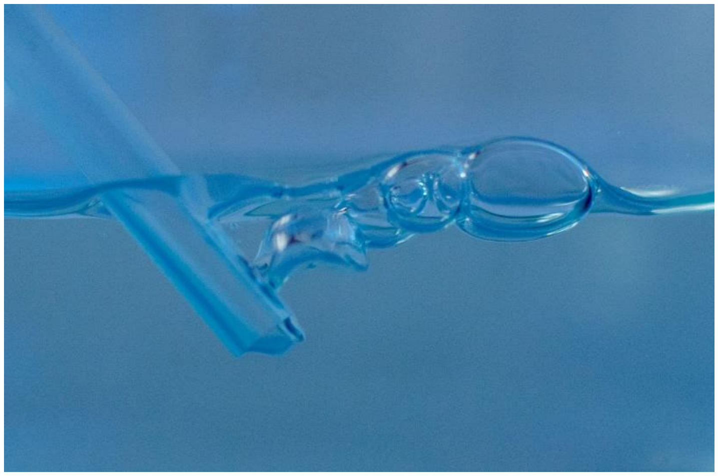

Figure 1. Bubbles exhaled through a plastic straw below the surface of water

Context

My goal for this image was to visualize the rise of bubbles exhaled through a straw to the surface. The bubbles were exhaled beneath the surface of water. I used a DSLR camera to capture the instantaneous motion of the bubbles as they rose to the surface as seen in Fig. 1. I received help from Christy Borfitz who held and exhaled through the straw while I took photos. She also helped me adjust the shutter speed and ISO on the DSLR to capture this image. Additionally, she lent me the light diffuser box with a white background which I used to obtain the correct lighting. I took about 90 pictures over the course of this experiment to get a shot that I liked. I ended up choosing this one because of its clarity. Viewers can see not only the bubbles near the surface of the water, but also the semicircular one that has just emerged from the end of the straw. I will discuss this interestingly shaped half-circular bubble in this report.

Flow Visualization Apparatus

The flow apparatus used in this experiment was relatively simple. I filled a clear glass bowl with water to the approximate level seen in Fig. 2 (a). I placed this bowl inside of a light diffusion box to properly illuminate the subject without creating any concentrated spots of light that could reflect off the glass and obstruct the point of interest. The light diffusion box was created using a cardboard frame with one side open for viewing. The adjacent two sides were made of diffusive pattern paper used in sewing. The back side was covered loosely with solid white paper to create a white background. I used two lamps to illuminate the diffusive sides. The light diffusion box and setup is shown in Fig. 2 (b).

Discussion of Flow

The flow in Fig. 1 is an example of bubbles emerging from a submerged orifice. The motion of the bubbles including their speed and trajectory is influenced by their size and wake (Kulkarni and Joshi 2005). Additionally, the speed of the gas flow and the depth of release also determine the bubble’s characteristics. For instance, in depths of more than 100 mm and slow velocities, single bubbles tend to form (Kulkarni and Joshi 2005).

To determine the scale of this project, I took some measurements but had to make some approximations as well. First, I approximated the flow rate of the air exiting the straw. According to Tang (2013), healthy females exhale approximately 400 mL per breath, which equals the volume $\forall$.

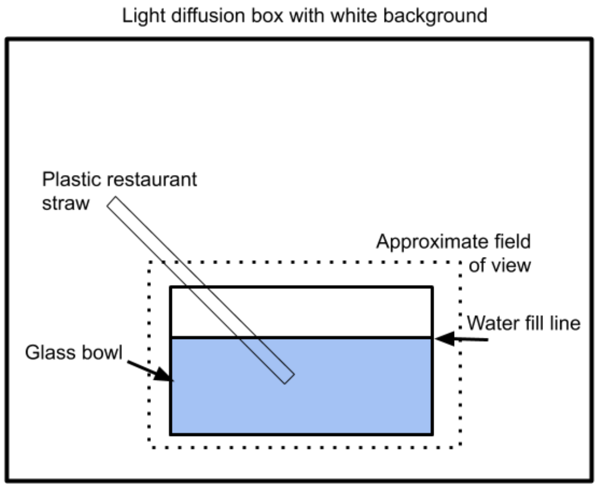

Fig. 2 (a) Experimental setup used to create bubbles with approximate field of view

