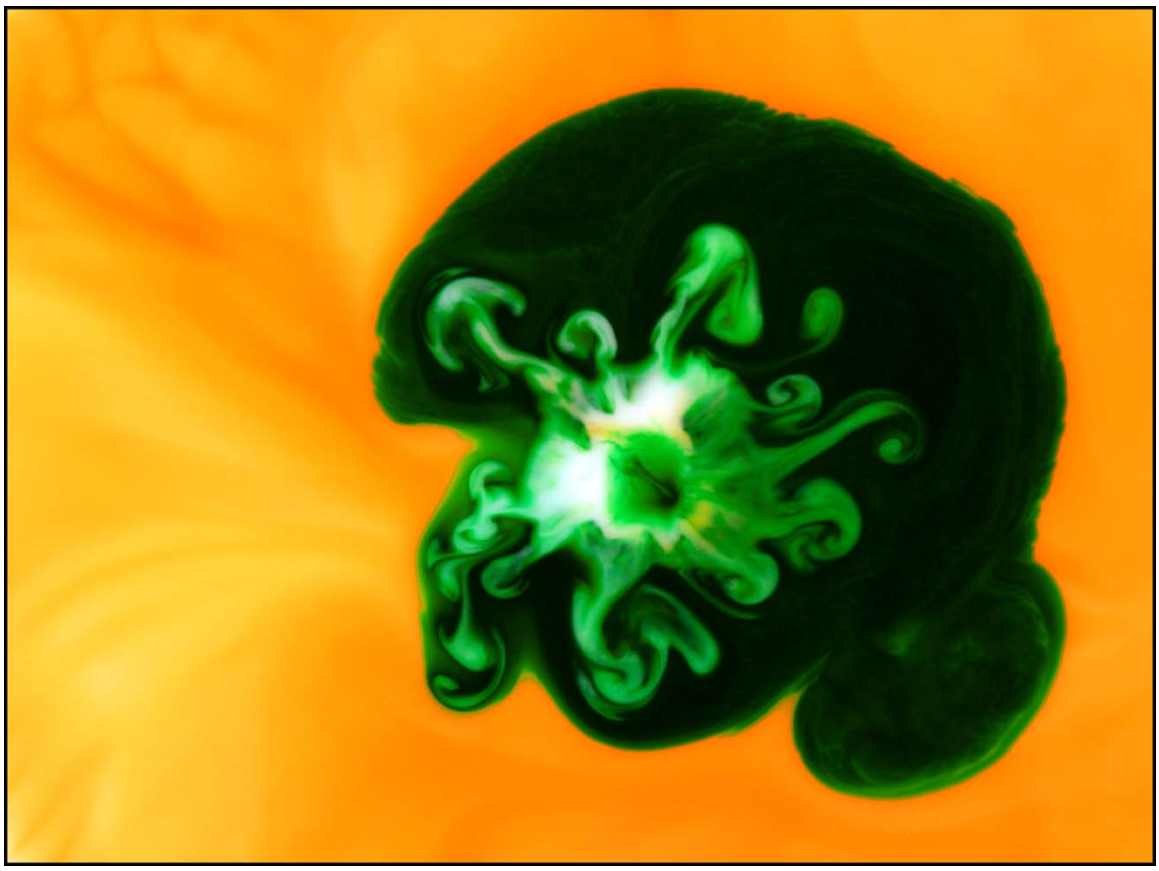
2/8/2010

GET WET

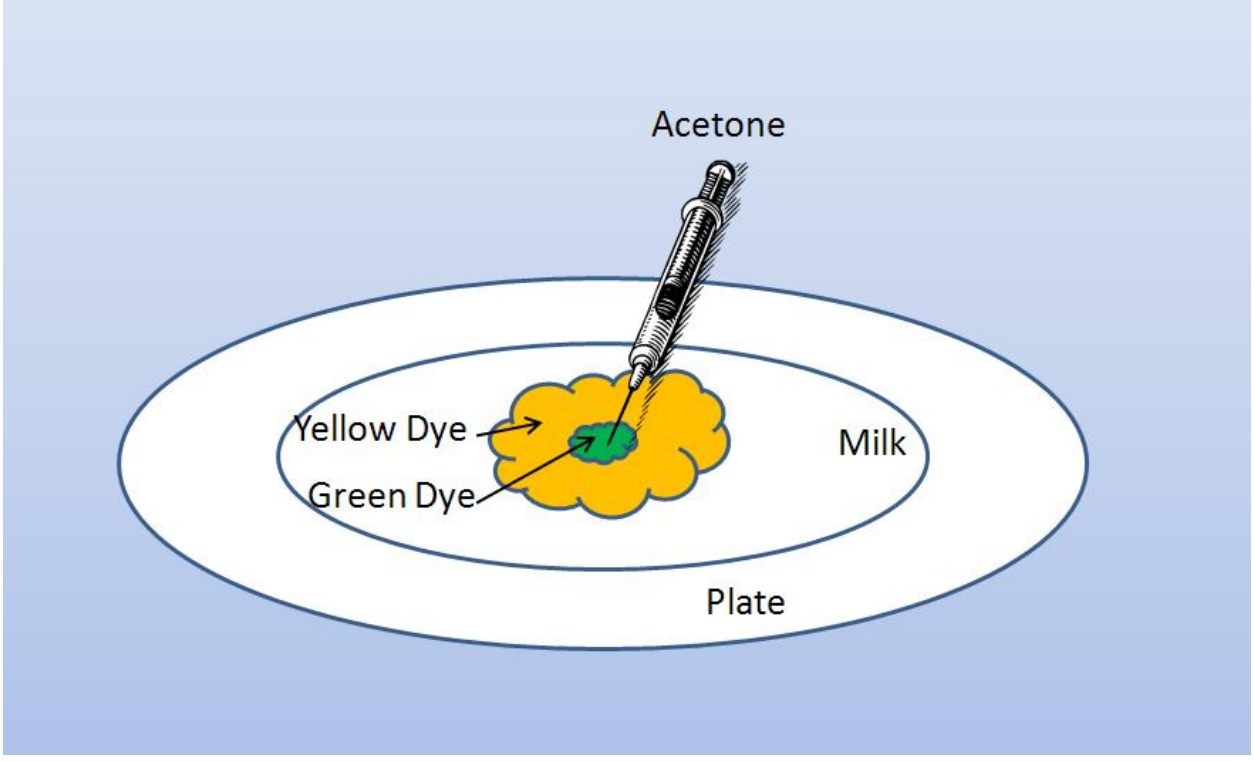
FLOW VISUALIZATION: THE PHYSICS AND ART OF FLUID FLOW



Benjamin Ross Britton | Mechanical Engineering

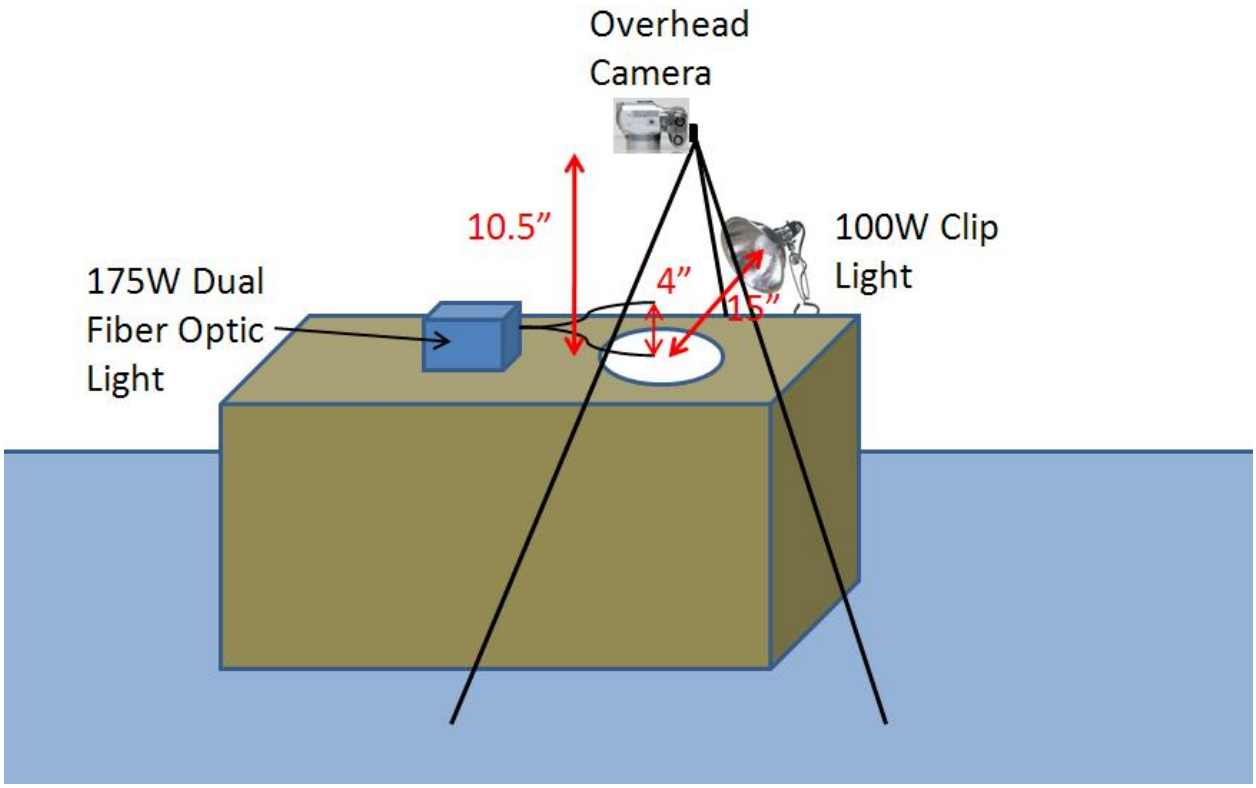
Some people may remember the simple experiment performed in middle school science class. A few drops of food coloring into a dish of milk followed by a drop of soap. The colors came alive and danced about for quite some time before another drop of soap, which activated the process all over again. The same effect can be reached using highly concentrated alcohol or acetone. This particular image was created using milk, yellow dye, green dye and acetone. The fluid phenomenon is called The Marangoni Effect and is a great demonstration of surface tension instabilities in fluids. The purpose of this image was to demonstrate that beautiful art may be created from simple household items.

