IV3 – Bubbles in Slow Motion

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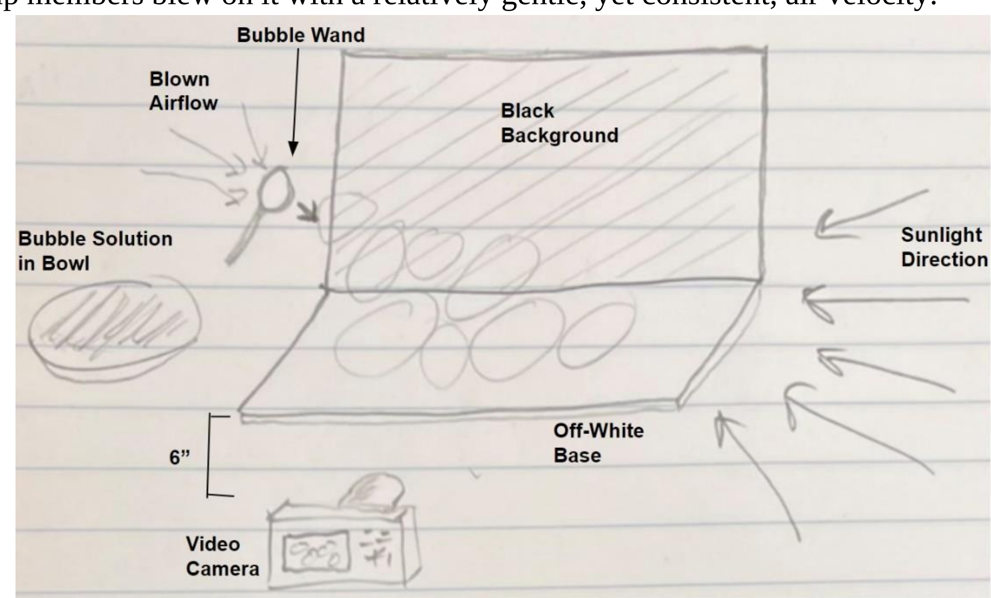
Context and Purpose

My *Bubbles in Slow Motion* video can be seen at: https://vimeo.com/762139596. When watching this video, ensure that the quality settings are at their highest for the best and most accurate viewing of the visualized phenomena. The intent of this video was to capture the unique fluid physics that occur during the popping of bubbles. These phenomena are normally not visible to the human eye, so we used a slow-motion video camera in order to properly capture the rupturing, crumpling, and cohesion phenomena of the bubble structure and its fluid. We first tried to capture bubble popping with an Olympus high speed camera from the early 2000s, at 6000fps. However, while some of my groupmates decided to use videos captured by this device, I decided that the results were too low-resolution despite being at a much higher frame rate than the clips I ended up using. Additionally, we initially attempted to capture videos of bubbles popping indoors, at night, with an off-the-shelf bubble solution. This also resulted in low quality, dark images of bubble pops that didn't illustrate the effects that we were hoping to visualize. These failed attempts ultimately led us to the setup as described in the remainder of this report. My teammates for this project were Robbie Cooper, Kendall Shepherd, and Lana Pivarnik, and I'd like to thank them for their assistance in setup of the flow apparatus. In this report, I will lay out the phenomena, techniques, and insights behind this beautiful bubble development process.

Flow Apparatus

The flow apparatus that we used was relatively simple in terms of the actual production of the bubbles as the defined flow. This was done by use of a "bubble wand", which is a plastic stick with a textured ring attached to the end of it. This apparatus was dipped into the bubble solution, and then one of our group members blew on it with a relatively gentle, yet consistent, air velocity. The bubble recipe was from an article on the Ars Technica website [3] and this solution was formulated by our group using Dawn dish soap, guar powder, rubbing alcohol, baking powder, and water. The basic flow type consists of highly surface tension driven bubbles that go through bubble-on-bubble and bubble-on-environment interactions. The scale



of the bubbles ranged in diameter anywhere from 1cm post-pop reformed bubbles, up to 7-10cm bubbles that take up much of the frame.

Fluid Phenomena

The bubbles captured in this slow-motion video look the way that they do because of air currents, bubble solution cohesion, and viscosity of the bubble fluid. Each bubble individually changes with time in terms of its shape and thickness as a result of primarily gravitational, viscous, and contact forces. Gravitational forces cause the bubbles to fall as they're denser than air, viscous and gravitational forces together cause varying bubble wall thicknesses on the various parts of the bubbles, and contact forces cause the bubbles to deform in shape, pop, or combine as they come into contact with each other and the environment, namely the base of the setup. Bubble popping is the most notable change over time that can be observed in this video, and can result from, "the effect of gravity-induced drainage and/or liquid evaporation and/or nuclei-induced inception depending on their composition." [5] This phenomenon can be quantified by the characteristic lifetime of the bubbles, which assumes that the gravity affected thickness of the bubbles isn't what causes popping. Instead, it calculates bubble lifetime based on the radius of curvature of the bubble *R*, the liquid density *rho*, the gravitational acceleration *g*, and the liquid dynamic viscosity *mu*. The values that I've assumed in this scenario are based on the large bubble on the left half of the video, seen from ~0:30 to 0:32, which is formed from the combination of two smaller bubbles. The diameter of this bubble is assumed to be approximately 3 inches, the liquid density is assumed to be that of water since most of the bubble solution is water, and the liquid dynamic viscosity is assumed to be 1.47 Pascale seconds due to its similar properties observed qualitatively, and in composition, to detergents. [6] The characteristic time equation and its calculation is as follows:

$$\tau = \frac{\mu}{\rho_{liq} * g * R} = \frac{1.47Pa * s}{1000\,\frac{kg}{m^3} * 9.8\,\frac{m}{s^2} * \frac{.076}{2}\,m} = 0.0039\,seconds = 3.9\,ms$$

