

Thoughts of a Bubble Past



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Team First

MCEN 5151: Flow Visualization

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Introduction

Thoughts of a Bubble Past was created for the Flow Visualization class at CU Boulder for the Team First Assignment. This class is where art meets science and focuses on showing and explaining the physics behind flow phenomena. The initial goal of this photo was to show a bubble popping and be able to visualize the fog flowing out of it. However, after experimenting with the shot, the residue of the bubble ring was captured and the intent shifted to capturing the wispy past of a bubble popping. A DSLR camera was used to take the image and help with the set up was received from classmates Joy Wakimura and Joshua Keller.

Experiment Setup

The equipment involved in the experiment included an Intertek FM-400P fog machine, high-density fog juice, bubble solution, a bowl, a tube, and soap. The fog machine and fog juice were borrowed from the Flow Visualization supplies. The experiment was set up on CU Campus on a balcony at ITLL to avoid filling an inside space with fog. The balcony was chosen because it had a power outlet to plug the fog machine into. The fog machine was filled with a fog juice made from a mixture of 35% triethylene glycol and purified water [1]. A 6.5" diameter plastic bowl was filled $\frac{1}{4}$ " with bubble solution which was made from a bubble wand from Target and some hand soap. The setup of the shot is shown below in Figure 2. The shot was taken facing directly towards the garden box which is into the page in the diagram below.

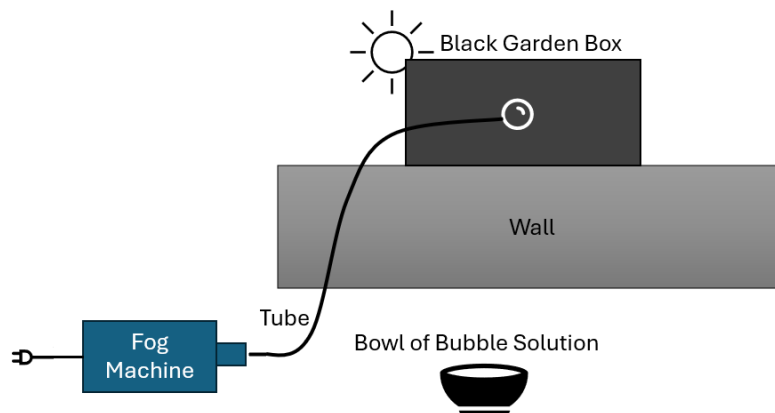


Figure 1: Experiment Setup Diagram



Equipment	Details
Fog Machine	Intertek FM-400P
Fog Juice	FogWorx Extreme High Density
Bubble Solution	Target Bubble Wand
Hand Soap	Equate Clear Hand Soap
Bowl	6.5" Diameter
Tube	¼" ID and 3' 10" long
Camera	DSLR

Table 1: Equipment List

Figure 2: Experiment Setup and Equipment

Once the fog machine had heated up, it produced a stream of dense fog. The team experimented with a few different ways to get fog into the bubbles. The first idea was to tape a funnel to the output of the fog machine and attach a tube to the end of the funnel. However, the fog was too hot and melted the funnel. The team settled on just holding the ¼" ID tube in the stream of fog close to the fog machine which resulted in the most fog going into the bubbles.

One team member held the fog machine, another team member held the tube, and the author of this report took the picture. The bubbles were formed by immersing the end of the tube into the bubble solution and then blowing fog through the tube to form the bubble with fog in it. The black background of a garden box was chosen because of its uniformity. For this shot, soap was smeared onto the garden box to allow the bubble to attach to the garden box and not immediately pop. The shot was taken just after the 1.5" diameter bubble had popped.

Flow

Bubbles are caused when gas gets stuck inside of a liquid film. In this case, the gas was fog vapor made of triethylene glycol and distilled water. The glycol water mixture was heated up in the fog machine to around 200°C. This vaporized the liquid fog juice which was then pumped out the front of the fog machine into the tube. The other end of the tube was dipped in a bubble solution so that when the fog pushed out of the tube it would create a bubble.

