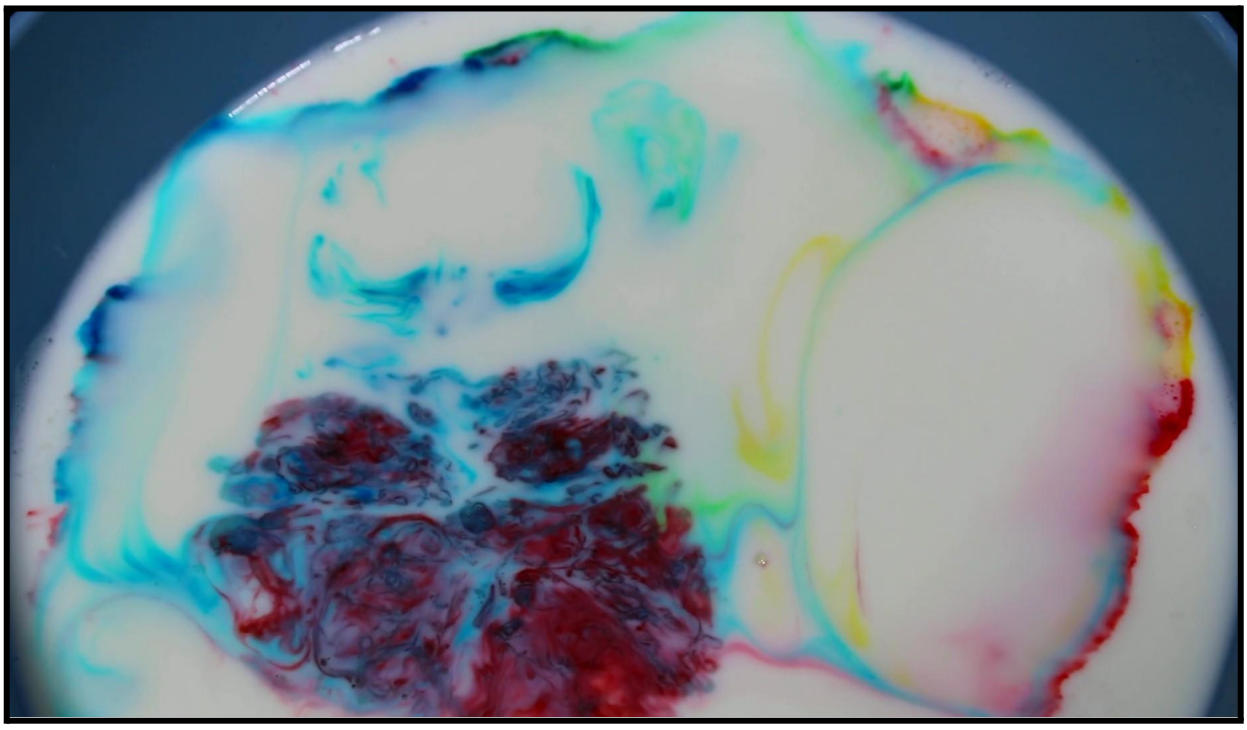
# Marangoni Effect:
# Magic Milk



Isaac Martinez
IV 1 - Get Wet
MCEN 5228: Flow Visualization
September 26, 2022

Image Purpose and Context

This video was taken with the help of Tobin Price, William Watkins, and Josh Greenburg offering support with lighting and camera setup as well as the space to take the photo. The objective was to obtain a video log of how the introduction of a surfactant (dish soap) into a fatty fluid (milk) would affect fluid flow. The interaction between two fluids with different surface tensions results in the Marangoni effect, which is the macroscopic manifestation of a liquid flow as a result of local differences (gradients) in interfacial tension[I]. Food coloring was dropped onto the surface of a bowl of milk to help visualize this phenomenon. My primary goal was to leverage the immediate and visually interesting reaction between the two fluids to generate a short video capturing a typically invisible reaction that occurs in everyday life, with various other fluids.

