UNIVERSITY OF COLORADO AT BOULDER

# Milk-Fat Surface Tension and Surfactant Interactions

## MCEN 5228 – Flow Visualization

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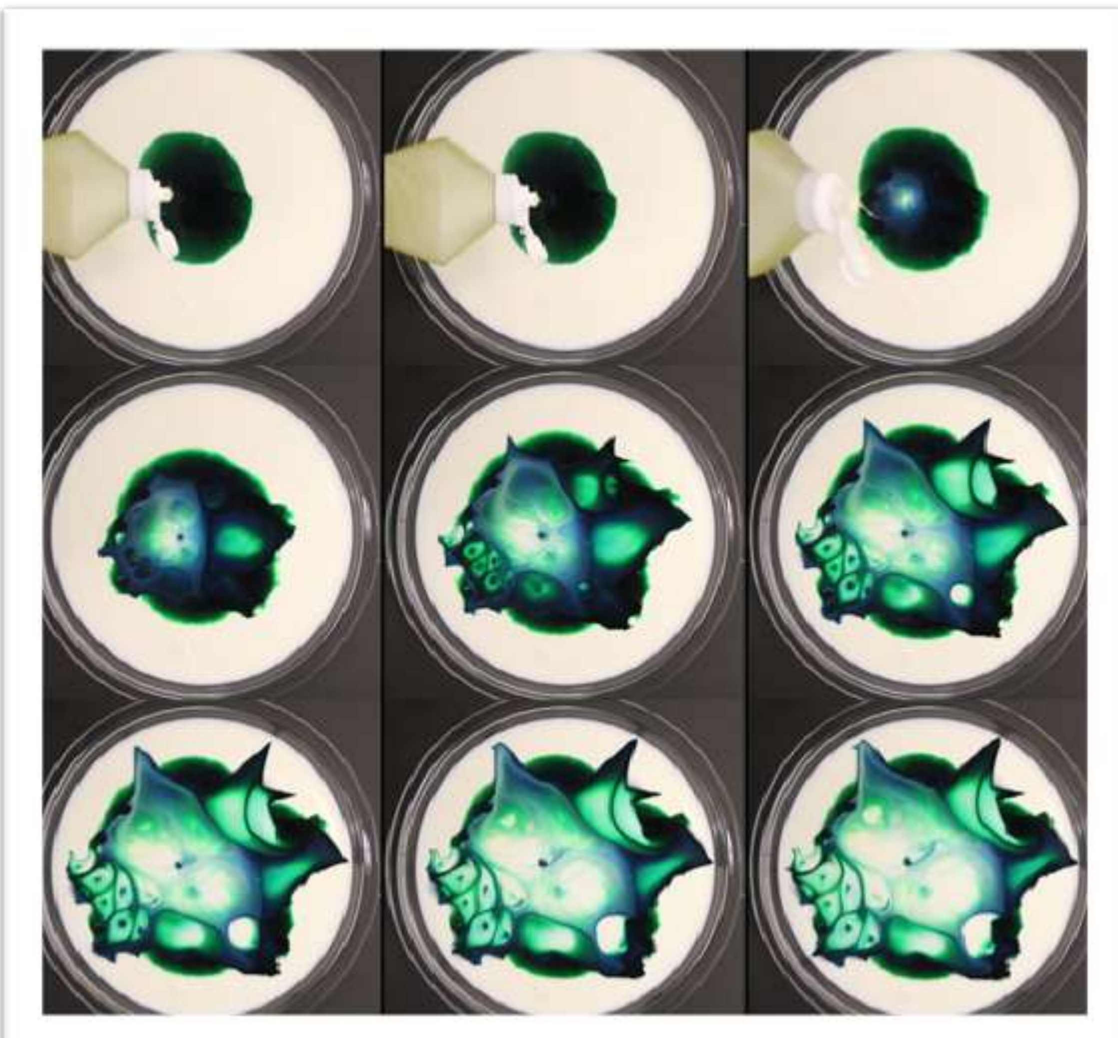

## Introduction:

It is well-known that food-dyes and milk can be mixed to make a colorful combination. However, that effect can be amplified (while simultaneous rendered inedible) by the addition of common dish soap. Dish soap is a surfactant (a compound that lowers the surface tension of other liquids) that creates an amusing and interesting effect when combined with the milk fat, as seen in the video and images captured for this project.

