Milk Mirage

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I Introduction

Marangoni flow is depicted in this image using physics and fluid dynamics detailed in this report. Likewise, the photographic and visualization techniques are used to capture the science behind the flow. This image was taken for the Get Wet assignment for the Flow Visualization course at the University of Colorado Boulder.

The image shows the resulting reaction that occurs when a cotton swab with dish soap is dipped into a plate of whole milk and orange and pink food coloring. Upon placing the cotton swab in the milk, the milk moved away from the soap, carrying the food coloring with it. This created the cool swirling pattern of colors seen in the photograph.

II Flow Apparatus

This experiment can be done by setting the plate on a flat surface and securing it in place. The plate is typically filled with milk and a few drops of food coloring focused at the center. For this image the plate was set on a table outside and the food coloring was spread randomly throughout the milk. The sun was used as the light source angled up and behind the plate. The experiment setup to capture the image is shown in **Figure 1**.

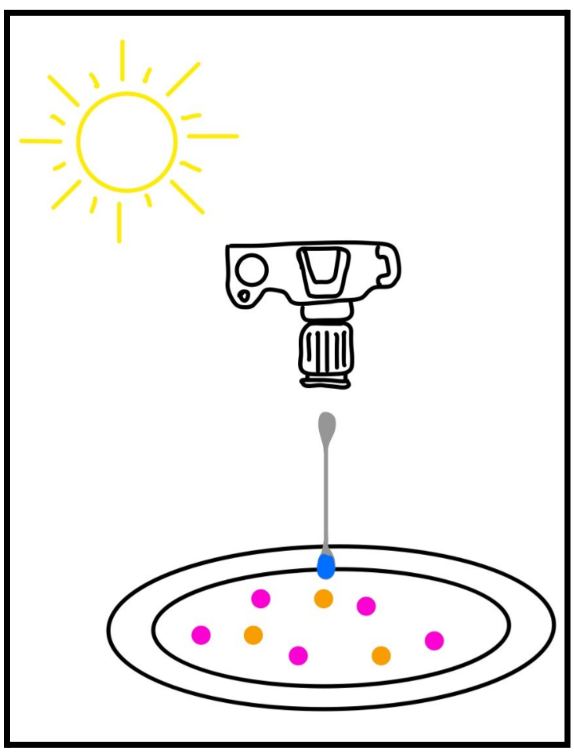

Figure 1: Diagram of experiment setup

The rate and duration of the reaction are influenced by the fat content in the milk. The soap molecules interact with the proteins in the milk, leading to a change in the molecular structure [1]. As a result, the soap molecules surround the fat globules creating micelles [2]. In this experiment, whole milk was selected due to its higher fat content, which facilitated a longer reaction period. Once the soap has reacted with all the fat molecules, the reaction will gradually come to a halt, and no further flow will be generated

In addition to this, the flow captured in the image is the result of Marangoni flow. A gradient in surface tension produces a Marangoni flow, in which mass transfers from one point to another. When the cotton swab with dish soap is placed into the milk it serves as a surfactant, lowering the existing surface tension and creating Marangoni instability [3], shown in **Figure 2**. The milk is then pulled towards the high-tension surface area and away from the soap, pulling the food coloring with it [4]. Creating trails of food coloring leads to the colors shown throughout the entire image.

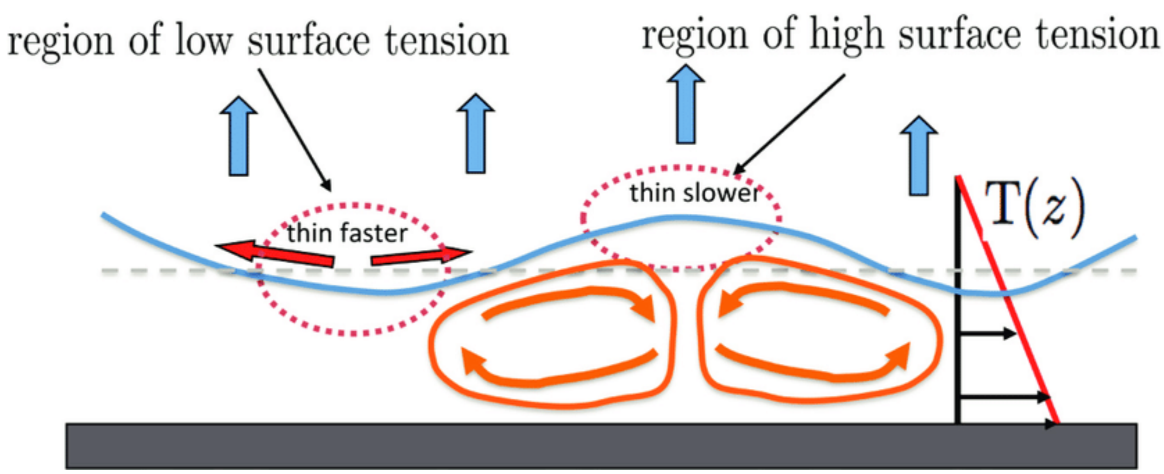

Figure 2: Marangoni instability creating Marangoni flow [3]

