Dillon Thorse

Flow Visualization

MCEN 4047

Team Project 2

April 9th, 2013

Introduction

For our second team image in my University of Colorado Flow Visualization class we decided to experiment with dyes on a thin layer of milk. Our intent as a group was to visualize first hand the amazing color displays this classic experiment has to offer. My intent was to create beauty through the simplicity of using red and blue dye on white milk, and to understand the physics that create this flow phenomenon. My teammates that I worked with on the project are Alex Meyer and Jeff Pilkington.

Flow Apparatus

The milk was poured into the plastic, rectangular container until the depth of the milk reached approximately a quarter-inch deep. The container was approximately seven by ten inches. The blue and red dyes were dropped next to each other, centered on the container, and touching each other as seen in Figure 1. The soap was dropped on the interface between the red and blue dyes.

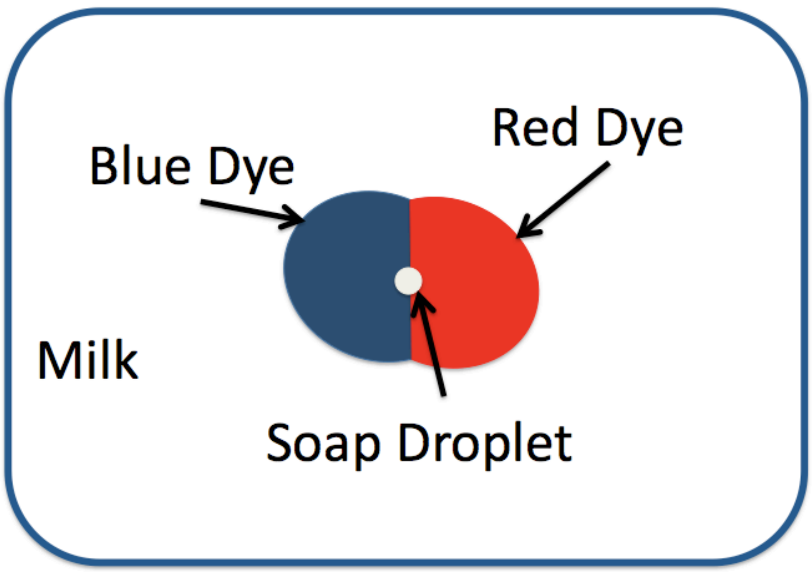

Figure 1: Schematic of Experimental Set-up

The movement of the dye was a result of the differences in surface tension. The soap greatly reduces the surface tension of the milk in the location where the soap is dripped. This area of low surface tension is surrounded by higher surface tension that pulls the milk outward. The movement of the milk can be visualized because of the dye that is placed on top of the milk. This will be discussed further in the next section.

Fluid Physics

The milk has a density great enough to hold the dye up, and it has a constant surface tension that holds the dye relatively steady. Soap is a surfactant which, when placed in milk, bonds with the fat globules in the milk weakening and dissolving their bonds with each other.[1,2] The soap is bipolar; one end attaches to the fat globules, and the other end attaches and dissolves in the water.[2] As the bonds between the fat globules weaken, the surface tension of the milk is reduced where the soap is interacting with the milk.

This creates an area of lesser surface tension surrounded by an area of greater surface tension. The higher surface tension pulls the surface of the milk outwards in all directions. The dye that is resting on top of the milk is pulled outwards along with the milk creating a spectacular mixing of colors in the plastic container. At the time that I took this image most of the soap had reacted with the milk and there was very little movement in the flow. I then shook the container very gently for about two seconds, which enhanced the creation of some of the fossil vortices shown in the image.