## Physics Background:

At the surface, it looks like the food coloring is being exploded by the dish soap, because it spreads and separates so rapidly. What the flow is actually doing is reacting to localized changes in surface tension in the milk [1]. As the dish soap reacts with the surface, it breaks apart some of the milk-fat molecules and lowers the surface tension of that region. As the surface tension is lowered in one region while remaining high in the rest of the solution, the high tension region pulls the low tension region apart. This results in the milk, and subsequently, the food dye, to be pulled apart in all directions. This phenomenon is what the experiment focused on and attempted to capture.

## Procedure:

The following ingredients/items were acquired for the experiment:

**Table 1**

| | |
|---|---|
| Food coloring dyes | Windex |
| Joy Lemon-Scented Dishwashing Soap | 2-Head Shop lamp (500 Watt/110 V/ 60Hz) |
| Acetone | Liquid Glycerin |
| Extra Virgin Olive Oil | 9 Inch Diameter Pyrex Dish |
| Clorox Bleach | Stir Rod |
| Black Background Board | Camera + Tripod |

The 9 inch diameter, glass Pyrex dish was used to contain the milk. This dish was placed upon a table on top of the black background to create a clean, featureless backdrop. The shop lamp was initially placed about two feet away from the rest of the set-up, as shown in Figure 1, but was experimented with until the lighting was ideal. Aesthetically, no positioning of the shop lamp seemed as nice as the ambient light, so it was eventually taken out of the set-up. For my purposes, it was not used, but some images did utilize the shop lamp. Photos were taken from several different angles, but the best ones were taken from directly above at a distance of approximately 12 inches and stabilized using a tripod and burst setting on the camera. The burst setting allowed for the camera operator to step away from the camera while the photographs were taken, thus stabilizing by removing the motion induced by a person pushing the button.

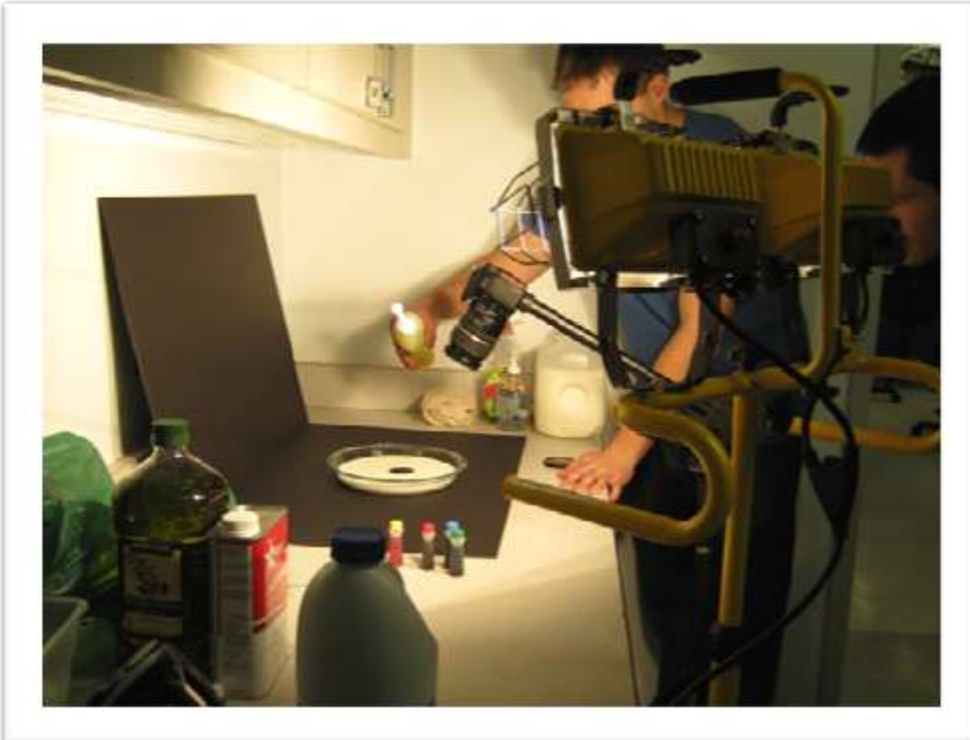

**Figure 1 – Laboratory Set-Up**

The set-up of the experiment was to add food dyes in various amounts, combinations, and configurations to the surface of the milk and/or various amounts of olive oil, and to drop liquid glycerine, soap, acetone, Windex, and bleach into it. This was to explore which surfactants would have the most interesting effects on subject liquids. After many trials with varying levels of success, it was determined that the milk, dish soap, and food dyes were most effective in producing and interesting and noteworthy outcomes. The stir rod was used to induce flow in some cases as well. Additionally, variations in the amount of time that the food coloring was given to diffuse into the milk on its own were experimented with.

