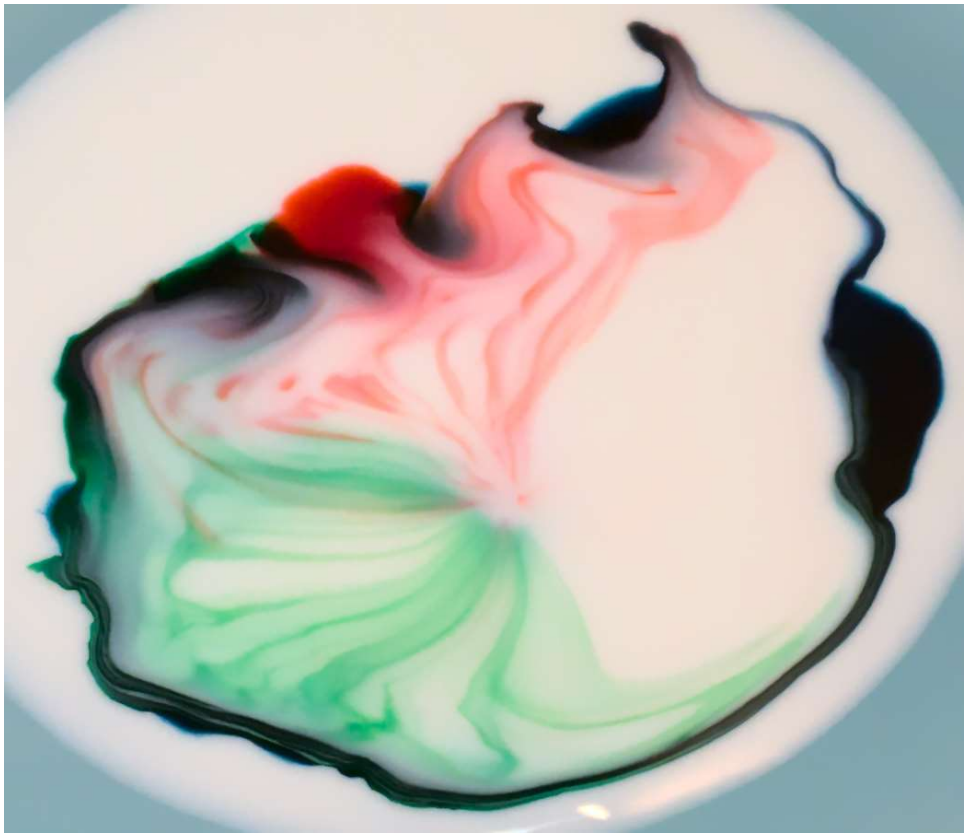
Marangoni Effect in Dyed Milk

Image-Video 1
MCEN 5151-001: Flow Visualization
University of Colorado Boulder
28 September 2020



Author: Matthew McCallum

Instructor: Jean Hertzberg

Contributors: Star Goldstein and Gavin Zimmerman

1. Introduction

This report will outline the setup that enabled this image, discuss the fluid dynamics involved in this image, and describe the visualization and photographic techniques used to take this image. This image was taken for the Image-Video 1 assignment for the “Flow Visualization” course (MCEN 5151) at CU Boulder. The image shows the result of dipping a cotton swab into the center of a plate filled with milk. Before the cotton swab was dipped into the milk, the cotton swab was coated in dish soap and the milk had 3 colors of food dye dropped into it near the center. Once the cotton swab touched the milk, it immediately and quickly moved away from the point of contact. As the milk moved, it brought most of the food dye with it but also left a light trail of the food dye as it went.