To gain a greater understanding of the soap's interaction with the milk, I will discuss surface tension and surfactants in greater detail. Surface tension is caused by the tendency of similar molecules to have a cohesive force attracting them to each other.[3] All the molecules in the liquid pull against their surrounding molecules with the same amount of force with the exception of the molecules on the outside of the liquid. These molecules are pulled in towards the rest creating a surface tension and causing small amounts of liquid to curve and, if small enough, form a ball or rounded shape.[3] Surface tension is also a result of the molecules of a liquid attempting to obtain their lowest energy state which is where they are in contact with as many similar molecules as possible.[3] This causes more molecules to be pulled towards the inside of the fluid creating a pressure holding the liquid together that is called surface tension.

A surfactant is a compound that lowers a liquid's surface tension.[4] Surfactants have both a hydrophile and a lipophile end. The hydrophile bonds with water and the lipophile bonds with "lipid-like substances"[5] such as milk's fat globules.[5] The lipophile tails bond with and surround fat globules in the milk trapping these globules inside micelles as seen in Figure 2, which is an example in which grease is the compound that the surfactant is bonding to (in our case, grease = fat globules)

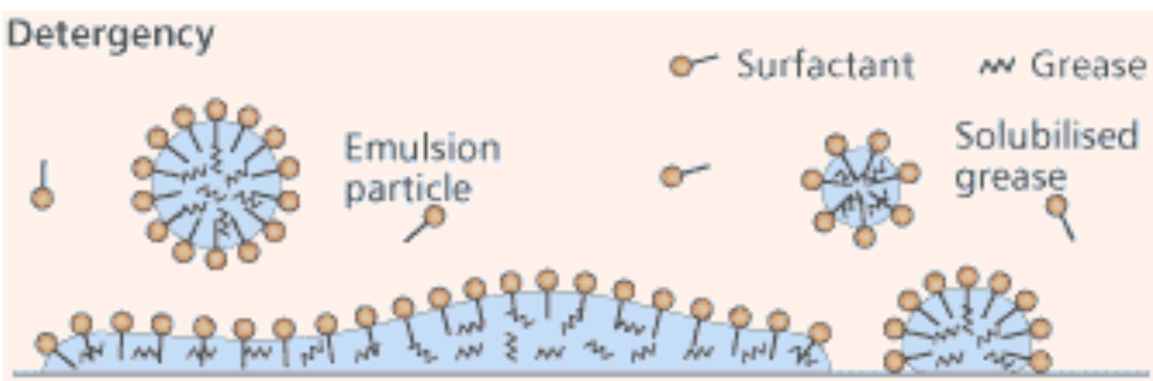

Figure 2: Example of Surfactants Interacting with Grease[5]

These micelles have hydrophile heads on the outside that dissolve in water. This effectively traps and dissolves the fat globules, which have been creating the higher surface tension. The fat globules are now surrounded by surfactants that dissolve in water; this is how a surfactant lowers the surface tension of a liquid such as milk.

"Turbulence is defined as an eddy-like state of fluid motion where the inertial-vortex forces of the eddies are larger than any of the forces which tend to damp them out."[6] There are visible vortexes and eddies in this image, but when the image was taken the fluid was moving so slowly that it was not any where near turbulent flow. In fact, the Reynolds Number was 5.53 as seen in Equation 1 where the velocity (u) of the fluid, distance (L) traveled, and kinematic viscosity (v) of milk are shown.

$$Re = uL/v = [(0.0025m/s)*(.0025m)]/(0.00000113m^2/s) = 5.53$$

Equation 1: Reynolds Number Calculation[7-9]

If the flow is very laminar, how can it show characteristics of turbulent flow such as vortices? The answer to this question is a phenomenon called fossil turbulence. “Fossil turbulence is defined as a fluctuation in any hydrophysical field produced by turbulence that persists after the fluid is no longer actively turbulent at the scale of the fluctuation.”[6] In this case, specifically ‘fossil vorticity turbulence’ is shown throughout the image, and it can be seen most clearly in the top left as a well-defined fossil vortex.

