Color Symphony

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Flow Visualization
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I. Introduction

This video represents one of five distinctive productions for the Flow Visualization course Team Project 2 at the University of Colorado at Boulder with the purpose of illustrating the effect of the combination of liquid soap and milk. The reaction of this mix is enhanced with the use of food dye, which acts as the only visual agent exemplifying the dynamics of the flow effect. This report will discuss the physical events that take place before and after soap is mixed with the milk, and it will discuss in detail the reasons why the effects of this mix occur.

II. Setup

This experimental setup consisted of a 2-inch deep clear glass plate, a liter of whole milk, food dye (yellow, blue, red and green) and liquid dish soap (in this case Dawn brand was used). The whole milk was poured into the glass bowl and filled to about half way in depth. After the milk had settled from the pour, a few drops of each colored dye were placed in the center of the bowl. To begin, the dye floated (being less dense than milk) in place at the surface of the milk. Once the desired amount of food coloring was added, a small drop of soap was released to fall in the center of the bowl and in the middle of the dye. Upon impact of this small drop of liquid soap, the effects of weakening molecule bonds, changes in surface tension and molecule movement began.

Before the drop of soap was released, the camera was placed above (about 50 cm form the liquid surface) and centered to the glass bowl. Two small working light reflectors (each with ~ 100 Watts) were placed about 20 cm from the subject to illuminate the bowl from adjacent sides (see Figure 1 for setup schematic). The camera began recording a few seconds before the liquid soap was released to capture every moment of the fluid dynamics.

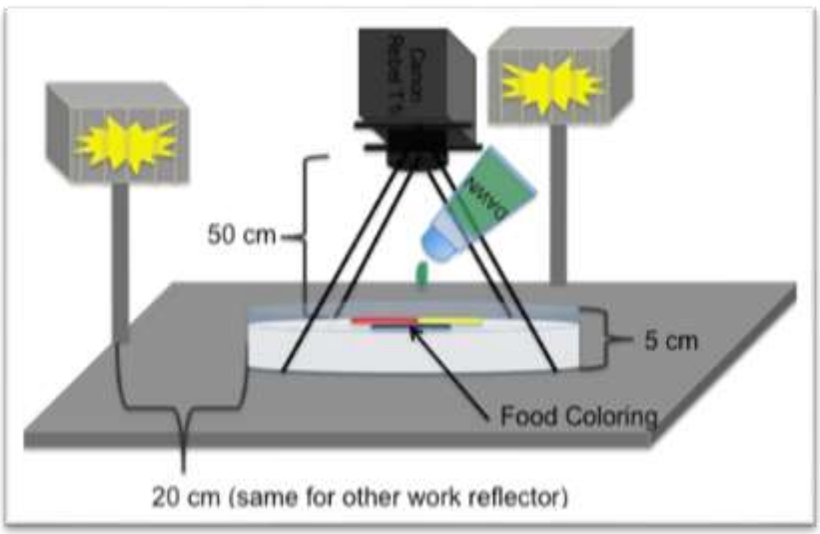

Figure 1: Schematic of experimental setup

III. Filming and Editing

The video was filmed with a Canon EOS Rebel T1i, digital SLR's HD video mode at a normal 30 fps. Most of the video play back speed kept this frame rate, however there are several sections that were played back at slower times to highlight details of the dye movements due to the fluid reactions taking place. The camera's video mode was set to auto adjustment to allow the exposure, f-stop and ISO to automatically fine-tune throughout the filming to capture at best quality.

The original video of 2.14 minutes was outputted directly as an MOV file from the Canon camera, and the resulting file was edited using iMovie. iMovie placed the video in a timeline strip where parts of the beginning and end were cut to take away unwanted footage. Parts of the filmstrip were copied or separated as stand alone clips, reverted and added to various parts of the sequence to view the effect in reverse and then forward mode. Also, some of these reverted sequences were played back at slower times and some of the original sequence was played at faster speeds to highlight details of the fluid flow. At the end of the video sequence, some still images taken throughout the experimental process were added. These images were manipulated with the Ken Burn's effect, which gives the viewer a ride through the image focusing at small segments at one time.