For the final image sequence chosen, green and blue food dyes were used, with a large amount (7-10 drops) of each concentrated as close to the center as possible by hand. After given approximately 10 seconds to diffuse, a large droplet of soap was added to the off-center location shown in Figure 1. The sequence of fluid flow afterward was captured in a 10 shot burst that took 5 seconds to capture. This sort of procedure was repeated for many different trials, and then modified slightly for much later trials, but this is sufficient to capture the flow shown in the remainder of this paper.

## Camera Settings:

For the original photographs, a medium ISO setting was chosen in order to reduce the graininess and pixelation that occasionally arise from higher sensitivity settings. The focus was set manually, and the photograph was taken from a short distance away (about 12 in). A ten-shot burst was used to capture the movement of the flow. The motion of the fluid flow was resolved nicely, which maintains the experimental context that was desired for the final image. Table 2 tabulates the individual settings on the camera in detail. Below, the differences between an original and a post-processed final image are discussed.

**Table 2**

| | |
|---|---|
| Camera Model | **Canon EOS Rebel T2i** |
| Lens | **28-80 mm** |
| F-Stop | **f/5.6** |
| Exposure | **1/100 sec** |
| ISO Setting | **ISO-800** |
| Exposure Bias | **0 step** |
| Focal Length | **80 mm (35mm equivalent = 120 mm)** |
| Aperture (Max) | **5** |
| Subject Distance | **Roughly 12 in ≈ 300 mm** |

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## Image Post-Processing:

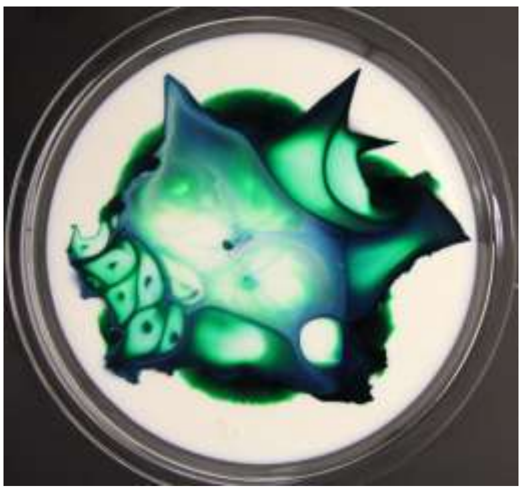

**Figure 2**

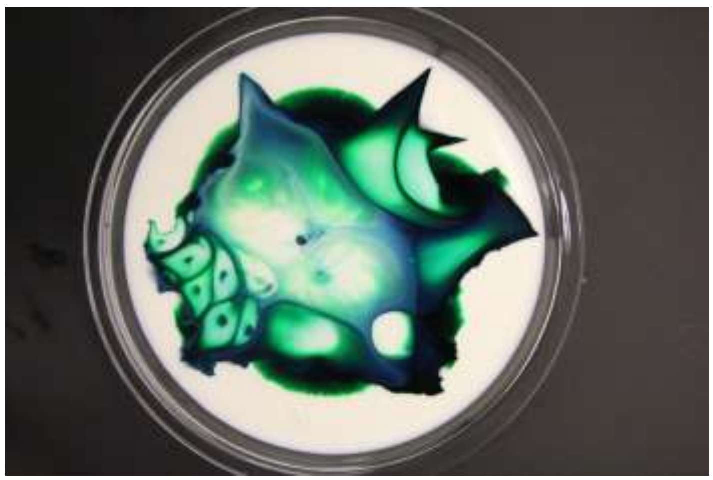

**Figure 4**

| Final Image Settings | Original Image Settings |
|---|---|
| Width - 3709 px | Width - 5184 px |
| Height - 3456 px | Height - 3456 px |
| Resolution - 72 dpi | Resolution - 72 dpi |
| Color Space - sRGB | Color Space - sRGB |

An example of the final images, Figure 3, was post-processed in the open-source program the GIMP (GNU Image Manipulation Program). It was cropped to the above dimensions in order to preserve the context of the experiment, while still narrowing the focus and scope. Attempts to modify the contrast, brightness and levels were made, but all of them seemed to remove detail from the flow, which is undesired. In the end, the cropping of the final photographs (Figure 4) is all that was done to modify them.