Visualization Technique

We used whole milk at approximately 50 degrees Fahrenheit when this image was taken. The dye was blue and red Kroger brand food coloring, and the soap was Up and Up brand dish soap. We took the pictures inside in the Integrated Teaching and Learning Laboratory Media Shack with two strategically placed 500-Watt Tungsten bulbs and no camera flash. The lights were placed six inches and three feet from the plastic container as to not create a glare off of the milk.

Photographic Technique

The field of view in the original image is of the entire plastic container; so, it is approximately seven by ten inches. After I cropped out the edges of the apparatus the field of view was reduced to approximately six by nine inches. The camera was placed on a tripod and angled down towards the apparatus. The distance from the lens to the milk was approximately twelve inches. The focal length was 69.0 millimeters. The image was taken with a digital Canon EOS 60D DSLR camera using an EF-S 18-135 zoom lens. The original image was 5184 x 3456 pixels and I reduced this to a final image to pixel dimensions that were 4557 x 2988 in order to remove the distracting rounded corners of the plastic container. The shutter speed was 1/30 seconds, the aperture was f/11, and the ISO setting was 100. We set the ISO to 100 to get the most clear and crisp image because we had more than enough light. In fact, because the light was so bright and would have oversaturated the image, we were able to use a high f-stop with a moderate shutter speed. The shutter speed was plenty fast enough to completely freeze the flow for this image. I did very little post processing, because when I manipulated the curves function in Photoshop in order to change the contrast of the image I found that no matter what I did I lost information and detail from the image. For this reason I decided that we had used very good camera settings and lighting for this image and I did not edit the image past cropping it. The image is very well resolved. In fact, it is resolved into the third decade as you can clearly make out lines that are three pixels wide and the image is approximately 3000 pixels in width. It is well resolved in both x and y directions, and any blur is from the gradual changing of colors in the fluid and not from the image that we captured.

Conclusion

This image reveals a beautiful display of several different shades of red, white, and blue. It shows the mixing that can occur during this surface tension experiment as well as reveals fossil vorticity turbulence. I fulfilled my intent of learning something new about fluid physics, creating an aesthetically pleasing image, and having fun observing an exciting new phenomenon I had never seen before in person. In the future, I would experiment with different soap types because each soap type that we used seemed to produce a different result from the other soaps. Some soaps lasted longer, some moved around the image, and some created the classic effect of the milk-and-dye surface tension experiment as seen in its later stages in my image.