Image Circumstances

One cup of milk was poured into a matte blue bowl to reduce any reflections from lighting. Food coloring was dropped onto the milk's surface in a ring and a short time after, the dish soap was dropped into the center of the fluid, so the coloring does not dissipate through the milk on its own. This image was lit with two lights with one lighting from the top and the other lighting near the surface of the liquid. The lights were placed in the orientation below to provide the most even lighting, with as minimal glare on the surface of the milk as possible. The garage door was closed, leaving the room in total darkness, so the only light applied to the subject came from the rented studio lights from the ITLL. No flash function was used on the camera to further ensure there was no glare or reflection off of the surface of the milk. The camera was placed above the surface of the liquid, but out of the light to ensure it did not cast a shadow over the subject. A drawing of the experimental setup can be seen below in Figure 1.

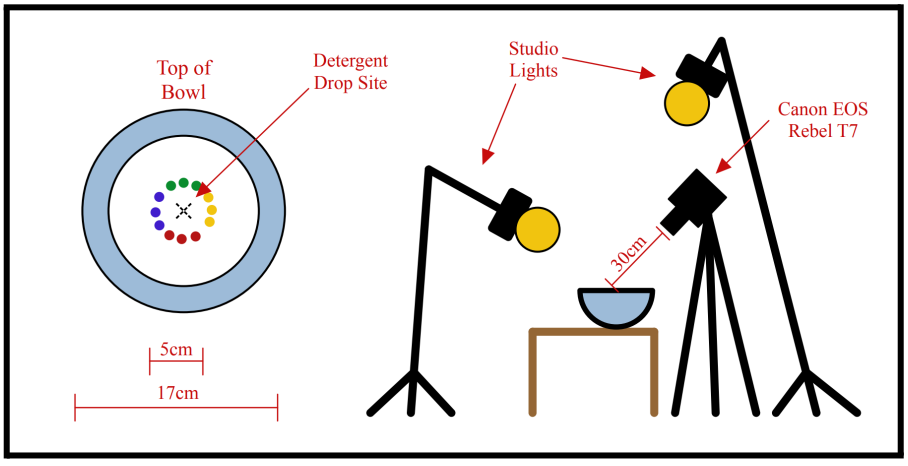



Figure 1: Experimental setup for recreating experiment and video

Dish soap is a surfactant and has a lower surface tension than milk, so once it is dropped onto the milk's surface it wants to flow away to areas of higher surface tension[II]. The surface tension decreases only at the site where the soap was dropped, which is why the food coloring

shoots towards the outer edges of the bowl. The instant the dish soap is added to the milk, the soap molecules begin bonding with the fat molecules in the milk, creating the swirling of color this experiment is famous for. Once all soap molecules have bonded to all of the available partners, the reaction slows down at the periphery.

As previously mentioned, this experiment provides a visual representation of the Marangoni effect, which states that fluid wants to flow from areas of lower surface tension to higher surface tension. One way to quantify this is by using the Marangoni number (Ma) which compares the rate of transport due to Marangoni flows. It can be calculated using the equation:

$$Ma = \frac{uL}{D} = \frac{\Delta\gamma L}{\mu D} = \frac{(\gamma_{milk} - \gamma_{soap})L}{\mu_{milk} D_{milk}}$$

Where $u$ is the flow speed, $L$ is the distance parallel to the surface of a liquid, μ is the viscosity of the fluid, γ is the surface tension, and $D$ is the diffusion constant of what is causing the surface tension difference. The Marangoni number could also be affected by the thermal gradients, but the dish soap and milk were both kept at the same temperature (room temperature), so this was not a factor. Milk is 87% water with the rest of it being made up of fats and other solids, so due to the lack of information on the fluidic properties of milk, I had to approximate some of the fluid properties as water. The Marangoni number was calculated with the information in the table below:

- L = 0.17 m
- Milk at 20℃
    - Surface tension: 50 dynes/cm = 0.05 N/m[III]
    - Viscosity of whole milk: 1.75 cP[IV] = 0.0175 Pa·s
    - Diffusivity constant (approximated as water due to lack of data): 2.025 $\mu m^2/ms$[V]=$2.025 m^2/s$
    - Specific heat: 3.94 J/g·K[VI]=3940 J/kg·K
    - Thermal diffusivity: 0.6 W/m·K[VII]
- Dish soap at 20℃ (approximated as soapy water)
    - Surface tension: 0.025 N/m[VIII]