## Discussion: [Adapted from teammate Andrew Beat's similar analysis]

The effect of a surfactant on a lipid surface are fairly complex, but will be simplified as follows.

The composition of milk is mostly water, but contains vitamins, minerals, proteins, and small particles of fat suspended in solution. Whole milk will simply have less water and more compounds than skim milk which is intentionally watered down for fat reduction. The important components of milk that pertain to this experiment are the fats and proteins which are extremely sensitive to changes in the surrounding solution, or milk. The addition of dish soap alters the chemical bonds that hold the proteins in suspension causing them to rapidly and semi-chaotically spread throughout. The food coloring is along for the ride; as the proteins move the coloring droplets are drug along allowing the path of the proteins to be visible.

After the initial drop of soap is added it forms a micelle, or a cluster of soap molecules. This cluster has a special structure which allows it to "grab" fat molecules [4]. Figure 5 shows the composition of a typical micelle.

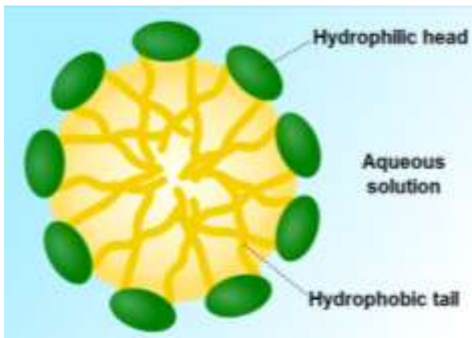


**Figure 5 – Typical Micelle [4]**

The tails of the soap molecule are hydrophobic, forcing them inward and away from water, and lipophilic, which causes the tails to secure a fat molecule. The result is a fat molecule surrounded by soap molecules [2]. As time passes, the micelle will distribute itself around the milk until both the soap and fat are evenly distributed. Once distributed, the motion in the milk will stop leaving a colorful display.

The flow seen in the image sequence chosen appears to laminar, indicating a likely Reynold's number of less than 2100. It is possible to characterize the flow as pressure-driven, due to the surface reaction introduced by the surfactant.

Another cause for the explosion of color is the change in surface tension. Since milk is primarily water, its surface will normally behave as such. This can be seen when the food coloring is first added and the droplets sit near the surface with minimal spreading and diffusion [3]. Dish soap is a surfactant which will change the surface properties of the milk, or water. In this case, the soap reduces the surface tension by dissolving fat molecules allowing the rapid mixing as described above.

## Conclusion:

In order to adequately describe the flow of the fluid, it would be important to take into account the surface tension effects of the air, as well as the dye. Additionally, the amount of dish soap would need to be more accurately accounted for, as well as the concentration of the dish soap. Overall, the geometry of the system is complicated, and it would be very difficult to describe the three-dimensional flow accurately.

## Suggestions:

Set up a digital timer circuit to take the photographs rather than trying to time it by hand, because it took nearly 300 photos to get the final photos that were used. Not all of the photos were poor (in fact, many were very good, albeit showcasing different colors, rates, and spreads), but it would have been nice to have more uniform photography and fluid flow. Also, finding a more precise way to set-up the food coloring and the surfactant drop into the milk would reduce variability inherent in the system. Also, paying more careful attention to the parameters of the flow (velocity, etc.) as well as the geometry of the food dye at the time of surfactant interaction would allow for a more advanced analysis than what can be seen here.

**Works Cited**


[1] Acheson, D. J. Elementary Fluid Dynamics. Oxford: Clarendon, 2006. Print.

[2] "Color Changing Milk at Steve Spangler Science." Science Projects Experiments, Educational Toys & Science Toys. Web. 14 Mar. 2011. <http://www.stevespanglerscience.com/experiment/00000066>.

[3] "Magic Milk." Www.nipissingu.ca. Web. <http://www.nipissingu.ca/education/jeffs/4284Winter/PDFS/MagicMilk.pdf>.

[4] Rosen, Milton J. Surfactants and Interfacial Phenomena. Hoboken, NJ: Wiley-Interscience, 2004. Print.