# Visualization of Surface Tension Dissociation

Zachary Wehner

*Get Wet Assignment: Flow Visualization MCEN 5151*

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## Introduction

The purpose of this photograph was to explore the artistic elements of a chosen fluid phenomena while gaining insight into the basics of photography. The submitted photograph was intended solely for the first assignment of the Flow Visualization course at CU Boulder, "Get Wet." The phenomena examined is the dissociation effect that dish soap creates when placed in milk, and can be visualized through the movement of dye suspended in the solution. This effect is primarily caused by a loss of surface tension at the surface of the milk from the concentration of surfactants in dish soap.

The inspiration for this image came from a simple elementary school science experiment, and a desire to further understand the driving factors at a higher level. While many fluid phenomena could have been imaged, it was up to the photographer's discretion as to what would create a good photograph. The mix of colours and interesting, almost random flows promised an image worth capturing.

## Flow Apparatus

The setup for this experiment in its most basic form is very simple, however there were a few changes made in order to ensure ease of imagery and flow control once the reaction starts. In its most basic form, this experiment consists of a thin layer of milk [$\approx$ 1 cm] poured into a bowl or saucer, droplets of food colouring added for visualization, and in a droplet of dish soap to catalyse the reaction. This simple setup, shown in figure 1, involves a droplet of soap being dropped into a pool of food colouring suspended on top of the layer milk.

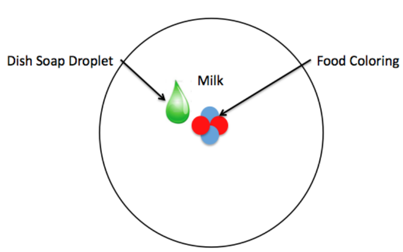


Figure 1: Basic Setup

The soap droplet causes an instability (explained later under Flow Analysis on pg 2) forcing the food colouring to mix quickly and nearly randomly. This needed to be backlit, directionalized, and colour controlled to ensure a decent photograph.

These factors were controlled and a final experiment was designed as shown in figure 2. The dyes (blue and red for contrast) were separated onto separate sides of a bowl (4 drops in total) and layered on top of a 1 cm film of milk. The bowl was lined with white paper on two sides in order to cast light on the scene without adding too much reflection. In order to add directionality to the flow a toothpick was soaked in soap for approximately 30 seconds before being placed in between the droplets of dye. This begins the reaction and forces the flow outward from the toothpick semi-linearly, and created two opportunities for interesting flow (1 for each side of the toothpick.

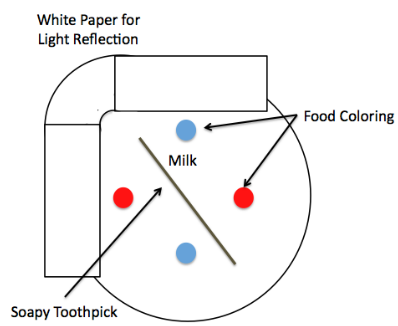


Figure 2: Final Setup

In order to capture the image multiple camera angles were explored. Unfortunately because milk is not transparent a side view through the bowl was out of the question. The fact that food colouring is less dense than milk also eliminates the prospect of an undershot up through the bowl. This led to the decision to take the photo from above the experiment looking straight down. In the final image the camera was 6 inches above the experiment.

## Flow Analysis

The flow in this design is governed by a gradient in the strength of the surface tension at various points in the milk. Milk is comprised mainly of water which has a surface tension of 72.8 dynes/cm [1]. This is fairly high compared to most common chemicals and is caused by the hydrogen bonding being stronger/more aligned between water molecules on the surface than those which are submerged. As a consequence they are attracted to like molecules on the surface forming a tensioned layer which can resist force. Soap is made up of a class of chemicals known as surfactants which reduce surface tension. This is possible by building chemicals which contain both a hydrophilic and hydrophobic component as shown in figure 3 [2].

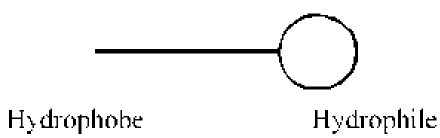


Figure 3: Composition of Soap [2]

The hydrophilic section aligns itself with the water molecules in the milk, while the hydrophobic section repels other water molecules. This forces the water molecules away from each other, pulling apart the weak hydrogen bonds, and as a result reducing the surface tension.

With large quantities of soap the surfactant can evenly disperse itself weakening the surface tension equally throughout the medium. However, in small quantities there is only a finite amount of surfactants and, as a result, the surface tension is weakened locally, and the overall medium retains its original strength. This results in a gradient similar to that of an electric field; molecules bonded to the surfactants no longer pull on molecules between them and the surrounding un-bonded molecules. This causes a rapid flow outward from the soap as the outside molecules pull on the inner molecules. This flow is clearly visualized when dye is added to the milk layer and pulled by adjacent molecules in the direction of the flow.

The resulting forces observed is dependant on the concentration of surfactant on the surface and limited by the critical micelle concentration (CMC) [4]. As surfactants are added to the solution they begin to align on the surface stacked side by side. However, as the concentration grows above the CMC micelles begin to form below the surface in circular patterns as shown in figure 4.

