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Soap Bubble Clusters in Thin Enclosures

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Soap bubbles and films have been of interest to artists and scientists for centuries [1, 2, 3, 4, 5]. Children like to blow soap bubbles, and soap bubbles evoke a pleasant feeling in most people. The author too has had a life-long fascination with soap bubbles and wished to design a soap bubble demonstration device for people to enjoy, without a need to clean up.

The objective was to develop an interactive, self-contained device suitable for repeated use over an extended period of time, and without a need for maintenance or electric power. The purpose was to use the device as a demonstration tool to enhance presentations in informal science education and outreach activities.

An effective and simple solution was devised to meet the objective: a sealed enclosure containing liquid soap and air. The enclosure is made of acrylic sheet stock (Plexiglas) and purposefully made thin, with the front-to-back spacing of 1.6 mm, for visual effect and weight consideration. In the narrow space, soap bubbles are flattened, formed in one layer, and easily seen. Small strips of acrylic sheet are placed and glued between the front and back surfaces to maintain the spacing (to prevent flexing of the surfaces), and in some designs, to alter the interaction between soap and air as discussed later.

Several preliminary enclosures were fabricated to investigate a number of parameters and their impacts on the overall visual effect. Figure 1 shows one of the preliminary enclosures, made of orange and clear acrylic sheets. The edge strips are 1.6 mm thick black acrylic, and two small spacers are used (in the form of an exclamation mark). The soap is white liquid dish washing soap as purchased from supermarket and undiluted. If desired, the soap could be easily colored by adding and mixing a few drops of food color. About 40% of the enclosure volume is filled with soap and the remainder is air.

When fabricating the enclosure, a small section of an edge strip is cut out to leave an opening. A hypodermic needle is inserted through the opening to fill the soap, after which the opening is plugged with the cut-out edge strip and sealed (seen in the upper right corner in Figure 1). Two kinds of acrylic adhesives were used to make and seal the enclosure.

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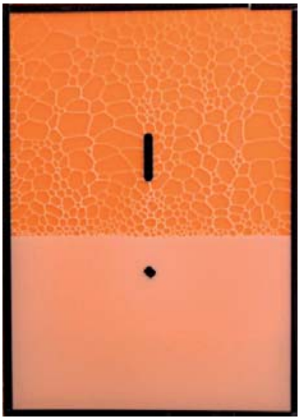

Figure 1 – Enclosure with white liquid soap. No digital alteration has been applied to this or any of the images that follow (with the exception of cropping)

1. Results

A sequence of operation of the enclosure is depicted in Figure 2. On the left, the soap is idle at the bottom and this is a stable condition. Upon turning the enclosure 180°, shown in the middle, the soap, which is heavier than air, becomes unstable and starts to flow down. As a result the air creeps up in the form of bubbles. An ever-changing interaction starts to take place between the soap and air, and in about a minute later, shown on the right, half of the soap is drained to the bottom. Most of the soap would drain to the bottom in another few minutes, leaving only soap bubbles on the top.

Figure 2 – From left to right, sequence of operation from idle and stable condition to ever-changing patterns. Large bubbles are formed after a very long idle (middle image)

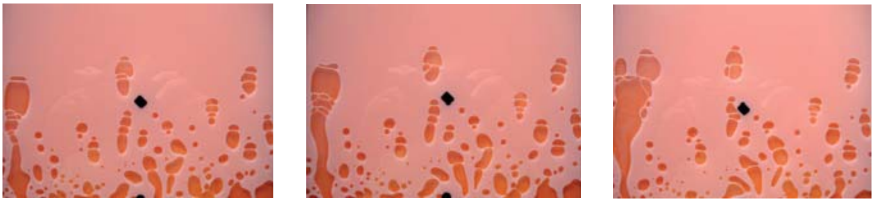

Figure 3 – From left to right, bubble clusters growth at time = 0, 3, and 11 seconds

The enclosure would then be ready for another turn. If the initial idle is very long, about several days when almost all of the soap would have been at the bottom, the resulting bubbles are large after the first turn. This was the case in Figure 2 (image in the middle). However, bubble size is reduced in subsequent turnings.

The soap-air interaction is affected by several external factors such as idle time prior to turning, temperature, and whether the front and back were squeezed together while turning. However, regardless of these factors, new patterns are created each time the enclosure is turned.

Three photographs covering a span of 11 seconds of bubble clusters growth just after a turning of the enclosure are presented in Figure 3. Note the tall bubble cluster on the left is evolving relatively quickly compared to the many smaller clusters elsewhere. This is due to the interaction between two opposing forces: buoyancy (upward force) and shear (downward force) acting on the clusters by the downward flow of the soap. The clusters often resemble worm like creatures, and eventually buoyancy prevails and all bubble clusters rise to the top.