2. Experimental Setup and Procedure

A diagram of the experimental setup can be seen in **Figure 1**. The plate that the experiment was performed in was placed on a table below a light source. The camera was mostly above the plate but was off to the side so that the camera would not cast a shadow on the plate and so that the glare was minimized. The experiment was performed in the following order. First, the plate was placed on the table and the milk was poured into the plate. Then, the milk was allowed to rest for a few minutes and any bubbles on the surface were popped. Next, one drop of each food dye color was added near the center of the plate. The cotton swab was then dipped into a cup with the dish soap in it. Next, the cotton swab was touched to the center of the plate for about a second. The cotton swab was then removed, and the image was quickly taken. The image needed to be taken quickly after the cotton swab was removed because the food dye would begin to diffuse into the milk if left in the milk for too long. The experiment could be repeated by dumping the milk off the plate and rinsing off any of the food dye or milk that remained on the plate. Then the experiment could be repeated from the beginning.

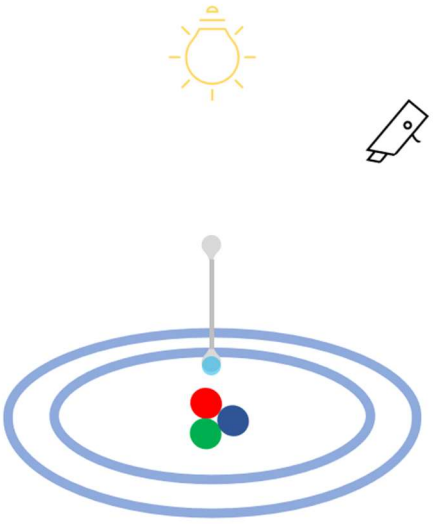


Figure 1 Diagram of the experimental setup.

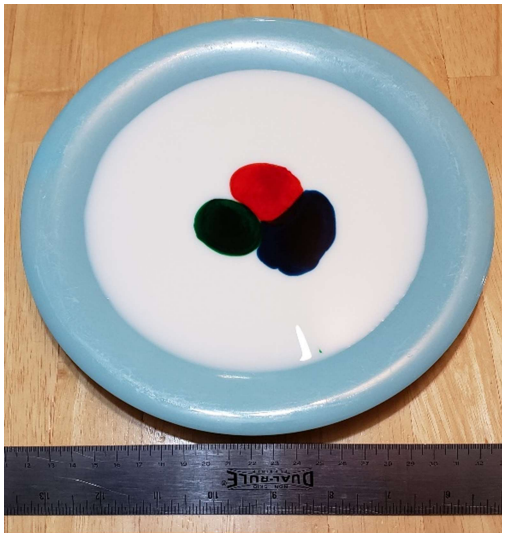


Figure 2 Image of the experimental setup before the experiment was performed.

3. Flow Discussion

This image shows the results of the Marangoni effect on a plate of milk. The Marangoni effect is when a fluid moves due to a gradient of the surface tension. A fluid particle usually experiences a uniform force in all directions from the surface tension between it and all the surrounding fluid particles. However, if there is a gradient in the surface tension, then the force from the surface tension will not be uniform in all directions. This results in a net force on the fluid, and therefore the fluid will move in the direction that the surface tension increases [2]. In this experiment, the surface tension is decreased by the addition of the dish soap to the milk [3]. The dish soap only being added to one location means that the surface tension is only decreasing in one spot. This spot having a decrease in the surface tension means that the surface tension in the surrounding fluid will be stronger and cause the fluid to flow radially outwards. As the flow moves outwards the food dye diffuses with the surrounding fluid. This increases the rate of diffusion of the food dye into the milk [1] and leaves behind a trail of the food dye. This trail of food dye is what shows the path that the fluid is flowing in. These fluid paths show that the flow moves in large smooth paths as it flows radially outwards. This shows that the fluid flow remains laminar as it moves. The Reynolds number a fluid flow is a measure of how likely the flow is laminar or turbulent. The Reynolds number (Re) of this fluid flow is:

$$Re = \frac{uL}{\nu} = \frac{(0.05[m/s])(0.15[m])}{1.13x10^{-6}[m^2/s]} = 6600$$

The Reynolds number at which a fluid flow transitions from laminar to turbulent can vary a lot. Reynolds himself found that the transition occurred between Re = 2000 and 13000 and could even happen as high as 40,000. Looking at the flow in the image, the long smooth flow paths show that the flow is mostly laminar but looking at the edges of the flow some large-scale vortices are forming. This is a sign that the flow is beginning to transition from laminar to turbulent, but that the flow is still mostly laminar.