Finally, after all the editing was finished, the soundtracks were added to follow the fluid dynamics as best as possible. Soundtracks from iMovie were used, and these were cut and edited to fit the video accordingly as it plays. To begin, Borealis soundtrack was added to follow the slow motion sequence as the ambient tune. Then, to follow the rest of the sequence, two Half Moon Bay Long tunes were adjusted to play along. During the playback of the latter soundtracks, two Warp Engineering sound effects were added to follow the reverse movements of the retracting dye and liquid soap drop. To finish off the sound editing, the still images were played with a Pastel Slide Long ambient tune for a sense of calmness and a feeling of slow movement through these images. Once all of the soundtracks were matched with the film and all editing was completed, the final product was exported as a high quality QuickTime Movie file.

IV. Analysis

Milk is a complex mixture of immiscible liquids, making it an emulsion. The gross properties of milk include the emulsion of fat globules and a suspension of casein micelles (casein, calcium, phosphorous), both of which are suspended in an aqueous (plasma) phase partially composed of lactose, whey proteins, and some minerals (see Figure 2)[1]. Milk, consisting mainly of water (80-90%), has strong cohesive forces between its liquid molecules, which is responsible for the phenomenon know as surface tension. This phenomenon is what helps maintain the suspension and stability of all the various molecules in milk. Milk goes through a homogenization process where the fat is broken up into smaller pieces (or globules) and spread throughout[2], giving it the look and sense of a one phase cloudy liquid. However, milk, being an emulsion, is made up of a dispersed (globules) and continuous (aqueous) phase that remains undisturbed and steady after homogenization.

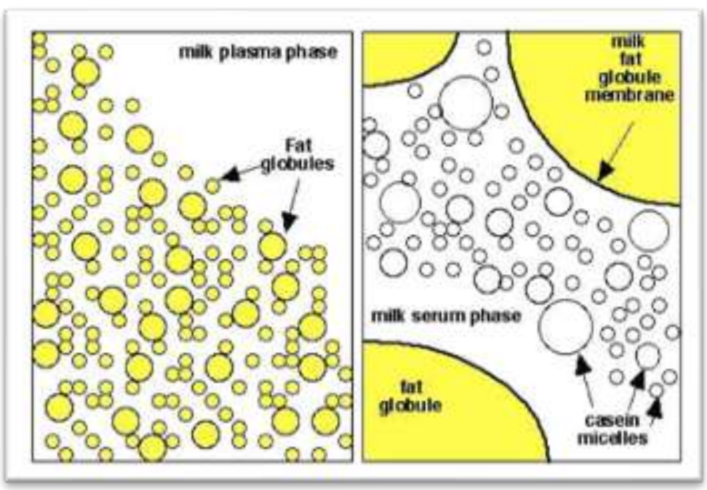

Figure 2: Microscopic image of milk's molecular structures

When the drops of food coloring were added, the fat globules and all other molecules were steady and undisturbed. Hence, these drops, being less dense than milk (food coloring is as dense as water, 1 g/cm^3, whereas milk is 1.036 g/cm^3), floated and sat on the surface without any mixing occurring. No fluid interaction was observed until the drop of liquid soap was added to the mixture. This fluid effect took place because the soap reduced the surface tension of the milk due to the soap's chemical active ingredient (surfactant) and created spontaneous disruption in every single molecule in the milk.

