Making of: Extrusion

Team First
MCEN 5151
3 October 2025

Brian Terasaki
Hank Goodman
Juan Sanchez

1 Introduction

Water and soapy water look nearly identical, but behave remarkably different when interfacing with air. Rigorously stirring tap water for a few seconds yields very little visible change, but doing the same in dishwater will yield a frothy concoction. Bubbles are an excellent example of how the invisible forces within fluids have a profound impact on flow. Within bubbles, surface tension, inertia, and gravity all act together to create oblong and organic shapes in the form of bubbles. This image explores the impact of these invisible forces on the visible bubble structures and pushes these forces to their limits.

2 Apparatus

Figure 1 below shows the apparatus for taking the images. The required materials for the experiment are distilled water, Dawn dish soap, glycerin, and gel food dye, baking tray, yarn, plastic straws, and gloves. A square bubble wand was created by passing yarn through two straws and tying the ends of the yarn together. This forms a rectangular loop about 6 inches by 12 inches which will be used to extrude a soap film.

Figure 1: Test apparatus, pictured Juan Sanchez

The working fluid used about 2 cups of distilled water, 1/4 cup of Dawn dish soap, a tablespoon of glycerin, and a teaspoon of gel food dye. All materials are combined in the baking tray and gently mixed with the bubble wand. This will combine all materials into a homogeneous solution ideally without creating too many bubbles within the baking tray.

To capture the flow, one person performs the experiment while another operates the camera. For the experiment, the operator dips the bubble wand into the solution until submerged. They then lift the wand vertically at a speed of roughly 1 m/s. While the operator lifts the bubble wand, the camera person captures the shape of the soap film. During the lift, the wand remains in the same orientation as when it was submerged. The soap film is highly sensitive to air currents and the speed of lifting the wand, so practice is required to ensure consistent film creation.

3 Flow Physics

The structures created in this experiment are ever-evolving. When lifting the bubble wand, the soapy film would form a bubble column of near-uniform width for the first half-second. After reaching a maximum height of about 2 ft, the column would then either spontaneously pop or narrow to a thin neck. Once the neck of the bubble closed, it would either pop, which happened most often, or would separate into two bubbles.

The fluid interactions of surface tension, gravity, and inertia all work together form the structure of the flow in the image. Surface tension is the result of strong intermolecular forces present in liquids which force liquids to coalesce during flow. This is the primary force maintaining the structure of the thin film; the intermolecular forces of the surfactant force water to form a thin film which have strong intermolecular forces within but repel excess water to prevent coalescence into a droplet. The directionality of these intermolecular forces are a type of Marangoni effect. The presence of these surface tension gradients is key to making the thin film bubble layers and ensuring stability within this thin layer [3]. Inertia works to allow the initial bubble structure to form. By moving the bubble wand quickly upwards, inertia keeps some solution in place and allows the rest to gradually accelerate as the bubble is formed. Finally, gravity acts to draw the liquid from the wand back to the tray of bubble solution. This severely limits the lifespan of the bubble since this redistribution of fluid will eventually thin out the bubble until it bursts [4].

To estimate the relative importance of these factors, the dimensionless Weber, Bond, and Froude numbers were calculated for this flow. Given characteristic length scale $l = 0.5$m, fluid density $\rho = 1000$kg/m^3, gravitational acceleration $g = 9.81$m/s^2, velocity $U = 1$m/s, and surface tension $\sigma = 0.025$N/m [1], the Weber, Bond, and Froude numbers can be calculated with the equations below [2]:

$$We = \frac{\rho U^2 l}{\sigma} \approx 20,000 \tag{1}$$

$$Bo = \frac{\rho g l^2}{\sigma} \approx 100,000 \tag{2}$$

$$Fr = \frac{U^2}{gl} \approx 0.2 \tag{3}$$

The Weber number describes the relative importance of inertial and surface tension forces. As seen in the calculation, the inertial forces are very important and heavily outweigh the surface tension forces, implying that they have a stronger impact on the film shape. The Bond number assesses the relative importance of gravitational forces and surface tension. Again, the influence of surface tension appears to be outweighed by the gravitational influence. Finally, looking at the Froude number, gravitational influence seems to have a greater impact on the flow than inertia.

4 Visualization and Photography

A solid background and lighting kit were used to help isolate the flow from the surroundings. The black background tarp hung over a metal bar provided a neutral background to isolate the soap film structure. Two 23 Watt, 6000 K LED lights were placed around 1 meter away from the experiment. These lights were pointed away from the flow at light umbrellas which reflected the light back towards the experiment. These lights illuminated the sides of the soap film which revealed the smooth, curving geometry of the film surface.

The image was captured using a Canon EOS 7D Mark II at a distance of about 2 feet. The field of view of the raw image was about 3 feet tall, 1 ft wide. The final image has with ISO of 1600, f/ of 3.5, shutter speed of 1/400 sec, and focal length of 18 mm. At the flow speed described in Section 3 above, the flow moved about 2.5mm during the capture. Thus, the flow was relatively stationary during the capture time. Figure 2 below compares the raw and final images. Using cropping, the raw image has a resolution of 3670 x 5496 pixels while the final edit has 2274 x 4412 pixels. Additionally, the image contrast was tweaked to enhance the visibility of the liquid film structure. Finally, some distracting elements such as the experiment operator's arm or folds in the background were patched over to provide a clean background.

Figure 2: Comparison of unedited and final images, left and right respectively

5 Conclusion

Extrude explores the interplay between surface tension, inertia, and gravity in its elegance and fragility. The curved structures are reminiscent of man-made glasswork which has fascinated people for centuries. While glass is considered delicate, this material is even more fleeting; its structure exists for mere seconds and is only able to be captured in a photograph frozen in time. By pushing these forces to the extreme, this image sparks the imagination to wonder what other creations are possible.

References

[1] Surface tension. *University Knoxville, Tennessee.*

[2] John W. M. Bush. Surface tension module. *Department of Mathematics, MIT.*

[3] Dominique Langevin. *Thin Liquid Films*, pages 71–127. Springer International Publishing, Cham, 2020.

[4] Aymeric Roux, Alexis Duchesne, and Michael Baudoin. Everlasting bubbles and liquid films resisting drainage, evaporation, and nuclei-induced bursting. *Physical Review Fluids*, 7(1), Jan 2022.