MCEN 5151 Image 2 Report

Ryan Cameron
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University of Colorado at Boulder

I. Purpose and Methodology

This photo was meant to visualize the formation of bubbles in water and the effects of pressure on the volume of fluid particles as they travel. When visualized, it serves as a good way of seeing how the pressure force acts on a fluid and to understand the principle of hydrostatic pressure, which applies to most all naturally occurring fluid flows from the depths of the ocean to the highest points in the atmosphere.

In order to obtain the final photograph, a simple denture cleaning tablet was taped to the bottom of a water jug as water was poured over it and then allowed to settle before the photo was snapped. This ensured that the camera focus could be maintained on the correct point as the tablet was taped down. Then, because the water was poured over it and was allowed to settle beforehand, a steady state of flow of bubbles was ensured with consistent starting conditions. Because of the steady state conditions here, it helps to narrow down the forces acting on the fluid volumes to just the hydrostatic pressure.

II. Scientific Principals

To discuss the science behind this photo a couple things must be considered. The first of which is the gas that is being released in bubbles by the tablets. Through a chemical reaction with the water, the hydrogen peroxide in the Efferdent tablets releases oxygen gas bubbles. With a density of around $1.33\frac{kg}{m^3}$ the oxygen gas is slightly heavier than air but still almost three orders of magnitude lighter than the water it is floating through. This will cause the bubble to rise with increasing velocity, since it is known that the initial velocity is 0 and there is a finite end velocity in the region of the photograph.

Now, the basic principles of this flow can be accounted for in the hydrostatic equation that is shown below.

$$P = \rho g h$$

Here, P is the pressure force that will be applied externally to the bubbles, ρ is the density of the fluid, g is the gravitational acceleration, and h is the depth of the fluid at a specified location. Knowing from this equation that pressure decreases the shallower the water, and that the radius of bubbles increases with velocity [2] (which in this case corresponds to height), the relationship can be made that as the pressure decreases on the fluid, the radius of the bubbles will grow. It is also important to note here that pressure is not the only force acting on the bubble as it rises. As the bubble flows through the water, a model can be created of a fluid flow around a sphere, where lift and drag now come into play, acting on the path of the bubble so that it does not rise in a completely straight line. That then leads to modulations in the flow field itself, and so as more bubbles encounter this, the flow keeps changing and eventually a turbulent state of the flow is attained.

Numerous studies have been done on the rising of bubbles in turbulent flow, but in relation to this photo and the purpose of relating pressure to the diameter of the bubble, it has been found that the bubbles actually rise more quickly the larger the radius [1], which can be attributed to the greater fluctuation in shape of the bubble as its radius increases as well, so that the lift and drag forces change more drastically as the radius of the sphere increases.

III. Visualization Technique

The technique used to take this photograph was rather simple really. There was no use of dyes or smoke in the setup, and rather then use seeding particles to track the flow overall, the purpose of the photo was in fact to look at the properties of the seeding particles themselves. The only issue that remained here was to figure out the best lighting scenario to illuminate the bubbles in the water jug. At first, three lamps were setup around the jug of water, two pointing at a white sheet in the background for backlighting illumination, and one pointing at the jug itself. In addition, the flashlight on a smartphone was placed directly under the jug in an attempt to light the bubbles directly. A few rounds of photos were taken with this setup for mediocre results in the end. But, in somewhat of a stroke of luck, the final photograph simply used a narrow beam of light through the blinders of a window in the room, and the just was placed directly in the path of this beam of light, which perfectly illuminated the bubbles in the jug. So, all the other lights in the room were turned off save for a single lamp pointing at the jug. These photos produced much better results than any of the previous so they were used in the end.

IV. Image Details

Since the details of the image being captured are on a very small scale, the field of view had to also be relatively small, only about 8 inches across in total before anything was cropped out. Also, since it was not possible to completely predict the exact locations of the bubbles that needed to be in focus, the aperture was set to an f-number of $f = 6.3$. This increased the depth of field a bit so that more of the bubbles would be in focus, but at the expense of the amount of light that could be let through. So, the ISO was increased to a value of 1600 to let more light in since the shutter speed also needed to be rather high (800 Hz) to capture the fast moving bubbles. This was all done on a Canon EOS Rebel T6i DSLR with a standard 18 - 55mm lens.

Then, the post-processing was all done in Darktable. Past the initial automatic adjustments, the biggest thing that needed fixing was a portion on the right side of the tablet that was overexposed from the light filtering in through the window. The first thing that was done was adjusting the light and dark points in the photo to darken the image overall which helped dim the overexposed point as well as the rest of the photo. Then, the color reconstruction module was used to assume the original color of what was in the overexposed region. This helped give some definition to the image. After this, a mask was created on the overexposed parts, and the RGB curves were all lowered in this region specifically to lower the brightness. This all did a decent enough job, and so the last thing that was done on the photo was to bring it to monochrome because there were really no specific colors that needed to be brought out. This brought the attention more to the bubbles themselves which was the original intent. Below is a before and after comparison of the RAW image and the adjusted image.

Figure 1. Initial image from the RAW file

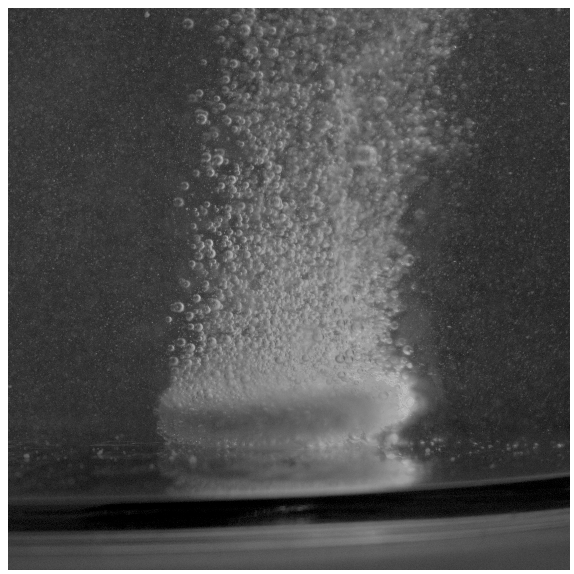

Figure 2. After post processing

V. Results

Overall, this photograph does a good job of bringing the eye to the bubbles that are created in this experiment, which was the focus of the research that was done into explaining how bubbles rise and the forces at work in the fluid flow. When examining the image after focusing on the science behind the flow, it becomes evident that is does in fact show how the bubbles closer to the top of the photo are much larger than those shown in the bottom of the photo near their creation. This matches well with the literature and the theory behind the behavior. It would be interesting though to attempt to take a video of this phenomena and perhaps follow one or a group of bubbles as they flow from the bottom of the jug to the top of the container, tracking how they increase in size as they rise. That would solidify, without question, the types of phenomena that are discussed in the scientific literature.

References

[1] D. J. Ruth, M. Vernet, S. Perrard, and L. Deike. The effect of nonlinear drag on the rise velocity of bubbles in turbulence. *Journal of Fluid Mechanics*, 924:A2, 2021.

[2] P. G. Saffman. On the rise of small air bubbles in water. *Journal of Fluid Mechanics*, 1(3):249–275, 1956.