Performing this experiment was quite easy. A white dinner plate was filled with milk in a thin layer (about 1/8”). Four drops of liquid yellow food dye were place directly in the center of the plate and allowed to sit for approximately 15 seconds. A syringe was then filled with acetone and one drop was placed directly in the middle of the yellow dye from an elevation of 0.5 inches. The Marangoni Effect took place for around 1.5-2 seconds and then the dye was allowed to sit for an additional minute. Next, 3 drops of liquid green food dye were placed in the middle of the yellow dye and allowed to sit for 15 seconds. One drop of acetone was placed in the green dye and the photograph was taken almost immediately (about 0.5 second



delay).

Although performing the experiment was quite easy, capturing this image in high quality proved to be a challenge. A white dinner plate was placed on a table with a tripod straddling the table. The front face of the lens was 10.5 inches from the top of the milk. A 100-watt clip work light was attached to one leg of the tripod 15 inches from the milk. A second 175-watt dual fiber optic microscope light was then used for intense, focused light on the subject. Flexible arms were bent to be at an angle of 45 degrees from the surface of the milk with both lights angled in opposite directions. The flash on the camera was also used to improve the lighting.



All liquid surfaces experience a force called surface tension. Molecules in a fluid tend to repel each other when very close and attract when farther apart. The molecules that are in the body of the fluid repel each other with a force equivalent to the pressure from neighboring