In this image, the soap was maneuvered in a zigzag pattern across the milk, resulting in various surface tension gradients across the milk's surface. This created multiple vortices of color throughout the plate of milk, rather than a single outward radial flow from a central point. Demonstrating a turbulent flow rather than a laminar flow. This can also be shown using the Reynolds number. The Reynolds number (Re) for the Marangoni flow in this experiment is 5,547, which was solved using the equation below [5].

$$Re = \rho\frac{uL}{\mu} = 1040\ \frac{kg}{m^3}\left(\frac{0.04\ m/s * 0.2\ m}{0.0015\ kg/m*s}\right) = 5,547$$

The Reynolds number is greater than 2000 suggesting that the flow is turbulent. Turbulent flow indicates that there is lots of mixing and eddies creating a swirling pattern. This is shown in the image with the various gradients of colors and vortices.

III Visualization Technique

The Marangoni flow was created using Palmolive dish soap, Kroger whole milk, and Wilton gel food coloring, as shown in **Figure 3** below.

Figure 3: Materials for experiment

The colors seen in the image are the magenta and orange from the package. The milk was poured on the plate until it covered the bottom of the dish. About twelve to fifteen drops of food coloring was added to the milk, directly out of the droppers. Palmolive dish soap was added to the tip of a cotton swab to allow for more control of where the soap was being placed. In order to get the brightest possible results, nothing in the experiment was diluted.

To attain the desired lighting, this experiment was conducted outside at roughly 4:00 pm. This allowed for the sun to be the light source without being directly above the experiment. That way the camera was able to be angled directly above the experiment without casting a shadow on the image.

IV Photographic Technique

The image was captured using a Canon EOS 5D camera with a Canon EF 28-200mm lens. The lens has an aperture of f/3.5-5.6 and a filter thread of 72 mm. The distance from the object to the lens was about 2 feet with a field of view of about 47°. The exposure was 1/125 seconds, the ISO was 100, and the focal length was 50 mm. I chose these settings to capture as much detail as possible, without sacrificing too much resolution. The original image was 5616x3744 px and the edited image was cropped to 2146x1642 px. The original and edited pictures are shown below.

Figure 4: Original Image

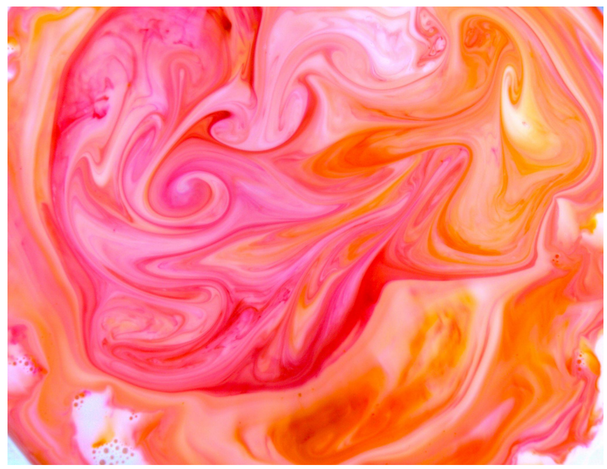

Figure 5: Edited image

The photo editing software I used was darktable. I adjusted the tone curve, increased the saturation, increased the exposure, and increased the color contrast. I also cropped and rotated the image. The goal of these edits was to make the orange and pink colors pop as much as possible.

V Image Analysis

The image provides an example of how surface tension gradients can cause a mass to move. I really like how my image turned out. I think the colors are very vibrant and the cropping enhanced the image as a whole. I think I could improve the image by enhancing it more with post-processing, a skill that I am working on. I think the fluid physics are shown very well. Even though this is often a simple experiment done for kids, it shows a very high-level and complex type of flow. I did fulfill my intent when creating this image. I think to develop this idea further, I could use a slow-motion camera to show the Marangoni flow happening over time.

VI References

[1] Prasad, S. (2023, March 3). *Magic milk experiment: Fun science experiment for kids*. Osmo Kids Learning. https://www.playosmo.com/kids-learning/magic-milk-science-experiment-for-kids/

[2] Doherty, P. (2003, January 9). Soap Driven Convection in Milk. Retrieved from Exo.net: http://www.exo.net/~pauld/activities/fluids/soapconvectionmilk.html

[3] Higgins, Brian. (2016). Coating Defects during the Consolidation of Colloidal Films during Drying. 6. 72.

[4] Roché, M., Li, Z., Griffiths, I. M., Roux, S. L., Cantat, I., Saint-Jalmes, A., & Stone, H. A. (2014, May 20). *Marangoni flow of soluble amphiphiles*. Physical Review Letters. https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.112.208302

[5] *Physical properties and composition of Milk - Aligarh Muslim University*. PHYSICAL PROPERTIES AND COMPOSITION OF MILK. (n.d.). https://old.amu.ac.in/emp/studym/99999175.pdf