Soaps are mixtures of sodium or potassium salts of fatty acids, which can be derived from oils, or fats by reacting with an alkali (such as sodium or potassium hydroxide) in a process know as saponification[3]:

fat + NaOH ---> glycerol + sodium salt of fatty acid

CH_2-OOC-R - CH-OOC-R - CH_2-OOC-R (fat) + 3 NaOH (or KOH) both heated --->

CH_2-OH -CH-OH - CH_2-OH (glycerol) + 3 R-CO_2-Na (soap) R=$(CH_2)_{14}CH_3$

The action of soap is determined by its polar and non-polar structures in conjunction with an application of solubility principles. The long hydrocarbon chain is non-polar and hydrophobic (repelled by water). The "salt" end of the soap molecule is ionic and hydrophilic (water soluble)[3]. See Figure 3 for schematic of soap molecule. When grease or oil (non-polar hydrocarbons) is mixed with soap - water solution, the soap molecules work as a bridge between polar water molecules and non-polar oil molecules. In this case, soap acted as a bridge between globules and the continuous immiscible liquid contained within milk (mostly water). Since soap molecules have both properties of non-polar and polar molecules the soap can act as an emulsifier or more specifically as a surface-active substance known as a surfactant. A surfactant is capable of dispersing one liquid into another immiscible liquid.

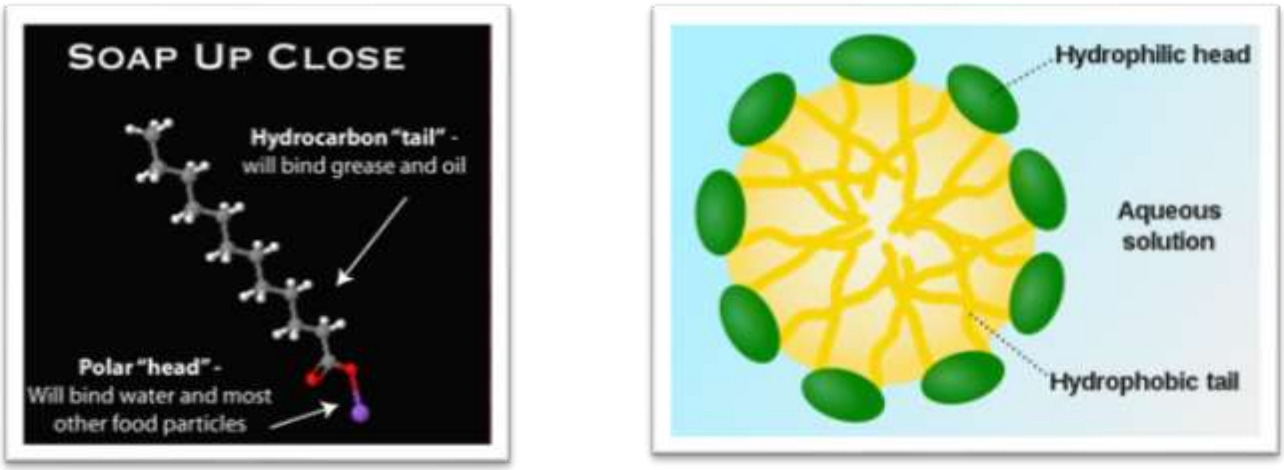

Figure 3: Schematic of a soap molecule and its distinct bipolar characteristics

Acting as the latter, the drop of liquid soap changed the surface properties of milk, greatly reducing the surface tension by dissolving the fat molecules and actually stabilizing the emulsion (milk) overall by increasing its kinetic stability (see Figure 4). This surface changed and stability adjustments created movements in all of the molecules, and thus mixing occurred much faster. When the advancing surfactant wave hit the food dye, the surface tension relaxed and the drops of color began to mix. The soap acted as a repelling agent from the weak bonding (less tension) collapsing and the strong bonding pulling away from the drop of soap creating chaotic movements of molecules in the milk. The food coloring moved with the surface and streamed away from the drop of dish soap. The disrupted molecules, in their search to join their matching poles (head or tail of the soap molecules) set up convection currents forcing the food dye under the surface and raising it in at different locations[4]. The motion of the surface and molecules continued until the liquid soap completely surrounded the fat globules in the milk, at which point everything slowed and the surface tension returned to its original strength. This sequence can be continued until all of the fat globules in the milk are surrounded by their matching soap poles, at which point these form stable fat micelles that remain on the surface, ceasing any surface motion (see Figure 5).