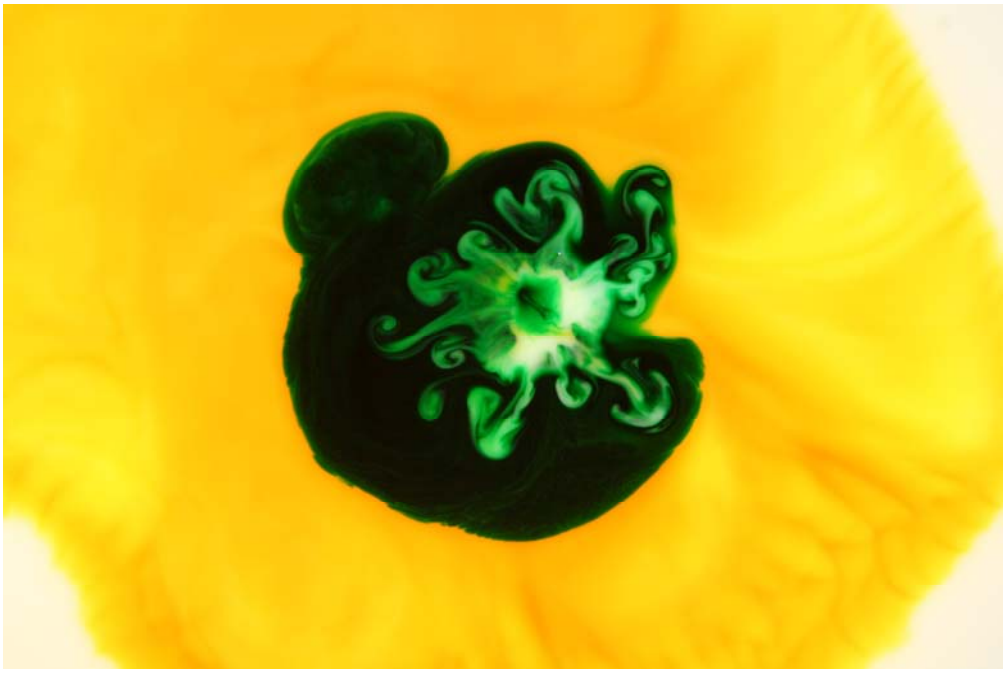
fluid particles. On the surface however, these molecules do not have the same pressure acting on them which causes them to separate far enough from surrounding particles to cause the attractive force known as surface tension (Trefethen 1969). Naturally, milk has a much higher surface tension than acetone (72.8 dynes/cm in milk compared to 25.2 dynes/cm in acetone) (Anonymous 2006). When the acetone hits the milk and dye, it rapidly reduces the surface tension of those fluids. The surrounding unaffected milk maintains high surface tension and therefore pulls quite strongly on the surrounding fluid of low surface tension. This instability rapidly pulls the dye outward, which creates the outward swirling effect seen. This photograph is particularly interesting because it appears that a Worthington Jet formed where the acetone was dropped. This is another fluid phenomenon that occurs when a drop of fluid hits a fluid bath, creating a cavity from the impact. This cavity quickly fills with the surrounding fluid so rapidly that a 'Worthington Jet' protrudes from the surface of the bath. It is difficult to say whether the jet in this image is protruding from the surface or just an effect of dye dispersion in the milk. The background shows great streaking, which occurred from the first drop of acetone on the yellow dye. The orange swirls show where the yellow dye was more concentrated.

The scale of this image is about 1.75 inches wide by 1.25 inches tall. The camera was set to a height of 10.5 inches above the subject with the zoom at full. This was the best way to get a close-up image with total clarity. The following is a table of data describing how the photo was taken:

Camera	Canon EOS Digital Rebel XT
Lens	Canon Zoom Lens EF 28-200mm 1 : 3.5 - 5.6 72mm ↔
Date	1/28/2010 @ 12:47PM
Shutter Speed	1/200 sec
Exposure Program	Normal Program
F-Stop	f/14
Aperture Value	f/14
ISO Speed Rating	800
Focal Length	200mm

Flash	No Strobe Return Detection (0)
	Compulsory Flash Firing (1)
	Flash Function Present
	Red-Eye Reduction
Metering Mode	Average
Pixel Dimensions	2417x1802
Orientation	Normal
Resolution	72 dpi
Color Space	sRGB

After capturing this photograph a slight manipulation was done in Photoshop. A few small flash spots were blended and removed from the picture. The 'curves' were changed by selecting the white portion and the black portion of the picture for an auto-adjustment. Lastly, the hue was changed 11 points towards red. These changes made the colors really pop and allowed the full clarity of the image to be realized. No apparent physics of the fluid flow were manipulated by making these changes. Below is a copy of the original picture:



I was very satisfied with how this image came out. The lighting was just enough to fully capture even the smallest fluid features. An accurate representation of the Marangoni Effect was produced with a possible bonus Worthington Jet as well. Out of the 350 images taken, this was the only one that demonstrated both fluid phenomena. I am curious what caused this Worthington Jet to form in this experiment but none of the others. I plan to attempt to replicate this photo to isolate all variables. The effect of the acetone also appeared to give the most beautiful swirling patterns in comparison to denatured alcohol and 70-proof vodka. I would like to work on bringing out more definition in the dark green dye that was not swirled. There are very interesting patterns that form when the dye is placed in milk, initially sinking from the fall but then rising to the surface due to buoyancy. I noticed that each color dye rises to the surface in different patterns. It would be interesting to play with this to create further artistic images.

References

Anonymous, 2006. “Surface tension values of some common test liquids for surface energy analysis”. DataPhysics Instruments. Online <http://www.surface-tension.de/>. Accessed 2/5/2010.

Trefethen Lloyd, 1969. “Film notes for surface tension in fluid mechanics”. National Committee for Fluid mechanics Films, Tufts University, Education Development Center. No 21610.