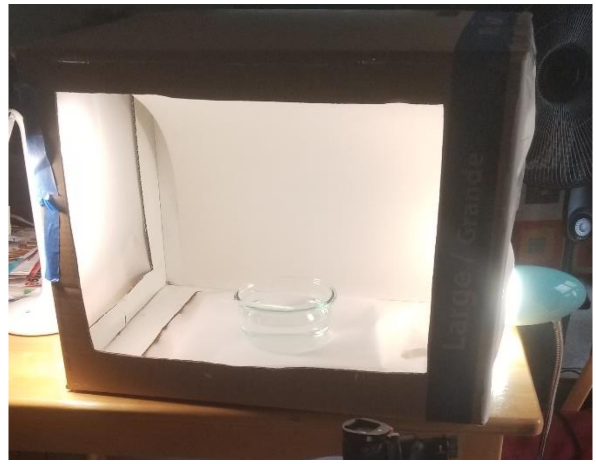

Fig. 2 (b) Light diffusion box and associated lighting

Figure 2. Bubble visualization apparatus used to capture the image in Fig. 1

I estimated that, for the experiment, Christy Borfitz exhaled for an approximate eight seconds while I was taking photos, so $\Delta t = 8s$. I assumed that the flow rate was not changing throughout the course of the breath. I measured the straw diameter to be about 0.5 cm. Then, I used the volumetric flow rate equation (Eq. 1) to calculate the velocity of the gas exiting the straw. In this equation, Q is the flow rate, A_c is the cross-sectional area of the straw, D is the inner diameter of the straw, $\forall$ is the volume of the exhale, Δt is the exhale time, and V is the velocity of the gas exiting the straw.

$$Q = \forall/\Delta t = A_c V = \pi D^2 V/4 \quad (1)$$

Rearranging, we can solve for the velocity V as follows:

$$V = \frac{4\forall}{\pi D^2 \Delta t} \quad (2)$$

Plugging in the approximated and measured values, I determined an estimated flow velocity 2.5 m/s.

Next, I used the properties of my original image to determine the depth of the orifice. I measured the lip of the bowl that I used to be 0.5 cm. I then used this scale to determine the depth of the bottom of the straw to be 1.2 cm as seen in Fig. 3.

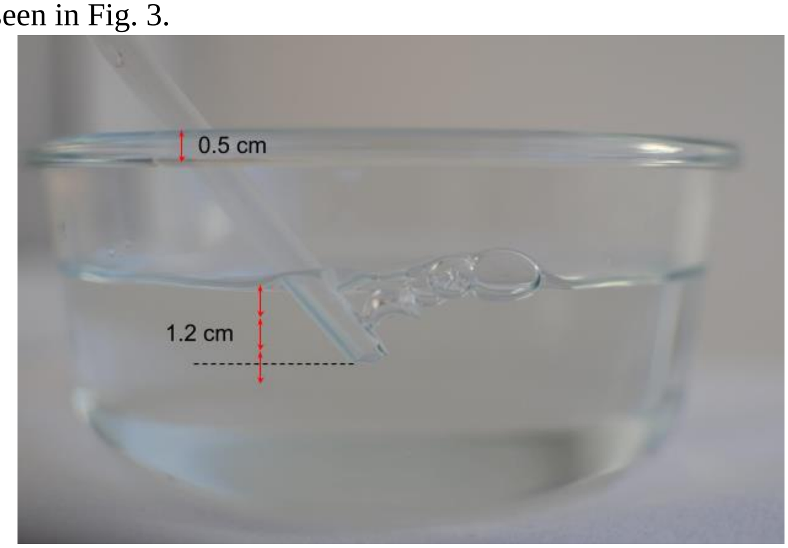

Figure 3. Using the 0.5 cm bowl lip measurement for scale, I determined the depth of the bottom of the straw to be about 1.2 cm in this photo.

