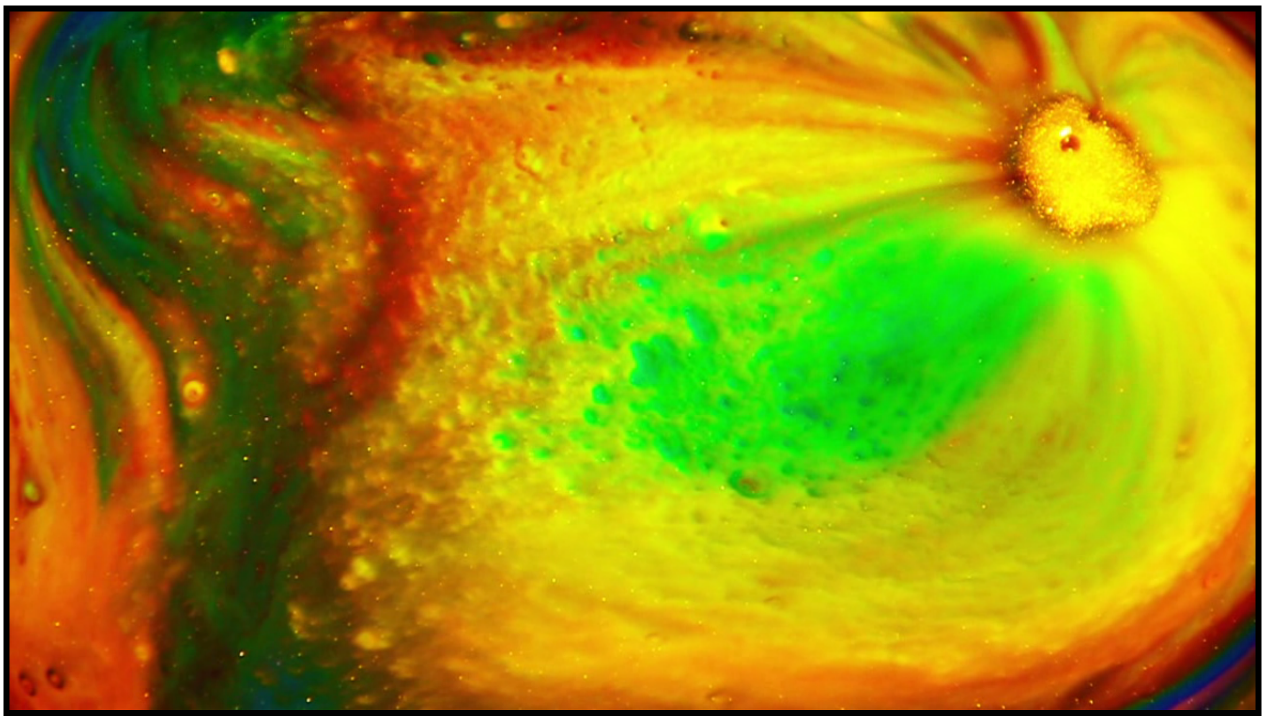
Colorado
University of Colorado at Boulder

Group Project
Marangoni Effect



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I. Background

This project was the second team assignment of our Flow Visualization course at the University of Colorado at Boulder. The purpose of this footage was to capture the fluid flow behavior of dyed milk as it interacts with additions of soap. We visualized this behavior using food dye, which created colorful patterns as the milk and soap interacted. The fluid phenomenon that causes this interactive movement is known as the Marangoni effect, which is created by a surface-tension gradient between two fluids (Tadmor 2008). This experiment was conducted with the assistance of Jeffrey Pilkington and Dillon Thorse.

II. Flow Analysis

The flow of the dyed milk is driven by a surface-tension gradient at the interface between the milk and the added soap. This gradient is created by the introduction of a surfactant, soap, to the milk, which causes an area of localized low surface tension (Rosen 2004). Milk is a colloid suspension of fats and proteins in water that reacts with the hydrophilic heads and hydrophobic tails of micelle structures, seen in Figure 1. Micelles form as soap aggregates in an aqueous solution. The hydrophilic heads dissolve in the water allowing the hydrophobic tails to attach to the fat molecules in the milk. This molecular reaction causes the reduction in surface tension that drives the flow described by the Marangoni effect (Schramm 2000).

