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MCEN 4151
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Team Second – Spring 2018

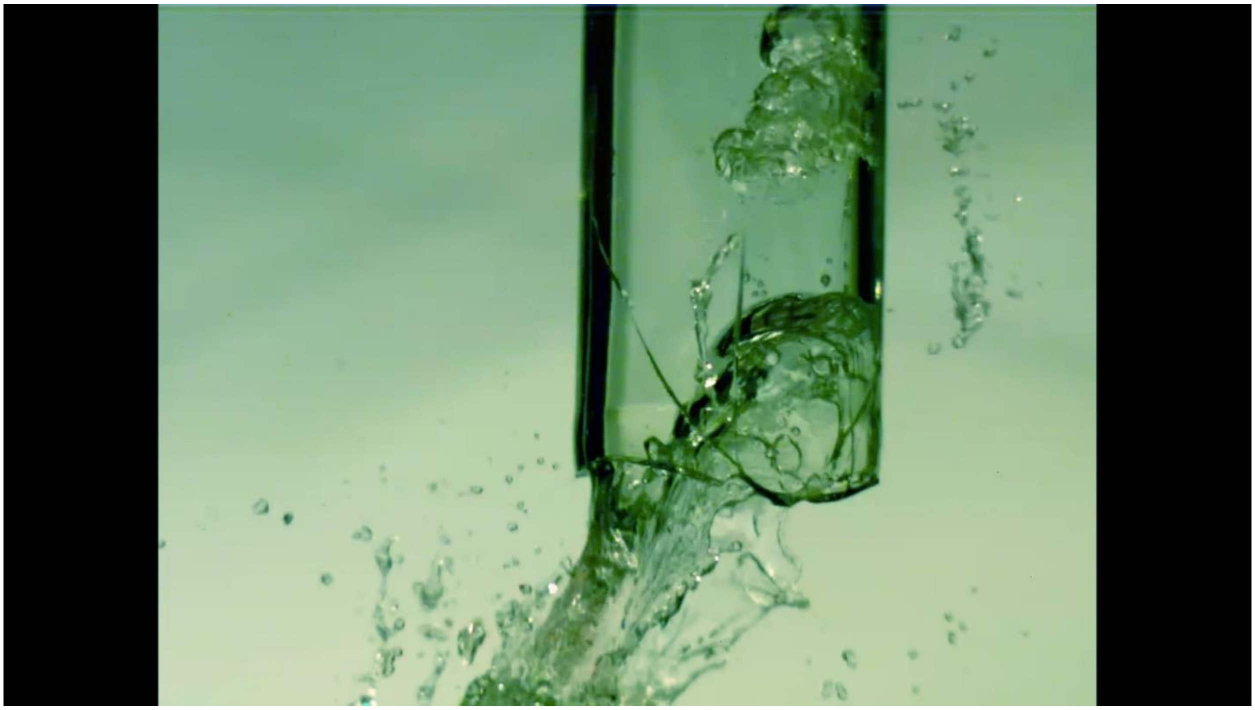

Figure 1: Screenshot from video

Context:

The team first assignment was the second group project of the semester. The aim is, as a group, to capture detailed flow visualizations with more elaborate setups. Observed in Figure 1 is a screenshot from the video, where the bottom of a bottle bursts out from cavitation. This is the second of three trials, which gave the most surprising results not in terms of cavitation but with water adhesion. With help from teammate, Geya Kairamkonda, we captured the devastating effects of cavitation with a high-speed camera.

Apparatus:

The phenomenon being observed in Figure 1 is known as cavitation in an incompressible fluid caused by acceleration, where pressure drops to a below the saturated vapor pressure and boiling occurs. This effect is only truly observed in large quantity with incompressible liquids, where dissolved gas is not present. Take, for example, a carbonated liquid. When pressure is lowered, the liquid relieves the stress with little bubbles or gaseous cavitation. In our case, there is no intermediary to relieve the vacuum bubbles, so the vacuum collapses violently resulting in material shattering or pitting in the surface if the material strength is tougher (Atkins and Escudier 2014). The material in the experiment is a glass, which will shatter under undue amounts of force, as seen in Figure 1. The reduction in pressure is often due to the acceleration of the fluid, either through a nozzle or other means. For our purposes, the bottle was accelerated downward with the exchange of momentum from a forceful impulse originating from my palm.