4. Visualization Technique

The fluid flow was visualized by using food dye that would leave a trail of where the fluid went. The food dye that was used was “Signature Select Assorted Food Coloring” and the red, green, and blue dyes from that package were used (the yellow dye in the package was not used). The milk that was used was Lucerne brand 2% milkfat milk. The dish soap that was used was “Ultra Ajax Charcoal + Citrus” and it was not diluted. The food dye was dropped directly out of the containers that the colors came in, and the cotton swab was dipped into undiluted dish soap.

The experiment was lit up by a light in the ceiling directly above the plate. The image did not require a large amount of light, so this lighting was sufficient. The main part of the lighting that needed to be considered was the glare off the subject of the image. The camera needed to be put off to the side of the plate a little bit for there to not be too much glare. Also, the camera being put off to the side prevented the camera’s shadow from being in the frame of the image.

5. Photographic Technique

The image was taken keeping two things in mind. The first was to frame the image so that the plate and the ruler were both in the image. This was done to ensure that the subject of the image was in frame, but also so that the dimensions of the experiment were known. The other key consideration was to minimize the glare coming off the milk. With the primary light source coming from directly above, the camera needed to be off to the side of the plate so that the glare only came from the plate and the very edge of the milk. The camera settings were left on the automatic because there were no parts of the image that gave the automatic settings any trouble. The setting that the image was taken on were:

Camera:	Samsung SM-G960U (Galaxy S9)
Aperture:	f/1.5
Exposure:	1/60
Focal Length:	4 mm
ISO:	320
Width:	4032 pixels
Height:	2268 pixels

The image was edited using Darktable and had 3 edits performed. The first edit was noise reduction. The built in denoise function was applied to the image with the default settings. The second edit was an increase to the saturation. The colors of the image did not stand out as well as I expected them too, so the saturation was increased from the base level. The third edit was a cropping of the image. The image was cropped so that the food dye dispersal occupied most of the frame and there were as few other parts of the image as possible.

6. Image Commentary

This image reveals the interesting nature of the Marangoni effect in a simple way. The combination of three common household items causes a smooth colorful flow to emerge because of this effect. This image shows an okay example of this effect, but its main issue is that it is too close to an experimental demonstration and too far from an artistic one. What I mean by this is that if this was done as an experiment, only one color of dye would be used to limit the distractions in the data, and if it was done as a work of art, there would more effort put into mixing the colors and having more of them. By only having three colors, this image is in a weird spot where it is trying to look good but not enough effort was put in to get there. Therefore, to improve this image more effort needs to be put in to mixing the colors and having more of them. Adding more colors would be an easy task to do. The food dye colors could be mixed outside of the milk and then added. The main problem to overcome with this is that the food dye would need to be added in smaller drops to avoid adding too much dye to the milk. The colors could be better mixed by adding more colors in different locations, and the dish soap could be added in multiple locations to make the flow more varied. The main problem to overcome with this would be to not oversaturate the milk with too much dish soap so that it no longer disperses when the dish soap is added.

References

[1] Kitahata H., Yoshinaga N. (2018) *Effective diffusion coefficient including the Marangoni effect.* J. Chem. Phys. 148, 134906; https://doi-org.colorado.idm.oclc.org/10.1063/1.5021502

[2] Roché M., et al. (2014) *Marangoni Flow of Soluble Amphiphiles*. Phys. Rev. Lett. 112, 208302; https://doi.org/10.1103/PhysRevLett.112.208302

[3] Sharp N. (2014) *The Marangoni Effect*. FYFD; https://fyfluiddynamics.com/2014/10/differences-in-surface-tension-can-create/