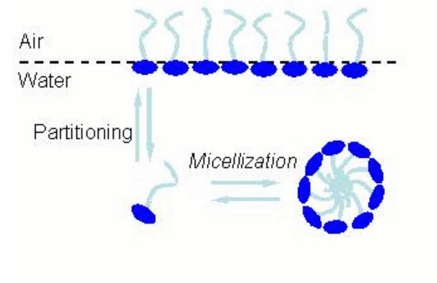


Figure 4: Micellization [4]

As the flow continues outward and the surface concentration decreases below the CMC, the micelles will break up and the surfactants will align themselves on the surface once again. This is how the concentration gradient is maintained and explains why the flow continues with time.

It is observed that the flow transitions from a smooth laminar flow to a more turbulent or recirculating flow as the milk moves away from the soap concentration. It is important to understand if this is driven by the intersection of multiple streams, of if the flow has actually transitioned into the transitional or turbulent regime. This can be easily decided by looking as the Reynolds number for this flow as defined by:

$$Re = \frac{\rho V L}{\mu} \tag{1}$$

The density and viscosity of milk are $0.003 Pa * s$[5] and $1030 kg/m^3$[6] respectively, and the characteristic length was measured to be approximately 6.35 cm (distance from soap to recirculating regime). The average velocity was estimated to be $0.0635 m/s$ by timing how long it took the fluid to cover the characteristic length ($\approx 1 sec$). Using these to calculate the Reynolds number:

$$Re = \frac{(1030)(0.0635)(0.0635)}{0.003} = 1384.4 \tag{2}$$

This allows for the conclusion to be made that the flow is laminar not turbulent, and that the recirculation flow is more likely caused by intersecting flows meeting, and the resulting forces.

There are other forces at work in the experiment besides electrochemical attraction and repulsion. A few of the other forces are friction, both with adjacent fluid and the air at the surface, buoyant forces as the dye is less dense than the milk, and even vibrations in the surface beneath the bowl. However, as these forces are much smaller than the electrochemical forces driving the flow they are nearly negligible.

## Visualization Technique

In order to visualize what was occurring from a flow standpoint, dye was added to the milk. The dye would be dragged in the direction of flow due to frictional effects and attraction to the molecules around it. This would provide an accurate representation of the phenomena being studied. In order to make the photo more interesting two different colours of dye were used to provide contrast and see the interaction of flows around the soap concentrated area.

Lighting was also an issue and needed to be addressed. Milk reflects light well which is great as the light used doesn't need to be very intense. However, this causes an issue as it can reflect direct light sources causing areas of overexposure. In order to solve this, white papers were distributed around the side of the bowl and a light source was directed so that light would reflect off the paper onto the layer of milk.

## Photographic Technique

As the flow from this design could change quickly a fast shutter speed was desirable in order to prevent blurring of the image. As a result the final speed was set to 1/160. However, as no direct light could be applied without adverse effects, reflected light was used and the aperture and ISO values had to be set accordingly. The f-stop value was set to 5.6 (largest aperture available) and the ISO remained at 400. This ensured that the resulting image was clear and had the appropriate exposure.

The purpose of this photo was to focus on the initial flow extruding from the soap concentration and blur the resulting streams as they progressed into the turbulent regime. This was achieved by slightly tilting the camera and keeping the plane of focus on the toothpick tip, forcing the rest of the image slightly out of focus. For reference the submitted photo was taken with a Canon EOS Rebel Xsi DSLR. This resulted in a 4272 X 2848 pixel resolution.

## Conclusion

This image allows for a mix of fluid flow analysis and artistic outlet. I personally liked that the image flowed from left to right showing the transition from laminar to turbulent flow while slowly blurring the image. I felt that the physics of the flow were shown well and that a good image was produced.

This initial delve into photography left me with many question. Lighting was always an issue, and while I feel that this was partially resolved in the photo, I want to learn more about controlling exposure and lighting techniques to reduce the amount of post-processing needed. After a group critique many comments showed that overexposure in the upper right hand corner became a distraction in the image. This could easily have been fixed with a better exposed raw image.

There were other photos taken for this project which may have better exemplified the flows being examined, however all of which contained un-salvageable errors in lighting, expose, or focus. These errors were caused simply from inexperience, and if I had had more time I would have looked further into photographic techniques in order to increase the success percentage.

Overall, I am excited about the image which was submitted and look forward to future work which will build on the introduction to flow visualization.

# Bibliography


1. "Surface Tension." Web log post. Surface Tension. Hyper Physics, n.d. Web. 25 Jan. 2013. http://hyperphysics.phy-astr.gsu.edu/hbase/surten.html
2. Surfactants: Detergent Chemistry. Rep. Kiwi Web, n.d. Web. 01 Feb. 2013. http://www.chemistry.co.nz/surfactants.htm.
3. Magic Milk. Rep. Sarah Mater and Lisa Hurlbut, n.d. Web. 2 Feb. 2013. http://www.nipissingu.ca/education/jeffs/4284Winter/PDFS/MagicMilk.pdf.
4. "The World Leader in Surface Tension Instrumentation." Surface Tension. Kibron Inc., n.d. Web. 9 Feb. 2013. http://www.kibron.com/surface-tension
5. "Viscosity." - The Physics Hypertextbook. N.p., n.d. Web. 10 Feb. 2013. http://physics.info/viscosity/.
6. "Density of Milk." Density of Milk. N.p., n.d. Web. 10 Feb. 2013. http://hypertextbook.com/facts/2002/AliciaNoelleJones.shtml