In terms of analyzing the system, the main indicator of cavitation can be quantized with the cavitation number given by

$$Ca = \frac{p_r - p_v}{\frac{1}{2}\rho v^2}, \tag{1}$$

where p_r is the reference pressure at the free surface, p_v is the liquid vapor pressure, ρ is the liquid density, and v is the local velocity. This physically represents that the large momentum of the fluid dominates other forces when cavitation occurs. The equation can be re-arranged with a reduced Navier-Stokes equation, integrated along the centerline velocity giving

$$Ca = \frac{p_r - p_v}{\rho a h}, \tag{2}$$

denoting the magnitude of the vertical component of $\partial v/\partial t$ as a, and the height of the liquid to be h (Pan et al. 2017). With a cavitation number less than 1, cavitation is likely to occur. I estimate the pressure at the top of the bottle to be atmospheric, or 101.3 kPa, the density to be 1000 kg/m^3, p_v equal to 2.3 kPa, and a water height of 190mm. A cavitation number less than 1 requires the bottle to accelerate at 0.52 m/s^2 or greater, which was most likely achieved and thus the bottle likely failed due to cavitation.

Even though the main vision of the project was to elicit catastrophic failure due to cavitation, a beautiful and interesting result is a byproduct. After the initial fracture of the container, a bubble forms at shattered bottom of the bottle. The water slow drains out, but because of water adhesion with the glass container, a smooth transition occurs until air reaches near the top of the neck where the flow of water turns to droplets instead of the smooth laminar flow that is initially observed. The video fades out as the last of the droplets fall.