This yielded a Marangoni number of $1.2*10^9$. Another way to analytically examine the flow is by calculating the Reynolds number, which can be calculated by using the Marangoni number and the Prandtl number:

$$Re = \sqrt{\frac{Ma}{Pr}},\ Pr = \frac{\mu C_p}{k}$$

Based on the calculated Marangoni number and the Pr number being 12.84 for whole milk, the Reynold's number was 9664, indicating that the flow was turbulent since it is well above the 2000, which is the transition from laminar to turbulent flow. This is corroborated visually by the violent scatter of color in the video, especially at the edges where the flow begins to curve.

Visualization Technique

Four colors from a pack of food coloring from Target (Assorted Food Coloring Bottles - 4pk/1.2oz - Market Pantry™) were dropped into a ring shape on the surface of whole milk to create a drastic contrast of colors. Whole milk was used for this experiment since fattier milk yields a more extreme reaction. In order to initiate the flow, Dawn™ dish soap was dropped into the center of the food coloring ring. At the instant the soap came into contact with the milk, the food coloring scattered across the surface. A short time later, there was a more extreme reaction at the site where the dish soap settled in the milk. The transient responses can be seen in Figure 2, below.

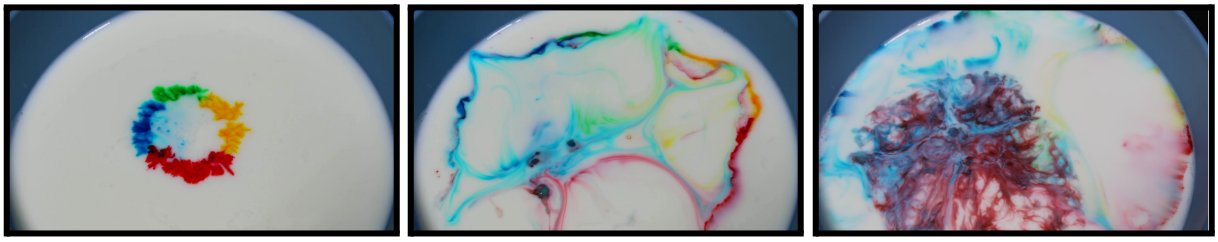


Figure 2: a) Fluid before soap droplets, b) Fluid immediately (2 sec) after soap droplets, c) Fluid after long period (50 sec) of rest

Photographic Technique

The video was taken with a Canon EOS Rebel T7 in video mode, with the EF-S 18-55mm f/3.5-5.6 IS II lens. The resolution of the video was 1920 x 1080 pixels with a focal length of 49 mm and field of view 4.5 inches wide and was recorded at 29.97 frames per second. The camera was about 30 centimeters away from the center of the milk bowl. The following settings were applied to the camera, in order to keep the subject in adequate focus and lighting.

- Aperture: f/5.0
- Exposure: 1/80
- Focal Length: 41 mm
- Focus Distance: 0.39 mm
- ISO: 125

The video was edited in MiniTool MovieMaker, where I adjusted the contrast, saturation, and brightness. The brightness was increased slightly, from 0 to 3.5, and the contrast and saturation were adjusted more dramatically, from 0 to 15 and 0 to 20, respectively, in order to make the colors appear more vibrant in the final video. I also cropped the video slightly to center the bowl in the frame, but this did not change the overall size of the video. A title and credits preceded the video and a copyright-free audio file called, “Retro Dancing Jazz” by Francesco Biondi was overlaid to help add to the lively vibe the fluid motion behavior gave off in the video. The final video length was 28.5 seconds with the fluid behavior making up 22.5 seconds.