The soap, which is a surfactant, creates a thin layer around the water like a sandwich. The surface tension created by the soap sandwich creates a round bubble and keeps it from popping. Gravity counteracts the surface tension and pulls the fluid down which makes the top thinner and over time the water evaporates. This eventually leads to the bubble popping, usually at the top where the film is thinnest. The Eötvös Number or Bond Number is a dimensionless number that measures the ratio of gravity to surface tension [2].

$$\text{Equation 1: } Bo = \frac{\rho g R^2}{\sigma_0}$$

Table 2: Bond Number Variables

Variable	Estimated Value
Density Difference Between Fluids: ρ	1.933 slug/ft ³
Gravity: g	32.2 ft/s ²
Bubble Radius: R	0.0625 ft
Surface Tension of Liquid/Gas: σ_0	0.053 lb/ft

The fog vapor density was approximated as water vapor with a density of 0.00089 slug/ft³ at 200°C [3]. The bubble solution was estimated as water with a density of 1.9338 slug/ft³ at 26°C [4]. The bubble radius was 0.75 in or 0.0625 ft. The surface tension of water is 0.053 lb/ft at 26°C which was used to approximate the surface tension of the soap solution.

$$\text{Equation 2: } Bo = \frac{\left(1.933 \frac{\text{slug}}{\text{ft}^3}\right) \left(32.2 \frac{\text{ft}}{\text{s}^2}\right) (0.0625 \text{ ft})^2}{0.052 \frac{\text{lb}}{\text{ft}}} = 4.68$$

A Bond Number of 4.68 means that gravity is 4.68 times stronger than the surface tension, but the surface tension still holds the bubble together for a little while [5]. Eventually, though, gravity pulls down too hard and the bubble pops. This releases the fog inside which floats away in the breeze and leaves only a ring of bubble solution where the bubble once was.

There is still a small bubble left on the side of the bubble ring which displays bright colors. These colors are due to the thin film effect. When the sun shines on the bubble, white light hits the bubble's outside. Some of this light reflects off the surface while other parts of the light enter the bubble. This light then reflects off the other side of the bubble and eventually makes it back out of the bubble. The wavelengths of the light add and cancel as the light is bouncing around the bubble and this is what creates beautiful colors [6].

Visualization Technique

The visualization technique used in this shot was marked boundary. Marked boundary uses two visually distinct fluids and the boundary between them to show the flow of the fluids. In this shot, the two fluids were fog and air, and the boundary was between the dense patches of fog and the air. This boundary can be seen easily because the fog is bright white and the clear air is in front of a dark black background.

Photography and Post Processing

The photo was shot using a DSLR camera with the specifications shown in Table 3.

Table 3: Camera specifications

Camera Model	Nikon D7500
Lens	AF-S NIKKOR 24-70mm 1:2.8G ED

Focal Lenth	62 mm
ISO	2000
Shutter Speed	1/200
Aperture	f 7.1
Field of View	21.6° horizontal, 14.3° vertical
Original Dimensions	5600 x 3728 pixels
Edited Dimensions	4218 x 3204 pixels
Distance from Bubble	12"

The image was taken approximately 12 inches away from the bubble. The scene was backlit with direct afternoon light which made getting good lighting difficult. The garden box was used as a shield to block the direct light. The camera settings were used to balance the exposure and provide good visual quality. The image was postprocessed in Darktable to create more contrast between the background and the fog. The image was also cropped to focus on just the bubble and fog and to have a consistent background. A before and after image is shown in Figure 3.



Figure 3: Original image on left and edited image on right

Conclusion

Thoughts of a Bubble Past reveals the whimsical nature of bubbles. They are beautiful but fleeting. The shot also reveals what happens to the air or fog trapped inside of a bubble after it pops. The author loves the contrast between the playfulness of the bubble and the dark black background. The author also loves the texture of the wall and the bubble ring. However, the author wonders how to capture the exact instant the bubble pops to be able to see the surface tension break. Despite changing intents, the author is very happy with the shot both with flow physics and aesthetics. The author would like to improve the focus of the shot and have a slightly larger background to see all the fog. To continue this shot, an indoor space without wind could be procured to increase the reproducibility of the bubble.

References

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