Using these measurements, I was able to reference prior literature to get an idea of what type of bubbles were forming. Since the depth of the straw is greater than 100 mm and that the velocity of the gas exiting the straw is slow, this means that single bubbles were probably forming (Kulkarni and Joshi 2005). Using the bubble regime chart in Fig. 4 (a), we can deduce that for the depth greater than 100 mm and 2.5 m/s velocity, it appears that we were producing bubbles in the 'perfect bubble' regime (Muller and Prince 1972). However, the bubble of interest has a semicircular shape, and the specifications of our approximations fall outside the depth boundary of the graph. Thus, we look to Fig. 4 (b) by Zhang and Shoji (2001). Here we can more directly compare the shape of the semicircular bubble to the ones presented in the chart. The bubble we are observing resembles the bubbles produced in panel 'b' of Fig. 4 (b). According to Zhang and Shoji (2001), this type of bubble is produced from an air flow rate of 300 to 700 cc/min. They classify this bubble formation as individual bubbles that are affected by the leading bubbles. The first bubble causes a wake that results in elongation of the following bubble (Zhang and Shoji 2001). This could be the reason that the bubbles in panel 'b' of Fig. 4 (b) have a similar appearance to the bubble of interest in my photo. However, my roughly approximated flow rate was in the range of 3000 cc/min, which is not close to the upper 700 cc/min that the bubbles in panel 'b' form at. This leads me to believe that my flow rate approximation is very inaccurate. However, we can also look to panel 'c' in Fig. 4 (b) to see a similar half circle bubble shape. This is due to a joining of two separate bubbles that occurs at the 700 cc/min flow rate (Zhang and Shoji 2001). This could also be the case in my photo.

Visualization Technique

In order to visualize this flow, I used proper lighting technique to ensure that the bubbles were visible without causing any concentrations of reflected light off the clear glass bowl. In this way, light refracted through the water and the bubbles so that they became clearly visible. I was able to avoid using the flash as well, which allowed me to see clearly into the glass bowl. I used a light diffusion box, two desk lamps, and some natural light to obtain the proper lighting.

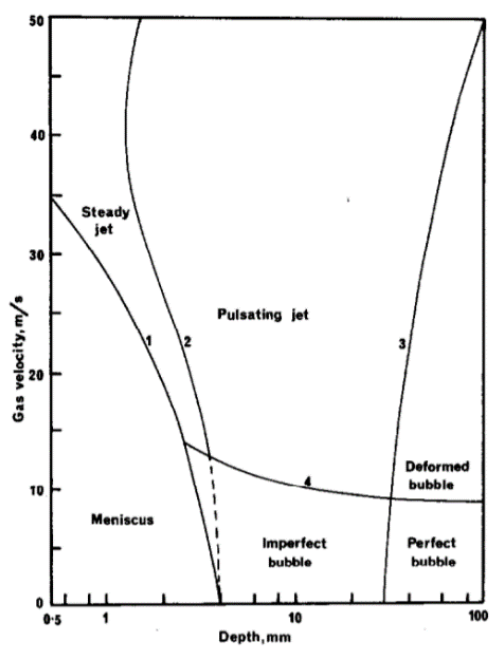

Fig. 4 (a) Bubble regimes based on depth and gas velocity (Muller and Prince 1972)

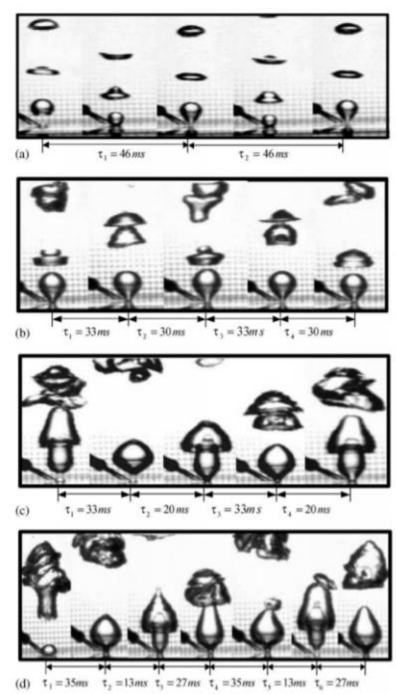

Fig. 4 (b) Bubble formations at certain flow rates and ReO (Zhang and Shoji 2001)

Figure 4. Bubble regimes and types based on bubble conditions.