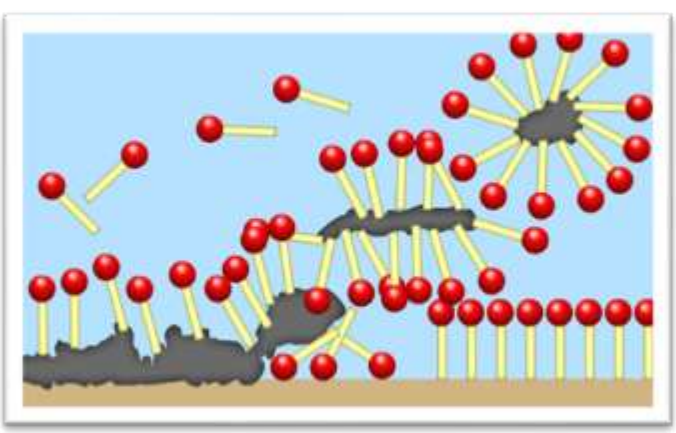

Figure 4: Soap molecules dissolving fat globules

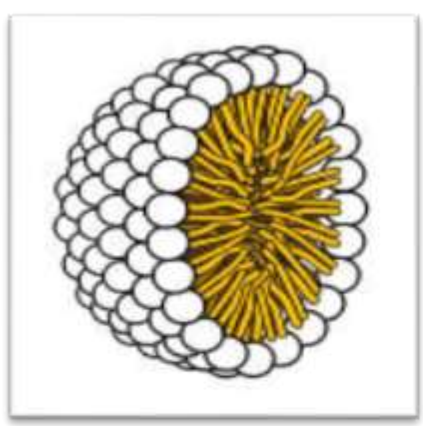

Figure 5: Fat globule micelle surrounded by soap molecules

V. Conclusion

The fluid dynamics that occur due to the chemistry of a small drop of liquid soap into milk seem unreal at first glance. However, once the physics behind this chaotic dynamic of racing molecules in search of stabilization is broken down in parts, it makes perfect sense. Due to the liquid soap's bipolar characteristics (nonpolar on one end and polar on the other), the chemical bonding that holds the proteins and fats in the solution is weakened. The soap's hydrophilic (nonpolar) end dissolves in water and its hydrophobic (polar) end attaches to the fat globules. The race of pole matching and rejection of mismatching poles causes turbulence in the bowl (also proven by the Reynolds number of ~ 6,000 in the processing elements[5]) as the soap breaks down the fat in the milk. This rapid mixing movement produces the food coloring to swirl, sink and rise as the surface of the milk changes and currents from moving molecules are produced.

Overall, this is a reaction that quickly becomes mind-boggling. It is an invisible activity that is highlighted and completely embraced by the food coloring. It is incredible to think that, in plain vision, the human eye misses physical fluid dynamics such as were depicted in this video due to the lack of visible agents. The chemistry is there. The reaction of this mixture always takes place. However, the food coloring is what makes it a real visualization.

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[1] W.L. Hurley, Animal Sciences Dept., University of Illinois <http://classes.ansci.illinois.edu/ansc438/index.html>
[2] Mech 2262 Project, Flow Visualization at Home <http://mech2262.drupalgardens.com/content/surface-tension-milk.
[3] World of Molecules, Soap, EdInformatics 1999 < http://www.worldofmolecules.com/interactive_molecules/soap.htm>
[4] D. Anderson, Cool Science < http://www.coolscience.org/CoolScience/KidScientists/tiedyemilk.htm>
[5] S. Tacholakova, N. D. Denkov, T. Danner, Langmuir, 20 (2004)