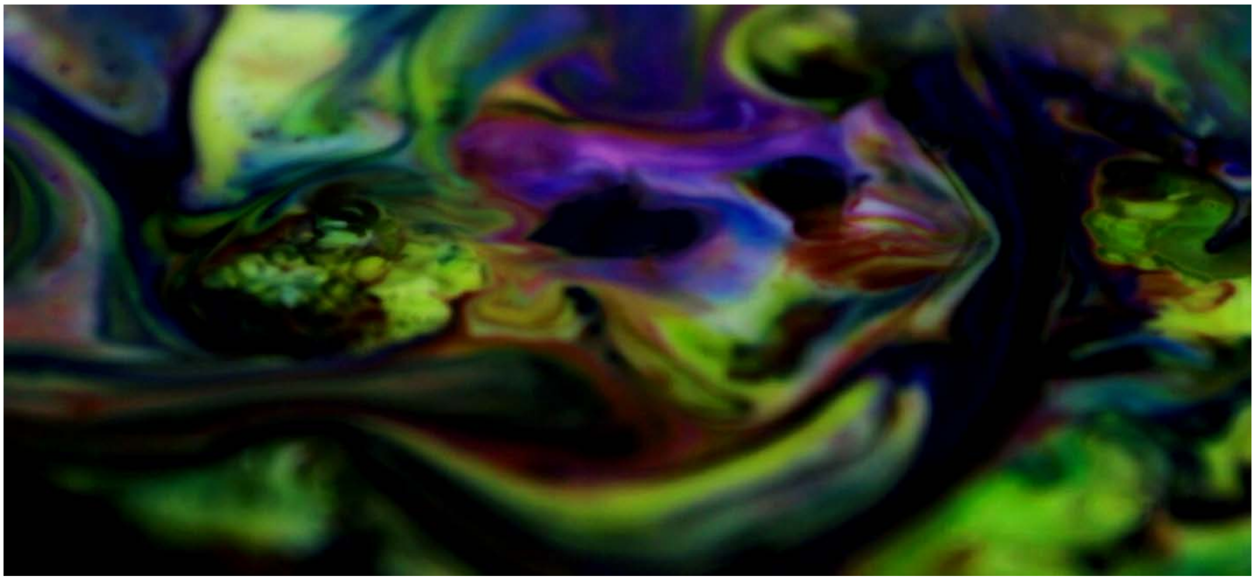
Milky Space:

Surface Tension Driven Flow



Adam Sokol

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Professor Hertzberg

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Purpose

For this introductory, “Get Wet,” assignment to the science and art of capturing fluid phenomena, students were asked to get to know their cameras by taking a photograph or video of any fluid, in any medium. I was watching YouTube videos of various fluid phenomena with a classmate and we came across an experiment typically referred to as “magic milk.” The videos seemed spectacular, so we aimed to perform our own versions of this phenomena. The goal was set to experiment with surface tension driven flow to achieve something visually appealing. Once the experiment was up and ready it became clear to me that I would use a video screenshot to select my favorite moment.

Figure 1: Beginning of experiment with just milk and food dye

Procedure/ Visualization Technique

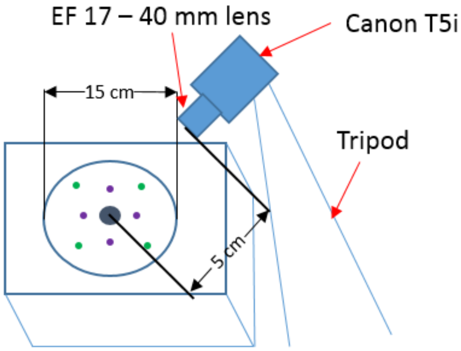

Figure 3: Diagram of experimental setup

Approximately ½ cup of whole milk filled a six inch diameter saucer. This saucer was placed on a stand filmed by a camera on a tripod as seen in Figure 2. Bright sunshine illuminated the outdoor setup. Then, 6 drops of blue food dye were dropped in the middle, 10 purple drops in a ring around the blue, and lastly 10 green drops in a ring around the purple. As you can see in figure 1, the wind quickly moved and spread out the droplets of dye. Two cotton swabs saturated in dish soap were then placed in the milk and food dye combination as seen in Figure 3. The low surface tension of the dish soap immediately caused the food dye to disperse away from the cotton swabs. The solution became very dark and murky, because of the blue, purple, and green not

Figure 2: Initial addition of dish soap with q-tips

mixing very well. So, I decided to drip approximately 2 teaspoons of dish soap in 5 dispersed locations around the saucer.