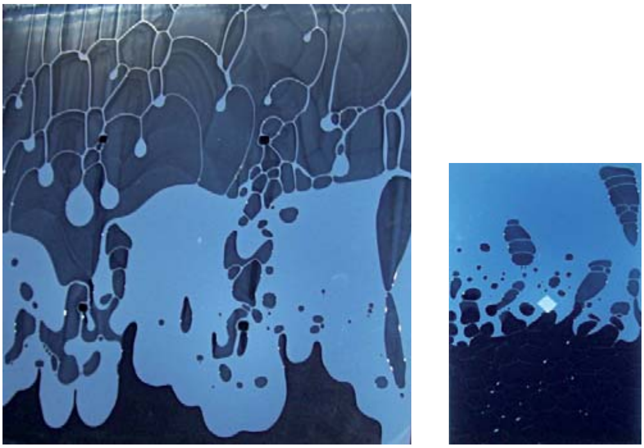

Figure 4 – Large (0.38 m × 0.38 m) and small (0.20 m × 0.12 m) enclosures

In preparation for the final design, a number of parameters were changed to examine their impact on the overall visual effect of the enclosure. The parameters were enclosure size and shape, interior details or partitions, and background color and soap color. Figure 4 shows two examples of large and small enclosures. The images are cropped to central areas for clarity. The materials are identical – black background, clear front, and white soap. The apparent difference in color is due to different lighting conditions when the photographs were taken.

Figure 5 – Three different enclosure shapes

The author found the soap drops falling through soap films, as evident in the upper portion of the left image in Figure 4, quite attractive. And this phase of the soap-air interaction might be useful to artists as an idea generator for line drawings or graphic design.

Three basic shapes of the enclosure were considered as shown in Figure 5. The circular enclosure is actually the final product (more on this later) and has the same internal spacing of 1.6 mm. The square shape was made in different sizes and was less expensive to fabricate than the circular one due to easier machining. The annulus enclosure was constructed of an inner PVC pipe (diameter = 7.6 cm) with its ends capped and an outer thin clear plastic tube, which is commonly used for storage.

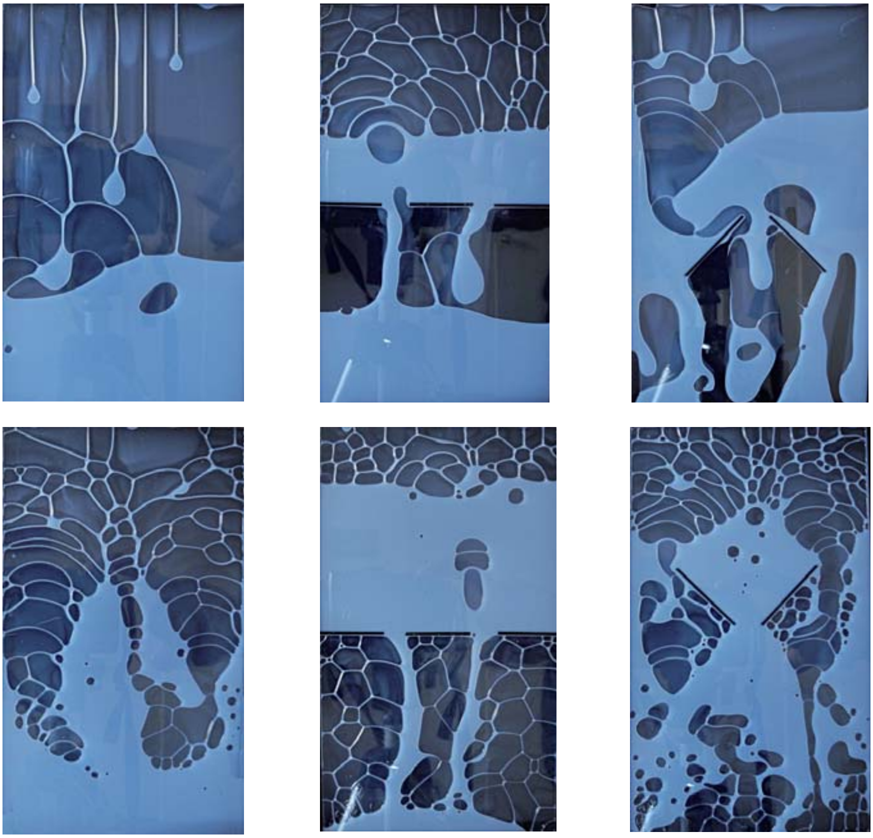

Figure 6 – Visual effect of internal details. Left column: no partition, middle column: 2-gap partition, and right column: V-shaped partition. Top row: flow just after a very long idle. Bottom row: flow after multiple turnings

The annulus spacing varies between 1.6 - 3.2 mm due to irregularities in the thin plastic tube. Several drops of blue food color were added to the white soap in the annulus. A two-piece cardboard stand supports this enclosure, allowing a user to manually rotate it to initiate the soap-air interaction.