This number means that given the assumptions made, due to the characteristic lifetime equation this bubble should burst over a time of .0039 seconds. However, this is a much shorter burst time than is shown in the video. As discovered through frame-by-frame analysis, the burst time in the video is approximately 0.5 seconds. Therefore, with 24fps in playback and 960fps as shot, this means that the captured burst took about 0.0125 seconds in real time, or 12.5 milliseconds, approximately an order of magnitude larger than the modeled value. This longer observed time is likely due to the guar powder and baking powder in the solution, as Justin Burton of Emory University and his lab discovered that, "a polymer allows a soap film to reach a 'sweet spot' that's viscous but also stretchy—just not so stretchy that it rips apart," and that, "polymers of different sizes become even more entangled than single-sized polymers, strengthening the elasticity of the film." [3] Due to guar powder being a fully organic product and baking powder being partially organic, there are varying polymer lengths within the solution which cause the longer bubble bursting time. Additionally, Detlef Lohse of the University of Twente states that, "accurately calculating the dynamics of a few air bubbles in turbulent flow is numerically still infeasible. Approximations are therefore required." [4] This means that, although approximation is necessary, it is still not possible to fully validate these approaches, and models may be somewhat inaccurate, especially in the scope of a video like the one I've captured. Lohse also states that, "for larger bubbles, all the approximations naturally get worse; in that regime, the bubble's shape also shows strong deviations from sphericity," which is visually validated not just with the bubble of concern but throughout the entire video that I've captured. [4]

Visualization Technique

The visualization techniques used here were the refractive index technique and the particle tracking technique. As described in the Flow Vis textbook, the refractive index technique is applicable to how, “soap bubbles and oil films change color” because, “at the interface between media with different refractive indexes, light will bend according to Snell’s law.” [2] Additionally, it was a particle tracking technique in some sense if you consider each of the bubbles to be a particle that is tracking the motion of the air currents that exist outside the IdeaForge where this setup took place. The camera was rented from the ITLL, the backgrounds were just pieces of scrap cardboard and plastic we had on hand, and the bubble blowing device was just a standard bubble wand, as described in the *Flow Apparatus* section. The image was captured around 3:30 PM on Wednesday, October 19th, 2022 at the IdeaForge loading bay in sunshine that was partially shaded. The sun was about halfway behind the IdeaForge building when this was captured, as can be seen in the reflection of the bubbles if the video is paused at certain spots, which led to the optimal lighting levels and unique reflections and colorations captured.

Photographic Technique

The abstract technique that I used was taking a “Super Slow Motion” video of the bubbles popping with a zoomed in perspective against respectively monochromatic backgrounds and surfaces. The size of the FOV was approximately 6 by 4.5 inches and the distance from the object to the lens, as stated previously, was 6 inches. The lens focal length had a range of 9.3 - 111.6 mm was 44 mm in this video, and the other lens specs are a thread diameter of 62 mm, however I didn’t use any lens filters. The camera used is a Sony HXR-NX80 which is a video camera capable of slow-motion capture.[1] My original video is 1920 by 1080 pixels and 139 megabytes in MTS format, and the exported high-quality video has the same number of pixels but is compressed to 63.7 megabytes. The aperture was 4, shutter speed was 1/500, and ISO was 1200. The framerate was 960 fps in this video. In terms of post-processing in MiniTool MovieMaker I turned the contrast up to 50.7 but left saturation and brightness at their base levels. Additionally, I added music, a title screen, a credits screen, and transitions. The FOV was chosen qualitatively to best show the artifacts that we were seeing with our eyes, the size of the video was the max that I was able to get in this super slow motion camera setting, and the aperture was chosen to let in more light during the capture period while still retaining the proper, relatively tight, focal length. The ISO was chosen to make the bubbles and their details as visible as possible against the bichrome backgrounds, while limiting any overexposure or excessive detail of the backgrounds. The distance from the object to the lens was chosen as being the most practical distance for me to be able to lie down on the ground and get the camera as close as possible without getting bubble solution on it. Finally, the focal length was chosen through experimentation additionally to get the bubbles in focus, while trying to keep a relatively narrow window of focus to not include detail of the background.

Image Insights

This video reveals the unique interactions between bubbles and how their fluid physics cause them to bounce off each other, their surroundings, and eventually pop, as well as how these pops happen and propagate throughout time. I love how this video has so many demonstrations of the same fluid principles of bubbles but shows interactions in various irreplicable ways. I think in this regard it also is fascinating to the viewer because there aren’t any periods of “downtime” in the video, and there's a lot of interesting colors, shapes, and shadows going on. My remaining questions mostly come in terms of how this visualization was produced, as this was the only attempt that we captured where the bubble blower was able to produce this many bubbles, this consistently, over this length of time. I would say that the intent of this image to illustrate bubble popping physics was fulfilled for the most part, especially with the unintentionally added illustration of bubble-to-bubble interactions. To improve and develop this idea further in the future, I'd like to get access to a high-speed camera with a higher frame rate capability than the one used, that is also able to capture a high-resolution image, in order to supplementarily illustrate the stringy cohesions seen during popping.

References

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