All of the initial food dye colors began reappearing as they dashed away from the newly added dish soap. This, combined with nature's wind created incredible vortices and streams of color. Figure 4 shows the last moments (approximately ten seconds) before the final picture chosen. Everything happened very quickly, especially with the wind in this experiment, but some of the final shapes can be seen here.

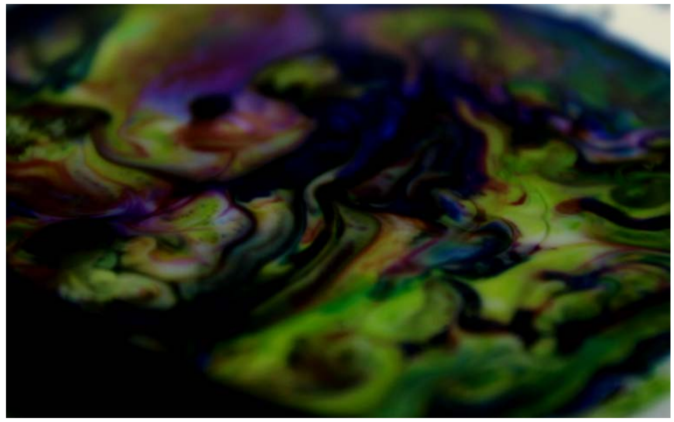

Figure 4: Image in final moments after drips of dish soap added

Physics Involved

The reason behind this "magic milk" phenomena is that soap is a surfactant. A surfactant greatly reduces the surface tension of other liquids it comes into contact with.[i] Milk has a high surface tension, and in result, a high contractive force.[ii] When the contact occurs between the milk and food dye with the soap, a current is formed from the net force created. In addition, the soap attaches to the fat molecules of the whole milk and breaks them down, lowering the surface tension even further.

The Marangoni effect explains that fluids like to go from areas of low surface tension to high surface tension.[iii] So, all of the fluid in contact with the dish soap rushes away towards the non-soapy areas. To calculate the Marangoni number, which is the ratio of surface tension and viscous forces, we approximate milk as water for surface tension and viscosity. This is done because the surface tension of water is readily known, and milk is mostly water.[iv] Values were found for the rest of the parameters. The milk was sitting in room temperature for an extended period of time so the temperature differential is approximated at only 1 degree Celsius.

$$\mathrm{Mg} = -\frac{d\sigma}{dT}\frac{L\Delta T}{\eta\alpha}$$

σ: surface tension, (SI units: N/m);
L: characteristic length, (SI units: m);
α: thermal diffusivity, (SI units: m^2/s);
η: dynamic viscosity, (SI units: kg/(s·m));
ΔT: temperature difference, (SI units: K).

From http://en.wikipedia.org/wiki/Marangoni_number

$$\sigma_{water} = .0729\,\frac{N}{m}, \qquad \sigma_{soapy\_water} = .025\,\frac{N}{m}\,^{\mathrm{v}}, \qquad L = 1 * 10^{-5} m\ (approximated),$$

$$\alpha_{milk} = 1.25 * 10^{-7}\frac{m^2}{s}\,^{\mathrm{vi}}, \qquad n = .0020\,\frac{N * s}{m^2}\,^{\mathrm{vii}}$$

$$Mg = \frac{-(.025 - .0729)\frac{N}{m}}{1K} * \frac{1 * 10^{-5} m}{.020\frac{N * s}{m^2} * \ 1.25 * 10^{-7}\frac{m^2}{s}} = 200$$