Figure 6 shows three enclosures with and without partitions. From left column to right, three examples of internal details are seen: no partition, horizontal partition with two openings, and V-shaped partition. The top row images depict the flow initiated after a long idle, and the bottom row images show the flow after a few turnings of the enclosures. Acrylic rod of 1.6 mm diameter served as partition material.

The partitions altered and slowed down the soap-air interaction as expected. Although the partitions create unique patterns, their addition makes the fabrication process more difficult and expensive, especially for the larger enclosures.

Soap bubbles and films demonstrate several scientific topics, and the designed device demonstrates a few fluid dynamics phenomena.

For example, as shown in the left image in Figure 7, bubbles are settled in no more than three-neighbor arrangement, which is referred to as Plateau border.

Also, Saffman-Taylor (viscous fingering) instability and Rayleigh-Taylor instability are seen in the right image in Figure 7.

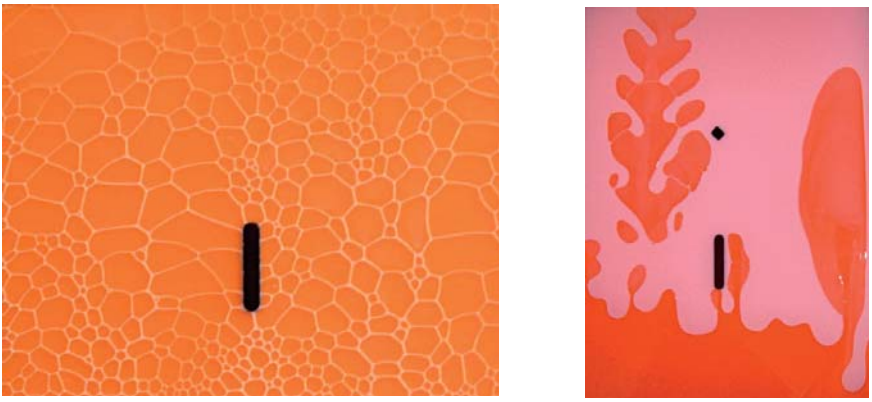

Figure 7 – Scientific phenomena demonstrated by the soap enclosure: Plateau borders on the left and two fluid dynamics instabilities on the right

2. Final Design

Based on what was learned from the preliminary enclosures, the following attributes were selected for the final design: a flat circular enclosure (diameter = 0.38 m) with black background, clear front, white soap, and four small square spacers (without partitions).

This design meets the objective and is appropriate for wall installation as shown in Figure 8.

Figure 8 – Soap enclosure installed at the University of the Pacific's Library, left. Close up on the right

The enclosure is attached to a turntable and housed in a frame secured to a wall in our campus library, which is open to public. The front face is of thicker acrylic sheet for safety. Two pegs with arrows glued onto the face of the enclosure prompt a user to turn the enclosure. Notice the frame's foot print is relatively small, about less than 8 cm protruding from the wall. (There are two more enclosures within the frame, one with beach sand and the other with thousands of tiny precision spheres, exhibiting flow of granular materials.) Text blocks affixed to the frame inform users how to use the device, outline scientific relevance, and suggest keywords for further studies. The display not only demonstrates several scientific phenomena but also enhances an otherwise blank wall. It is a combination of scientific demonstrations and visually engaging display.

After nearly two years of installation, the enclosure functions as designed. However, the soap in two of the preliminary enclosures (out of a total of eight made) had turned into gel, after approximately one and one half years. No noticeable leak from either enclosure was ever detected. The liquid to gel transformation could be due to loss of some water content via evaporation and escape through possible micro-cracks on the edges, or absorption of water into acrylic (although the hygroscopic property of plastic is of minor

Figure 9 – Pattern in soap turned into gel. (Image is cropped and frame artificially added.)

consideration here). Figure 9 shows a visually attractive image that was accidentally created in the gel by pressing the front to the back of one of the square enclosures.

3. Summary

An interactive, self-contained circular enclosure that exhibits flowing soap bubble clusters and some associated scientific phenomena was developed for public use, enhancing a blank wall, and perhaps as an idea generator for line drawings. In addition, the development of the enclosure was therapeutic for the author.

Future work will improve the current design by focusing on its aesthetic aspect, perhaps producing decorative objects for wall installation.

Acknowledgements

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