Photographic Technique

In my photo, I used the approximate field of view illustrated in Fig. 2 (a) to capture the entire bowl since I wasn't sure which part would be of interest, but I wanted to get close enough to capture enough detail. This ended up being about 7 inches away from my 35 mm focal length lens. I used this lens since I could get close enough to the subject without needing zoom functionality. This lens also allowed me to set the manual focus to capture the bubbles. I set the shutter speed to be quick at 1/500 sec and made this my priority since the bubbles were moving quickly and I wanted to capture them clearly. I used an aperture of f/2.50 and an ISO speed rating of 800. I didn't need a large depth of field since the bubbles were small. I used a Nikon D700 DSLR camera to take the image and got an original image size of 4928x3624 pixels. The DSLR allowed me to set my focal length manually and prioritize my shutter speed. I sized my final image to be 1300x856 pixels. In post-processing, I sharpened the image and altered the color to make it appear more interesting. Since the original image was clear, as seen in Fig. 5 (a), I adjusted the colors to create a blue tint to the image as seen in Fig. 5 (b). This way, I was still able to see the physics of what was happening but make the image more colorful to look at and even possibly easier to see due to the color contrast. I also sharpened the image to try and get a clearer picture of the bubble shape.

Image Reflection

My final image reveals a semicircular shaped bubble that could be the cause of several different physical effects. Aesthetically, I like the contrast in my final image and the color, but I don't know if I like the graininess of the photo. While it adds a particular aesthetic look, I may have preferred more clarity and less grainy. I would like to know why the bubble of interest looks that way. Is it because of the wake of the previous bubble? Or is it due to a combination of bubbles? To improve this experiment and answer these questions, I could make more accurate measurements of the volumetric flow rate and speed of the gas exiting the straw. My original intent was to capture bubbles mid-rise to the surface. At first, I had thought to submerge the straw even more, but due to the logistics of the light box setup and focusing the camera, I changed this to be just below the surface. However, I did manage to capture this particularly interesting bubble as it rose to the surface. With regard to future improvements, I could try to take more precise measurements and I could also change the composition of the liquid. I used plain water as the liquid, but this experiment may be modified by using a water and soap mixture or maybe water with an oil layer on top. Overall, I like how this image turned out but there are several ways in which it could be improved.

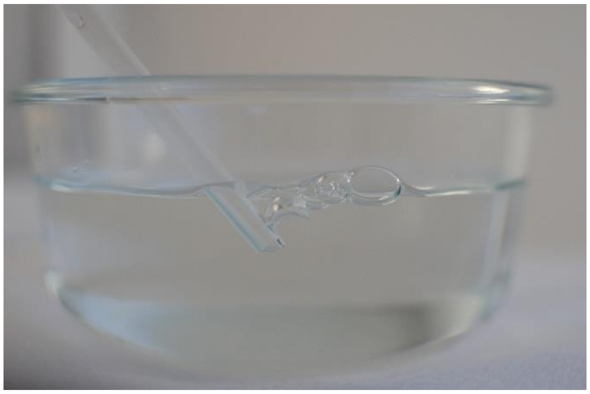

Fig. 5 (a) Original photo

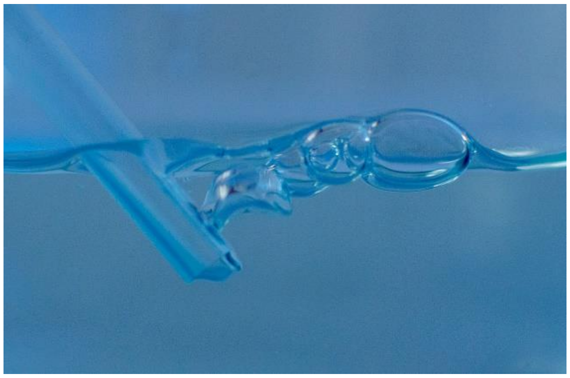

Fig. 5 (b) Post-edited final image

Figure 5. Comparison of original and final images

Bibliography

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