Image Reveals

The final video demonstrates the transient behavior of the Marangoni effect in a colorful context. The use of food coloring provided a clear, visually appealing tracer in the fluid that

showed the milk moving up the surface tension gradient. While I am happy with the outcome of this experiment and video, if I were to do this again with the additional knowledge I have of the phenomena, I would use more food coloring in different orientations in order to create a more custom pattern than what I got. In future iterations, I would also use a syringe to get more control of the amount of soap added to the fluid as well as its location, since I struggled to get the droplets directly into the center of the dye ring. This could increase some of the uniformity to the flow after the soap comes into contact. Overall, I believe the turbulent flow instigated by the Marangoni effect is well represented in this video and its accompanying images.

References: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Link to Video: https://youtu.be/QysGN4wTCwQ

**Image Assessment Form**
**Flow Visualization**
**Spring 2013**

Name(s) Isaac Martinez

Assignment: Get Wet Date: 9/24

Scale: +, ! = excellent √ = meets expectations; good. ~ = Ok, could be better. X = needs work. NA = not applicable

| **Art** | Your assessment | Comments |
|---|---|---|
| Intent was realized | √ | |
| Effective | √ | |
| Impact | ~ | |
| Interesting | ! | Visualized flow I have never seen before |
| Beautiful | √ | |
| Dramatic | √ | |
| Feel/texture | √ | |
| No distracting elements | ~ | Some reflections, the bowl is vis., and shadows |
| Framing/cropping enhances image | √ | |

| **Flow** | Your assessment | Comments |
|---|---|---|
| Clearly illustrates phenomena | √ | |
| Flow is understandable | √ | |
| Physics revealed | √ | |
| Details visible | √ | |
| Flow is reproducible | √ | |
| Flow is controlled | √ | |
| Creative flow or technique | √ | |
| Publishable quality | √ | It is a bit grainy, but clear |

| **Photographic/video technique** | Your assessment | Comments |
|---|---|---|
| Exposure: highlights detailed | √ | |
| Exposure: shadows detailed | √ | |
| Full contrast range | √ | |
| Focus | √/~ | |
| Depth of field | √ | |
| Time resolved | √ | Displayed in video at real time |
| Spatially resolved | √ | Dimensions provided |
| Photoshop/ post-processing enhances intent | √ | Increases contrast, brightness, and color range. |
| Photoshop/ post-processing does not decrease important information | √ | |

| **Report** | | Your assessment | Comments |
|---|---|---|---|
| Collaborators acknowledged | | ✓ | |
| Describes intent | Artistic | ✓ | |
| | Scientific | ! | Deep physical dive: qual. + quant. |
| Describes fluid phenomena | | ✓ | |
| Estimates appropriate scales | Reynolds number etc. | ✓ | Explains physical rel. + implications |
| Calculation of time resolution etc. | How far did flow move during exposure? | ~ | Not outwardly stated, but bowl dimensions + time lapsed images are present |
| References: | Web level | ✓ | |
| | Refereed journal level | ! | Wide variety of published sources |
| Clearly written | | ✓ | |
| Information is organized | | ✓ | |
| Good spelling and grammar | | ✓ | |
| Professional language (publishable) | | ✓ | |
| Provides information needed for reproducing flow | Fluid data, flow rates | ~ | Could have tracked more exp. info |
| | geometry | ✓ | |
| | timing | ✓ | |
| Provides information needed for reproducing vis technique | Method | ✓ | |
| | dilution | ~ | |
| | injection speed | ~ | Could have provided more about soap quant. |
| | settings | ✓ | |
| lighting type | (strobe/tungsten, watts, number) | ~ | Need bulb type & wattage |
| | light position, distance | ✓ | |
| Provides information for reproducing image | Camera type and model | ✓ | |
| | Camera-subject distance | ✓ | |
| | Field of view | ✓ | |
| | Focal length | ✓ | |
| | aperture | ✓ | |
| | shutter speed | X | Need this information, but can get it |
| | Frame rate, playback rate | ✓ | |
| | ISO setting | ✓ | |
| | # pixels (width X ht) | ✓ | |
| | Photoshop and post-processing techniques | ✓ | |
| | "before" Photoshop image | X | Need to provide this |