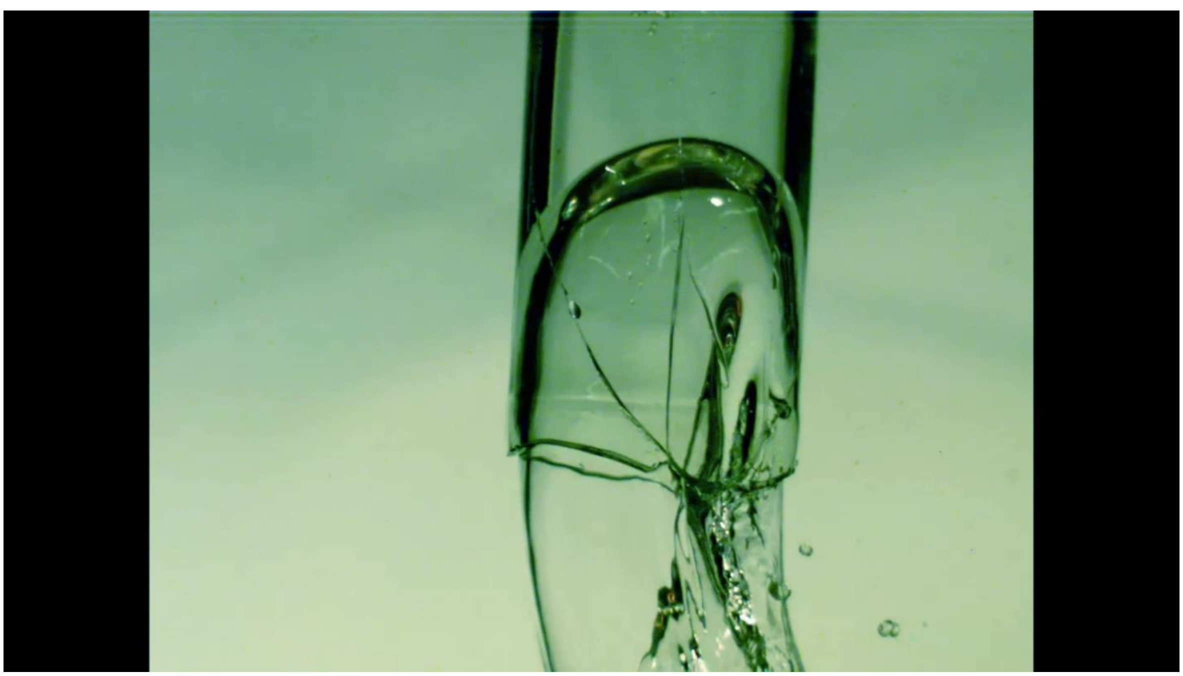

Figure 2: Interior Bubble formation

To minimize clean up after the experiment, the glass bottle was shattered into an ice cooler to retain the water and avoid splashing. The glass shards and bottle were also contained and disposed of properly after the experiment. See the schematic below for an image representation of the setup.

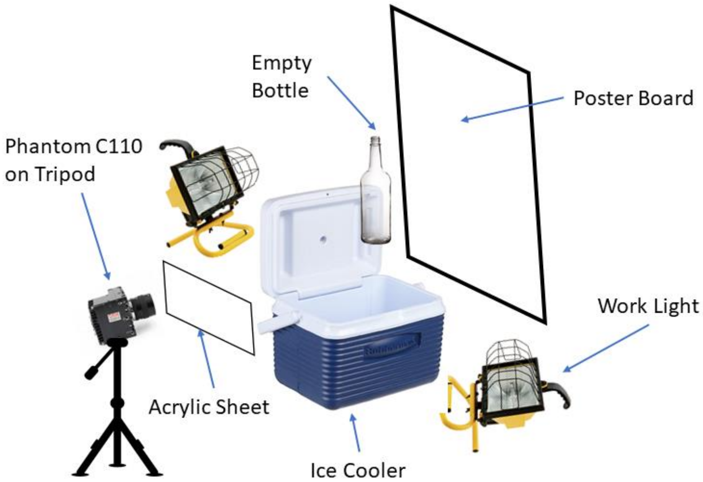

Figure 3: Setup Schematic

Visualization technique:

To get the effect visualized in Figure 1, I used bottles from a 4-pack of *IZZE* (12 oz) sparkling juice filled to above the taper of the neck with tap water. The labels were removed using degreaser and 0000 steel wool, and polished with *Sprayway* glass cleaner. Once the bottles were prepped, I held the bottle with a leather glove and accelerated the bottle with enough force to cause cavitation at the base of the container. My teammate oversaw recording and held a sheet of acrylic in front of the camera lens to avoid any splashing affects from the experiment. This project was performed in the basement of the ITLL with the phantom micro C110.

Photographic Technique:

The original video was shot in 1024 pixels x 768 pixels at a sample rate of 800 pps. The camera, phantom micro C110, was placed on a tripod horizontally at approximately 3ft away from the setup. The field of view is approximately 7”, with the bottle being 2.5” in diameter. The video was edited in post processing using Davinci resolve 12. This was to add the title page, fade in and out, as well as add the music: Concrete Warriors by Shaolin Dub. A color shift was also applied to match the ‘cool’ tone of the music and make the water have a blue hue. I lined up the music to correspond with the collapse of the cavitation bubbles.

Critique:

The video reveals the main phenomenon I wanted to capture, cavitation. However, it is more bizarre how slowly the fluid leaks out of the container after the bottom has burst outward. I would like to learn more about this phenomenon and why it occurs. If redone, I still would like to attempt the project with a much higher sample rate and attach an accelerometer to the bottom of the bottle. This is advantageous in seeing how quickly the cracks in the glass progress, and determining the cavitation number for each setup. The exposure and focus are well resolved and I wouldn’t change the lighting setup. Overall, I would consider the project a success.

References:

[1] Atkins, Tony and Marcel Escudier. 2014. *Dictionary of Mechanical Engineering*.

[2] Pan, Zhao et al. 2017. “Cavitation Onset Caused by Acceleration.” *Proceedings of the National Academy of Sciences* 201702502. Retrieved (http://www.pnas.org/lookup/doi/10.1073/pnas.1702502114).