The reynolds number can also be calculated to determine if our flow is laminar, transitional, or turbulent. The velocity of the fluid was approximated by taking a point, and approximating its distance over a specific time in the video.

$$Re = \frac{pvL_c}{\mu}, p = density\ of\ milk = 1033\ \frac{kg}{m^3}, \quad v = approximate\ velocity,$$
$$Lc = characteristic\ length = \ 1.5\, m \quad \mu = dynamic\ viscoity\ of\ milk = .0020\frac{N * s}{m^2}$$

$$v = \frac{.04\, m}{3\, s} = .01\frac{m}{s}$$

$$Re = \frac{1033 * .01 * 1.5}{.0020} = 8000$$

This high reynolds number shows that turbulence existed within the flow, causing a lot of the instability seen in the photograph

Photographic Technique

The image was taken with a Canon T5i camera in video mode, with a EF 17-40 mm lens attached. The ISO was set to 100 due to the high amount of brightness created by the sunlight. The resolution was set to 1920 x 1080, the F number was at 16, shutter speed at 1/160, focal length at 40, field of view at 4.5 inches wide, and approximately a 5 inch distance from the object to the lens. The frame rate of the video was 29.97 fps. A screenshot was taken of the video, which could have made some of these parameters inaccurate.

Post-image processing was done using Photoshop following the screenshot of the video. I increased the brightness to 52, increased the contrast to 15, and increased the saturation to 10. In addition, I changed the midtones of cyan to red to -20, and the highlights of yellow to blue to -15. The original photograph, before post-image processing can be seen in Figure 5.

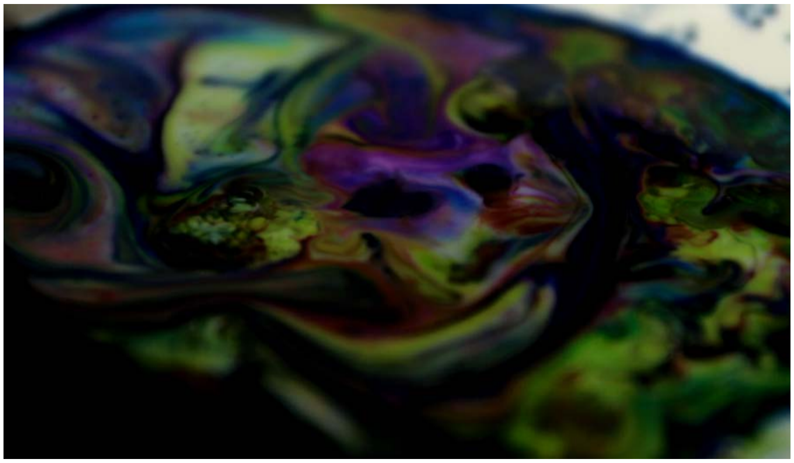

Figure 5: Original image

Conclusion

I like that the image turned out very different and mysterious while still visually appealing. The more you look into the picture, the more shapes and figures you see. However, the physics surrounding surface tension driven flow is very complicated, and all of the necessary parameters were not measured before doing the experiment. Due to the fact that the picture is from a video, the focus is also not great. Nevertheless, the goal of getting used to cameras and creating beautiful flow has been achieved, and I am better prepared to create exceptional pictures and videos in the future.

Special thanks to Andrei Molchanov for filming and keeping focus while I created the fluid phenomena.

Bibliography

[i] http://www.nipissingu.ca/education/jeffs/4284Winter/PDFS/MagicMilk.pdf

[ii] http://www.youtube.com/watch?v=rq55eXGVvis

[iii] http://en.wikipedia.org/wiki/Marangoni_effect

[iv] http://en.wikipedia.org/wiki/Milk
[v] http://www.engineeringtoolbox.com/surface-tension-d_962.html
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[vii] http://www.engineeringtoolbox.com/absolute-viscosity-foods-d_1827.html