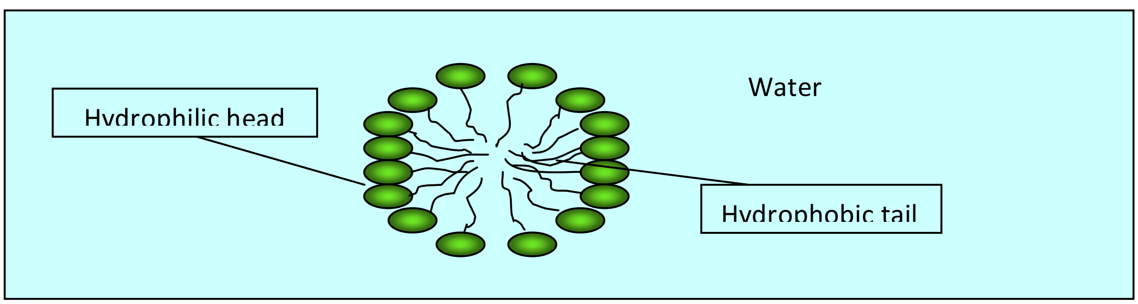

Figure 1: A micelle structure formed in aggregated soap, which contains hydrophilic heads and hydrophobic tails

The velocity of the fluid flow can be approximated by measuring the movement of the gold-colored particles of body wash within the milk. The particles are moving at a rate of approximately one centimeter per second, which is the velocity of the fluid, v. The flow conditions of the milk can be calculated using the Reynolds number (Inamdar 2012):

$$\mathrm{Re} = \frac{vL}{\upsilon} \qquad (1)$$

In Equation 1, v represents the previously calculated fluid velocity, L is the characteristic length, and υ is the kinematic viscosity. The kinematic viscosity is approximately that of milk, which is $\upsilon = 1.13 \times 10^{-6}\ m^2/s$ ("Fluids-kinematic viscosity" 2013). In this situation, the characteristic length is represented by the hydraulic radius of an open channel (Inamdar 2012):

$$L = \frac{A}{WP} = \frac{144cm^2}{2(16cm) + 2(9cm)} = 2.88cm \quad (2)$$

Using the determined quantities, we can calculate the Reynolds number that represents the condition of the flow:

$$\text{Re} = \frac{(1.00cm/s)(2.88cm)}{(1.13 \times 10^{-6} m^2/s)} \approx 255$$

A Reynolds number of less than 2,000 represents a flow in the laminar region, so the flow of the milk is most definitely laminar. This evaluation makes sense because the viscous forces of the milk should be greater than the inertial forces of the fluid flow. Despite the relatively low velocity of the fluid flow, it is worth noting that the amount of kinetic energy created by the Marangoni effect is quite impressive.

III. Visualization Technique

This experiment was performed in a 9x16 cm plastic container with whole milk, food dye, and body wash soap. The milk was poured to a depth of approximately one inch, and then various colors of food dye were dropped in liberal doses around the perimeter of the container. A drop of body wash was then added to the milk, causing fluid flow to occur. Convective currents created by the fluid flow mix the vibrant spectrum of dye in the video, creating blends and textures of color.

Two 500 W tungsten bulbs lit the experiment from approximately 36 inches away, as directly perpendicular to the milk surface as possible. The plastic container was then moved to a position where the glare of the lights was not contained in the frame.

IV. Photographic Technique and Settings

The field of view used to capture the footage was approximately 9x16 centimeters across, with the surface of the milk at a distance of approximately 10 inches from the lens of the camera. The footage was captured on an EF-S 18-135 mm zoom lens at a focal length of 126 mm. A Canon EOS 60D DSLR camera was used to shoot the original footage that was 5184 x 3456 pixels in resolution. The video footage was captured at f/13 and 100 ISO at 60 fps. Post processing was done in Adobe Aftereffects by providing fade in/out effects, adjusting exposure settings, as well as making adjustments to the vibrance and contrast curves of the image. The final video is in 1080 x 720 resolution played back in DivX format.

V. Conclusions

The Marangoni effect is a very interesting phenomenon, and the dyed milk and soap experiment was a very good way to visualize its effects in an aesthetic manner. This video was very successful in capturing the vivid, shifting hues of the dyed milk as the surface-tension gradient drove convective currents within the fluid. While conducting this experiment is actually quite simple, the scientific principles involved are quite complex. The surfactant reactions that produce the convective fluid flow are very captivating, and it could be interesting to research further into how surfactants can be used in practical applications.

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