Appendix

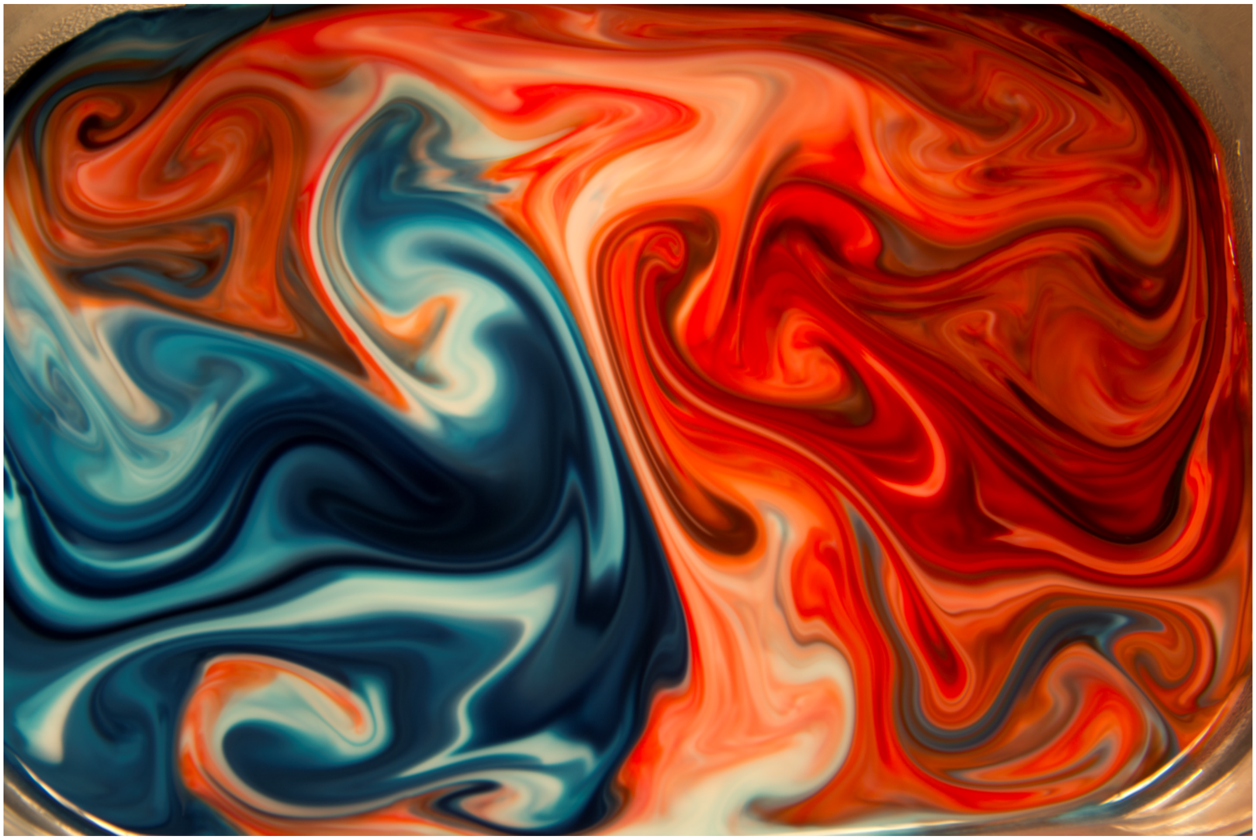

Figure 1-A: Original Image

References

[1] Anderson, David, Dr. "Tie-Dyed Milk." *Cool Science*. N.p., n.d. Web. 09 Apr. 2013. <http://www.coolscience.org/CoolScience/KidScientists/tiedyemilk.htm>.

[2] "Color Changing Milk." *Steve Spangler Science*. N.p., n.d. Web. 9 Apr. 2013. <http://www.stevespanglerscience.com/experiment/milk-color-explosion>.

[3] "Surface Tension." *Wikipedia*. Wikimedia Foundation, 04 Sept. 2013. Web. 09 Apr. 2013. <http://en.wikipedia.org/wiki/Surface_tension>.

[4] "Surfactant." *Wikipedia*. Wikimedia Foundation, 04 Sept. 2013. Web. 9 Apr. 2013. <http://en.wikipedia.org/wiki/Surfactant>.

[5] "Surfactants: The Ubiquitous Amphiphiles." *RSC: Advancing the Chemical Sciences*. Royal Society of Chemistry, n.d. Web. 9 Apr. 2013. <http://www.rsc.org/chemistryworld/Issues/2003/July/amphiphiles.asp>.

[6] Gibson, Carle H. "Fossil Turbulence Revisited." *Journal of Marine Systems* (1999): 147-67. Elsevier Science B.V. Web.

[7] "Reynolds Number." *Wikipedia*. Wikimedia Foundation, 04 Sept. 2013. Web. 10 Apr. 2013. <http://en.wikipedia.org/wiki/Reynolds_number>.

[8] "Fluids - Kinematic Viscosities." *Engineering Toolbox*. N.p., n.d. Web. 10 Apr. 2013. <http://www.engineeringtoolbox.com/kinematic-viscosity-d_397.html>.

[9] "Online Unit Converters - Hydraulics — Fluids - Kinematic Viscosity." *Translator's Cafe*. N.p., n.d. Web. 10 Apr. 2013. <http://www.translatorscafe.com/cafe/EN/units-converter/viscosity-kinematic/1-18/>.